Azadi Ka Amrit Mahotsav

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Shodh Chintan

National Conference on Climate Resilient and Sustainable Development of Horticulture

H.P. Singh • D.R. Singh • Babita Singh • H. Choudhary • J.S. Parihar

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14th Swadesh Prem Jagriti Sangosthi - 2022

National Conference on Climate Resilient and Sustainable Development of Horticulture

28-31 May, 2022

Chandra Shekhar Azad University of Agriculture & Technology (CSAUA&T), Kanpur, Uttar Pradesh, India

Organised By

Lt. Amit Singh Memorial Foundation

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Volume 14, 2022

National Conference on Climate Resilient and Sustainable Development of Horticulture

Compiled and Edited by
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त्रिलोचन महापात्र, पीएच.डी.
सचिव, एवं महानिदेशक
TRILOCHAN MOHAPATRA, Ph.D.
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MESSAGE

I am happy to know that **Lt. Amit Singh Memorial Foundation, New Delhi**, along with **Chandra Shekhar Azad University of Agriculture & Technology (CSAUA&T), Kanpur, Uttar Pradesh,** is organizing **NationalConference on Climate Resilient and Sustainable Development of Horticulture**, from 28th to 31st, May, 2022, at Kanpur.

Horticulture, comprising of fruits, vegetables including tuber, floriculture, spices, plantation crops and medicinal aromatics plants has emerged vital for socio economic development of the country, to ensure nutritional security, environment services, employment generation, health care and above all effective and productive land use. It is also interesting to note that there is paradigm shift in dietary choice of health conscious population, with rise in expandable income. This shift will demand more horticulture produce, which has to be produced with declining land and water in the scenario of climate change. Although, there has been appreciable growth in horticulture, maintaining the decadal growth of above 6%, but emerging challenges are much greater than before. This calls for climate resilient and sustainable development of horticulture to meet the emerging needs. IndianCouncil **of** AgriculturalResearch has focused attention in research on horticultural crops through institutes located across the country, which has enabled developing climate resilient varieties (drought tolerant and disease resistant cultivars) and technologies. The council is committed to bring about a definite change for developing technologies to address emerging challenges. The government has also provided focused attention to horticulture by addressing the challenges in mission mode. The current conference shall take stock of situation, identify challenges and develop strategies to address these issues, for converting challenges in to the opportunity.

To commemorate this highly topical National conference, organizers are bringing out **Shodh Chintan, Vol.14**, containing articles from the expert in the field for the benefit of all the stakeholders. I compliment editors for their efforts in compiling the information together in the form of a valuable document.

Dated the …. April, 2022
New Delhi

(T. Mohapatra)

From the Chairman's Desk . . .

The year 2021 was highly challenging, as whole world was challenged to save the life of people and contain the economic losses. The pandemic made us to think differently for our food, life style and working environment. Work from home, digital dialogues and conferences become new normal. In this scenario the ASM Foundation also organised many webinars but the physical conference, which was to be organised in the month of May, 2020 was postponed and organized during 16-19 September, 2021 at PJTSAU, Hyderabad with grace of God, things are becoming normal, thus we are having this conference in physical form.

Devotion to humanity and beneficence is patriotism, thus Lt. Amit Singh Memorial Foundation (ASM Foundation) is charged with the responsibility of spreading patriotism among the youth, through education, health care, economic development and inculcation of ethics and values. Accordingly, the focus of ASM Foundation has been on developmental activities which address children education, self-reliance of youth, confidence building and health care for people and technology-led development of agriculture/horticulture for the benefit of the farmers. The ASM Foundation is working for fulfilling its objectives and mandate. I am happy that the Foundation is in totality implementing the proposed programmes, and bringing out overall development of the marginalized people, in all aspects, at the same time taking them towards self- sufficiency.

Inspired by the past efforts, the ASM Foundation organised the 13th Swadesh Prem Jagriti Sangosthi- 2021 (SPJS-2021), and Global Conference on Innovative Approaches for Enhancing Water Productivity in Agriculture including Horticulture, at PJTSAU, Rajendranagar, Hyderabad, from 16-19th September, 2021. In view of critical conditions due to Covid-19 pandemic in the preceeding year the conference was organised using digital communication, postponing the Physical conference. The Sangosthi platform was shared by diverse group of stakeholders, such as farmers, extension workers, scientists, entrepreneurs, industrialists, policy makers and planners, which facilitated an effective interaction. The participation of diverse group of people was the uniqueness of the Sangosthi, which benefitted large number of people including youth and farmers.

The 12th SPJS organised as Webinar, had participation of more than 1000 delegates globally. Post Pandemic (COVID-19) Challenges and Options in Agriculture including Horticulture was the theme which aimed to analyse the global impacts of COVID-19 on society and economy and develop strategies to turn this adversity into opportunity. Main recommendation emerged that changing paradigm will demand technological changes, upfront policy and technology led value chain management. In the current year, Foundation is organizing a National conference on Climate Resilient and Sustainable Development of Horticulture at CSAUA&T, Kanpur.

The activities during the year 2021 also included, distribution of seeds, school bags to school children, demonstration of new technologies to farmers and confidence building in youth.

The Foundation organized a camp for distribution of food, sentiser and mask to poor in the year of Covid-19 Pandemic In the honour of Lt. Amit Singh, "Shaheed Diwas" was observed on 3rd September 2021. One day Webinar was organized to discuss about fruit production and utilization. Know-how empowerment of farmers was done through sharing the knowledge by the experts. Apart from the above, the ASM Foundation office at Mahamada executed several activities for the benefit of children by providing them education, vocational support, and celebrating the Independence Day and Republic Day. This office is involved in several activities to improve livelihood and socio-economic conditions of the rural people. Notable among them are dissemination of improved agricultural technology and distribution of seeds. The Foundation also distributed blanket for the poor people in many villages. We are grateful to Dr. Praveen Rao, Vice-Chancellor, **PJTSAU**for hosting the Global conference at **Rajendranagar, Hyderabad**. I am also thankful to Dr. D.R. Singh, honourable Vice Chancellor, CSAUA&T, Kanpur for hosting this important National Conference.

ASM foundation has also instituted many awards in various categories *viz*., Amit Krishi Rishi Award, Amit Padma Jagriti Award, Amit Prabudh Manishi Award, Amit Swah Award, to confer on the achievers, who have made outstandin contribution to Indian Agriculture and have dedicated their service to Nation. Amit Udyan Ratan Award, Lt. Amit Singh Memorial Award for best Coordinating Centre of AICRP and National Elocution/Essay Competition for school students have now become a regular phenomenon. I wish to congratulate all the recipients of the awards. Award of 2020 will be given with the Award of 2021. The Foundation is also a receipient of **Institutional Excellence Award-2017** in recognition of outstanding contribution to Rural India through involvement of youth in Agricultural transformation, by AIASA, New Delhi. The CNRI also recognized the services of Foundation by conferring Award in 2019. During the year, 2019, foundation stone for the construction of Amit Gyan Sambhardan Kendra and also office cum training centre was layed at Mahamada, Pusa, Samastipur, Bihar. The training centre is complete and it was inaugurated on 21st April, 2019 and has become functional. The Foundation has now established Amit Memorial Rural Institute for Transformation (Amrit). At this centre, office, training hall and arrangements for stay have been created.

I take this opportunity to express my sincere gratitude to all the staff, volunteers and well-wishers of the Foundation, who are incessantly working hard for achieving the objectives of the Foundation. I also congratulate all farmers/ students/delegates/guests who have contributed significantly during the last SPJS-2021, and owe the entire credit for our successful journey into 2022 and for helping in preparation for **NationalConference on Climate Resilient and Sustainable Development of Horticulture**. I also express our gratitude to the Vice-Chancellor, Dr. D.R. Singh, CSAUA&T, Kanpur, Uttar Pradeshfor hosting this National Conference.

I have a great pleasure in presenting you this Sodh Chintan-Vol.I4 (ISBN:ISBN 978-81-932266-9-8) which contain article from experts in the field of horticulture. The Sodh Chintan, Vol.14, has articles on all the facets of water productivity, which may enrich the knowledge. I am sure, you will find this book useful as a reference book. I also compliment Dr. H.P. Singh, Founder and Chairman, CHAI and his team for the excellent work in compiling and editing this important book. I also thank the contributors of the articles who have taken time for providing valuable information in their article. I also thank all those, who have directly or indirectly helped in bringing out this book.

G. Trivedi
Chairman, ASM Foundation

Preface

Lt. Amit Singh Memorial (ASM) Foundation, committed to achieve its goal and mission, is carrying out various activities since its inception, in 2001. To achieve its objectives, the ASM Foundation has instituted ten awards in various categories and is committed to give impetus to the overall growth of the society. The Foundation recognize the outstanding contributions of the leaders in the development of agriculture and horticulture, through the science, technology and policies. To recognize the industry and its leaders, the Foundation confers awards to them. The ASM Foundation is also committed for the cause of farmers in India. It is leaving no stone unturned in taking lead for motivating farmers for overall development of agriculture/ horticulture at the national level. I am happy to share with you that an **Institutional Excellence Award-2017** was conferred on ASM Foundation in recognition of outstanding contributions for reconstruction of Rural India through involvement of youth in agricultural transformation, by AIASA, New Delhi, CNRI, New Delhi also recognised the contribution of Lt Amit Singh Memorial Foundation in developing patriotic society by conferring Appreciation Award of CNRI-2019. To recognise outstanding contributions for transforming national agricultural scenario, awards like Amit Krishi Rishi, Amit Padam Jagriti and Amit Prabudh Manishi are given to distinguished agriculturists/horticulturists. Highly motivated innovative horticulture farmers, who are keen and receptive to learn advanced technique for technology led development and have displayed their competence by refining technologies to suit local conditions at district or state level, are conferred with Amit Udyan Ratna Award, to sustain the momentum of positive change and encourage other farmers. Amit Swah Award recognises the distinguished services of the leaders in wellness of mankind.

Innovations have no hierarchical considerations and it may come out from a person of any age and position. In fact, many a time young brains given opportunity generate more useful concept to solve the long-lasting research problems. To encourage intelligent brains and to develop path-breaking concept notes of practical relevance, Amit Agrani Award was instituted for young scientists, up to the level of senior scientists, for their creative thinking and conceiving new concept. Every small bit of contribution is important to secure national level success of mega projects, but very often these contributions remain unnoticed. The Foundation has initiated Best Performing AICRP Coordinating Centre Award for AICRPs., H. S. Mehta Award, instituted by Mehta Foundation, Salem, Tamil Nadu, is also conferred through the ASM Foundation, on the occasion of SPJS and conference organised by ASM Foundation .

I am happy to present this book Sodh Chintan, Vol.14, which has contributed articles from the experts in the field of water conservation, utilization, on farm water management, water in agriculture and enhancing water productivity. The Foundation has been organizing the National/International conferences and Swadesh Prem Jagariti Sangosthi every year. This conference is 14th in the series and highly topical as well as important to address the issues. This Shodh Chintan has articles on the subject from experts providing valuable information. I express my sincere gratitude to contributors of articles as well as all those who have worked very hard to compile and edit this book Shodh Chintan, Vol.14, especially Dr. H.P. Singh, and team. I am sure this book will be of great value to all the stakeholders, as reference book, on horticulture. Finally, I thank all those who worked hard to bring out this book.

Bimala Singh
Managing Trustee, ASM Foundation

About ASM Foundation

(An organization certified for ISO 9001-2015)

Lt. Amit Singh Memorial Foundation (ASM Foundation), since its inception, in 2001, has appreciably grown in its outreach and the spectrum of activities carried out to fulfill its commitments, within the ambit of its stated aims and objectives to develop a patriotic society, through education, secured health, economic development and inculcation of ethics and values among the masses, in general, and youth in particular. To begin with, the foundation started its activities with the distribution ofbooks and school bags amongst the poor and needy children to support their education. The Foundation is organizing health camps to improve the health status of poor and needy; scientific exhibitions and workshops to disseminate the knowledge of newly developed technologies, particularly in the field of agriculture and horticulture, to empower the farmers with up-to-date knowledge, and inspirational discourse by spiritual leaders to inculcate social ethics and values, especially among youth.

In its strive to achieve the aims and objectives, the Foundation organized the first Swadesh Prem Jagriti Sangosthi (SPJS-2009), a national level, mega event in, 2009, to commemorate the birthday of the Martyr Lt. Amit Singh, at his birth place, Mahamada, Pusa, Samastipur, Bihar. This Sangosthi included activities like inauguration of Smriti Bhawan, essay/elocution competition and talent search for students of schools and higher secondary schools from different states, health camps, national conference on horticulture, national exhibition, farmers quiz, distribution of quality seeds and planting materials of the agricultural and horticultural crops, diversity shows, litchi/mango eating competition and spiritual discourse to inculcate ethics and values. This Sangosthi was a big success as it was a well attended event. The overwhelming response and encouraging feedback of participants of the first Sangosthi made it annual feature of the activities of the Foundation. Beside farmers, students and scientists, some prominent political personalities also attended the event. Swadesh Prem Jagariti Sangosthi and conference are an annual function. Since then, 2nd Swadesh Prem Jagriti Sangosthi (SPJS) was organised at Bangalore in 2010. Subsequently, 3rd SPJS in 2011 at Dehradun. The events was a great success. 4th Swadesh Prem Jagriti Sangosthi was organised from 27-31 May, 2012 at OUAT, Bhubaneswar, and 5th SPJS was organised on May 28-31, 2013, at JISL Jalgaon, Maharashtra. 6th SPJS was organized at NAU, Navsari and 7th SPJS was organised at Chitrakoot, Satna, Madhya Pradesh. The 8th SPJS was organized at JISL Jalgaon, Maharashtra and 9th SPJS was organized at JAU, Junagadh, Gujarat. Subsequently 10th SPJS was organized at DRPCAU, Pusa, Samastipur, Bihar, 28th to 31st May, 2018 and 11th SPJS was organized at GBPUA&T, Pantnagar, Uttarakhand in May 2019. Due to Covid-19, virtual SPJS-2020 was organized from Dubai and SPJS-13 was organized at PJTSAU, Rajendranagar, Hyderabad, Telangana, from 16-19 September, 2021.

During the Pandemic (Covid-19), the Foundation conducted its activities adapting digital technologies matching to requirements of the conditions under New normal. The Foundation organised 12th Swadesh Prem Jagriti Sangosthi in the form of webinar entitled "Post Pandemic (Covi-19) Challenges and Options in Agriculture Including Horticulture" on 28th May, 2020, which was well attended from across the globe by more than 1000 delegates. The conference highlighted the emerging issues, caused due to pandemic and discussed various options. The recommendations were communicated to all the stakeholder for action. The Foundation fed poor people and distributed food to large number of needy people. On 3rd September another webinar was organized on production and utilization of fruits. The ASM Foundation also supported webinar organized by CHAI and other organizations.

In order to inculcate the spirit of healthy and fair competitiveness and catalyse the minds of the people to serve the society better, ASM Foundation has instituted many rewards and awards. The rewards include the cash prizes to the winners of national debates/elocution of National Talent search in Horticulture. Awards instituted by the Foundation to recognise the outstanding contributions made by people in their respective fields for the welfare of the society, at large include, **Amit Krishi Rishi Award, Amit Padma Jagriti Award, Amit Prabudh Manishi Award, Amit Swah Award, Amit Udyan Ratna Award, Amit Agrani Award, National Talent Award in Horticulture, Best All Rounder Awards** (for school students), and **Lt. Amit Singh Memorial Best Performing Centre of AICRP**. Amit Best student Award (JAU, Junagadh and DrYSRHU, Venkataramannagudem, West Godawari, AP.) The recipients of these awards are leading and distinguished educationists, corporate sectors, scientists, entrepreneurs, farmers, students and leading research institutes, which act as a great driving and inspirational force for the participants and stakeholders to work harder with full zeal in their respective fields, to be among the recipient of such awards. The activities of the Foundation carried, so far, have been very successful, as is evident from the impact on impressionable tender minds of youth to inculcate patriotism and building nationalistic fervour in them; economic empowerment of the poor farmers through innovative technologies and current knowledge disseminated through conferences and exhibitions on agriculture and horticulture.

The Foundation has expanded its activities over the years with its major focus on improving the health of children and empowerment of women. The emphasis is also given on improving the income of farmers through distribution of quality seeds and planting material, dissemination of modern technologies and techniques, knowledge and imparting training and awareness. The Foundation has also supported few meritorious economically poor student to persue his Engineering, who has now joined the mainstream job. The Foundation brings out various publications on Topical issues for the benefit of people. The activities of ASM Foundation have been recognised by conferring Institutional Excellence Award-2016 reconstruction of Rural India through involvement of Youth in Agricultural transformation by AIASA, New Delhi. The Award included a Citation, Plaque of Honour and a Certificate. was given by the Chief Guest, Honourable Minister of State for Agriculture & Farmer's Welfare and MOS of Panchayati Raj, Shri Parshottam Bhai Rupala, on 20th Feb., 2017. During the year 2018, Foundation stone was laid for the construction of Amit Gyan Sambardhan Kendra (ASK) and office cum training centre. This training centre and office was inaugurated on 21stApril, 2019and operational now. During the year Amit Memorial Rural Institute for Transformation have also been established.

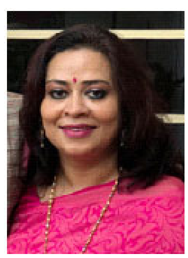
ASM Foundation Team

Dr. H. P. Singh
Former DDG, Horticulture
ICAR, New Delhi

Dr. G. Trivedi
Chairman
Former VC, RAU, Pusa, Bihar

Trustees of Foundation

Ms. Bimala Singh
Managing Trustee



Ms. Neeta Singh
Trustee

Prof. (Dr.) Babita Singh
Trustee

About the Organizers

ASM Foundation, an ISO 9001:2008 certified organization is committed to economic development and knowledge empowerment of people through various activities. It has head quarter at New Delhi, India. The ASM Foundation has successfully organised Global and National Conferences, in the country and is known nationally and internationally. The Foundation, besides organising the conferences, exhibitions, and farmer friendly activities, is committed to education, health care and economic development. The Foundation also confers awards in various categories to recognise the contribution of individuals/ organizations. The effort of the Foundation has been recognised by conferring awards by many institutions. www.ltamitsingh.org

Chandra Shekhar Azad University of Agriculture and Technology (CSAUAT), Kanpur, started its journey in 1893 as Revenue Officers' Training Centre, became Agriculture College Cownpore (Kanpur) in 1906, popularly known as **'*Patther College*',** which was upgraded to U.P. Institute of Agriculture Science in 1969, and subsequently, the university in 1975. The University offers degree programs *in* Agriculture, Forestry, Horticulture, Community Science, Fisheries Science, Dairy Tech., Ag. Engg., Mech. Engg., Computer Science, Elect. & Comm. Engg., and Masters in Agri. Business, Agriculture, Home Science, Horticulture, through its 8 constituent colleges. Research is done through 4 Research Stations, 5 Regional Research Stations and 4 Crop Research Units supported by fourteen Research cum Seed Production Farms. The university has developed 295 cultivars with their agro-technologies. National Academy of Agricultural Sciences honoured the University, in 2015, for developing rust resistant dwarf varieties of wheat, which contributed to green revolution. Every year a significant number of agriculture graduates of this university get awarded with ICAR-JRF and SRF for their higher education. Development work of the University is spread over 22 districts of the States.

About the Collaborators

The Trust for Advancement of Agricultural Sciences (TAAS) was established on October 17, 2002 for harnessing the agricultural sciences for the welfare of the people through scientific interactions and partnerships. The TAAS acts as think tank on key policy issues relating to agricultural research for development (ARD). The main activities include organizing foundation day lectures, special lectures, brain storming sessions/ symposia/ seminars/ workshops on important themes, developing strategy papers on key policy matters, promoting farmers' innovations and conferring Dr. M.S. Swaminathan Award for Leadership in Agriculture. **www.taas.in**

Jain Irrigation Systems Ltd. known as **JISL**, India is a multinational organization with global presence in 120 countries, provides solution for efficient management of water, protected cultivation, quality planting material, farmers access to market and processing, solar energy, waste utilization, and education. The company is one of the largest agro-based company in the world and have many innovations to its credit. The company in its recognition has been conferred with highest national award and much International recognition. **www.jains.com**

Confederation of Horticulture Association of INDIA (CHAI), an ISO 9001:2008 certified, non-profit organization, is a forum of stakeholders in horticulture/agriculture to work together in a mission mode with set goals and objectives. The aims of CHAI are the furtherance of horticulture/ agriculture research and development, through; conduct and support in organizing of National/International conferences, workshops, publication of journal- International Journal of Innovative Horticulture. To bring the competitiveness, the CHAI has instituted various awards to motivate the innovators for the excellence in research, education, extension, teaching and farming. **www.confedhorti.org**

Contents

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Climate Resilient and Sustainable Development of Horticulture-Options and Opportunities

H. P. SINGH AND BABITA SINGH

Introduction

Agriculture often referred to as culture has played a critical role in the Indian economy and society for thousands of years, evident from sophisticated irrigation and water storage structures built in 3000 BC, during the Indus Valley Civilization. The Kallanai, an ancient dam built on the Kaveri River, around the first century AD, is considered the oldest in–use water regulating structure in the world. In fact, agriculture is deeply ingrained in the Indian cultural ethos. Since medieval times, agriculture has remained the predominant occupation of the populace. It satisfied a village's food requirements, besides providing raw materials for industries like textile, food processing, and crafts. During the late middle ages, till the start of colonial rule, construction of water works and improvement in irrigation techniques brought about economic growth. The colonial era was not particularly good for agriculture as it saw frequent famines and growth rate of 0.1 percent in production during 1900 to 1947. The country gained Independence a few years after the Great Bengal Famine (1942 to 1943), The agricultural scenario, post–Independence, was quite challenging and agriculture continued to remain the mainstay of the economy. Despite many initiatives of the Government, growth in food production was inadequate to meet the consumption needs of the growing population and food imports became essential in India till the mid–1960s. India responded to the challenge by reorganising research and undertaking agricultural activities, creation of institutions, price support mechanism to the produce.

All these steps led to a quantum jump in the productivity of crops such as wheat and rice, a phenomenon christened the Green Revolution in 1968. The efforts continue to bear fruit today to put the progress since 1950 in perspective — food grain production has increased 6 times; horticulture 13 times, and oilseed and milk production is up 6 times. Organisational initiatives like Technology Missions were introduced, resulting in a rapid rise in horticulture production. Despite liberalisation, and the growth in services and manufacturing, the role of agriculture remains vital to the overall development and well–being of the nation accounting for a little over 13.5 percent of gross domestic product, and employing the largest proportion of the workforce (about 45.5 percent), agriculture remains a strong lever of growth for the Indian economy. Ensuring food and nutritional security becomes a challenging task, especially with increased nutritional intake, greater urbanisation, and stagnant (or declining) cultivable area. With stagnating production and increasing demand, guaranteeing food and nutritional security will continue to be a challenge. This will further strain the already–under–stress urban infrastructure. Finally, the widening income disparity between the non–agrarian and agrarian segments could cause social unrest. Therefore, we have to envision the challenges and options for food and nutritional security along with better aggravating economy.

The past revolutions (green revolution, white revolution, yellow revolution and Golden revolution together the rainbow revolution) have been possible due to technical interventions, new cultivars and

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production technology, which are also evident from the fact that area has remained static to 142±2 million hectare for the last 40 years, but production has increased manifold, not only of cereals but of all the agricultural produce, from the same land area. Pressure on the cultivable land for agriculture continues to be high as Indian agriculture supports 17% of world population and 11% of livestock only from 2.4% of global land and 4.5 % of water. At global level also, meeting the food and nutritional needs of population, which will be about 10 billion in 2050 is a cause of concern and is being debated across the globe. Looking into population growth, declining land and water coupled with challenges of climate change, has created much greater concern to feed the growing population. Thus, the challenge before us is much greater than before, and has to be addressed with strategic approaches utilising innovations in science and technology. Efforts made through research and development have been a key driver for this development.

Climate change – a global phenomena

Climate change refers to significant variation in either mean state of climate or its variability, persisting for an extended period (typically decades or longer), which may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The earth is the only planate in the solar system that supports life because of unique environmental conditions that are present – water, an oxygen-rich atmosphere and a suitable surface temperature. It has an atmosphere of proper depth and chemical composition. About 30% of incoming energy from the sun is reflected back to space, while the rest reaches the earth, warming the air, oceans and land, maintaining an average surface temperature of about 15^{0}C. The chemical concentration in atmosphere for nitrogen is 78%; about 21% is oxygen, which all animals need to survive; and only a small (0.036%) proportion is made up of carbon dioxide which plants use for photosynthesis. In atmosphere, energy is absorbed by the land, seas, mountains, etc. and simultaneously released in the form of infrared waves. All this released heat is not lost to space, but is partly absorbed by some gases present in very small quantities in atmosphere, called greenhouse gases consisting of carbon dioxide, methane, nitrous oxide, water vapour, ozone and a few others. Thus, increased concentration of greenhouse gases leads to increased temperature which in turn has impact on the world climate, leading to the phenomena known as climate change.

The earth's climate system constantly adjusts so as to maintain the balance between the energy that reaches it from the sun and the energy that goes from earth back to space. This means that even a small rise in temperature could mean accompanying changes in cloud cover and wind patterns. Some of these changes may enhance the warming, while others may counteract. Cooling effect may result from an increase in the levels of aerosols (small particles of matter or liquid that can be produced by natural or man-made activities). Positive feedback may result from an increase in water vapour due to high evaporation with rise in temperature and can further add to the warming effect. The significant change may impact agriculture/horticulture/fish/ livestock and consequently food supply. Climate change *per se* is not necessarily harmful, but the problems arise from extreme events that are difficult to predict, like more erratic rainfall pattern and unpredicted warm spells shall affect productivity. At the same time, more availability of CO_2 would help in improved yield of root crops, and increased temperature may shorten the period.

Climate change in Asian perspective

The increase in temperature due to global warming is 0.76^{0}C since 1850. The rate of warming in the last 50 years is double than that for the last century. As many as 11 of the past 12 years were warmest since 1850, when records began. The likely increase in temperature is 1.8-4^{0}C by nest century (IPCC 2007). The threshold value of temperature rise is 2^{0}C for devastating, dangerous and irreversible consequences of warming to manifest world over. Global warming is occurring along with shifting pattern of rainfall and increasing incident of extreme weather events like floods, droughts and frosting. Recent studies suggest clear evidence of reduction in light intensity, rapid melting of glaciers and rise in sea level. The estimates of Indian Institute of Tropical Meteorology, Pune, indicate similar trends in India with slightly higher magnitude. It is projected that rainfall over India will increase by 15-40%, and the mean annual temperature will increase by 3-60C by the end of twenty-first century. Warming is likely to be more pronounced over land areas with the maximum increase over northern India. The winter and post-monsoon seasons are likely to be more affected by warming. Besides, there would be more fluctuation in temperature, and water availability may decline.

The South Asian region is projected to be one of the most vulnerable to climate change. It is attributed to increasing population pressure, extreme poverty and predominance of agriculture and resource crunch in the region. It is projected that by 2020, food requirement in South Asia would be 50% more than the current demand. The challenges is to produce the same from constant or even shrinking land resources due to competition for land from other sectors like infrastructure, industry and housing. Poverty alleviation and food security for teeming millions in India under adverse climate change scenario would be a daunting task. These changes in global environment will have profound effects and serious consequences for agriculture, horticulture, arable ecosystem and society as a whole.

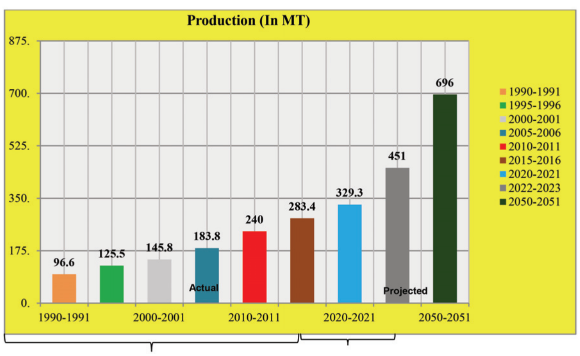
The vulnerability of agriculture to climate change depends on both the expected regional climate change and the sector's ability to adapt. The projected increases in temperature, variability in precipitation patterns, increase in frequency of extreme weather events such as heat, cold waves, frost days, droughts, floods would severely affect the production of horticultural commodities. These stresses at different crop developmental phases in varying intensities would ultimately determine productivity and quality. The emission of carbon dioxide due to anthropogenic activities has enriched the atmosphere. The carbon dioxide enrichment influences the carbon fixation and productivity of crops. The studies suggest a positive effect of increase in atmospheric carbon dioxide in C_3 photosynthetic pathway crops, promoting their growth and productivity. The studies also indicate the increase in water use efficiency (WUE) of crops due to reduction in transpiration rates. However, the adverse effects of associated excessive heat and drought stress might offset the positive effects of elevated CO_2. The interplay of all these factors associated with climate change would subsequently determine the extent of impact on different crops in different agro-ecological regions. It could bring about both adverse and beneficial impacts on crop production depending on the prevailing climatic conditions of the agro-ecological regions, crop species and season. It could affect the growth, development and quality of horticultural crops and alter the zones of crop adaptation.

Accelerating the growth of Indian Horticulture

Indian, horticulture development has five phases of growth, characterised by pleasantry, a hobby in pre- independent India, which moved further to adopt innovations in fifth phase of growth heralding Golden Revolution. Expanding horticulture is demanding knowledge, skills, and technologies for growing plants intensively to achieve efficient, profitable and competitive horticultural industry. The sector includes a wide variety of crops under different groups such as fruits, vegetables, root and tuber crops, mushroom, floriculture, medicinal and aromatic plants, nuts, plantation crops including coconut and oil palm. Government of India has accorded high priority for the development of this sector, particularly, since the VIII Plan-and beyond, which has impacted production, reaching to 329.6 million tons, in 2021, from 96 million in 1990-91, contributing 34.45 to the AGDP only from 11% cropped area. This trend of development in horticulture has been termed as Golden Revolution. However, challenges to feed growing population suiting to their dietary behaviour and nutrition requirements, is demanding science and technology led development, backed by enabling environments, resource utilization strategies. Change in dynamics of horticulture is now for health care through the use of horticultural produce for the treatment of many diseases, therapy, and environment services and above all to the improved quality of life of people living in rural as well as in urban area. The paradigm necessitates for knowledge empowered human resources, who can provide leadership in technology development and policy formulation to attract investment, and keep the pace of development. Horticultural crops is now playing a unique role in India's economy by improving the income of the rural populace and provide enormous opportunities to small and marginal farmers with higher return per unit of land than any other staple crops, beside overcoming vitamin and micronutrient deficiencies and is emerging as the main growth engine of Indian economy.

4.1 Policy framework in livestock:

National Agriculture Policy 2000 categorically emphasized on integrated development of horticulture, which should be knowledge based, technology driven and farmers'centric. The policy also emphasized on rural institutions, reforms and development of infrastructure. There is no policy document for horticulture, but focus has been given on post harvest management in the policy paper of food processing industries. Most notably policy change is related to storage, processing and marketing of horticultural produce. Backward and forward linked marketing with reform in agriculture produce marketing act, encouragement for contract farming are some of important policy changes which are likely to impart production, quality and competitiveness of horticultural produce. Other area of reform needed is in aggregating of land law, which can help in better investment as well as adoption of technology. To enhance the delivery their is a need for innovations in PPP mode for its better adoption in agriculture.



Targeted in document perspective of horticulture, Ministry of agriculture, 2000, Target made in respect of DFI, 2017, Estimated with assumption of changes, dietary needs, urbanisation, population growth, income and trend in growth, 2011, report submitted to planning

4.2 Challenges of Horticulture

The main challenges to horticulture sector have been the investment and capital, access to technology and the initial learning curve to develop the required skills. An attempt to address many of the issues was made through mission mode approach to horticulture by launching of technology mission for development, to start with in North East in 1999, extending it to Himalayan states, in 2003 and to the whole country in 2005 as National Horticulture Mission (NHM), which continued as Mission for Integrated Development of Horticulture. Mission and National Programme on Micro-Irrigation ushered in horticulture revolution referred to as Golden revolution, in the country, providing opportunity for the farmers to enhance farm income and attract educated youth to farming, as horticulture proved to be economically rewarding and intellectually satisfying. In call of the nation for doubling farmers' income horticulture was identified to be a prime mover in achieving the goal.

With a surge in the middle and upper income group in the population, demand for fresh fruits and vegetables is bound to increase several fold. In this context, in addition to more food, the young, rich and urban population would demand diversified nutritious and safe food of high quality, and as a result of this there will be pressure on supply of horticulture produce. The report of committee on Doubling Farmers Income (DFI), 2018, estimated that by the year 2022- 23, production level of 451 million tones has to be achieved (trend in production and target fig1). The report states that it can be achieved through 2.8 % increase in area and 3.1 percent in productivity. It is evident that from the year 2000 to 2016 horticulture has growth rate of 5.8%. owing to technological changes, investment and policy environment. Many new technologies of seeds and planting material, drip and fertigation, greenhouse, hydroponics, marketing models and quality assurance trough branding have been adopted and the success stories are replicated. Past trend shows that target of production envisaged in 2000, for 2021 is achievable, as we have reached to production of 314.67 million tonnes in 2017-18. Thus, there are option of opportunities and challenges, which will need attention. The issue which require to be addressed are Innovation in technologies through institutional support as well as import of knowledge and technological backing for development through skills. Development strategies should be for cluster approach linked with post-harvest management and marketing, quality seeds and planting material, precision farming and smart horticulture, environmentally controlled horticulture, and enhanced ICT use to add efficiency to input management, knowledge transfer etc., and major emphasis to be given to value chain development & management for better profits. Keeping the above in view the following action would ne necessitated.

4.3 Horticulture for Adoption to Climate Change

Many horticultural crops especially perennial fruit trees, spices and plantation crops have a major role to play in carbon sequestration, containing Green House Gas (GHG) and mitigating climate change. Therefore, promoting horticulture would be an option to address the challenges not only for food and nutrition but also for environmental services. Thus, horticulture must be declared as priority sector. Improved planting stock through high-tech nurseries and use of hybrids in vegetable have to be emphasised to boost the production in horticultural crops. With advancement in technology, it has been possible to grow various crops out of season, by modification in weather variability. Therefore, there is a need to develop cultivars and production technologies, which can fit well for industrial production under controlled climate and light conditions.

A new paradigm is encapsulated in integrated water source management, which promotes land development and management of water and related resources, for maximizing the related economic and social welfare without compromising the sustainability of vital system. Therefore, integrated system of water managements requires to be promoted. The Govt. of India is operating, Prime Minister Krishi Sinchai Yojna (PMKSY), to achieve the convergence of investment at field level, as to enhance the productivity of water through water saving technologies, **more crop per drop**. Therefore, there is need for covering more areas under micro irrigation and fertigation system in mission mode approach, to enhance the income of the farmers. Water and nutrients are most critical inputs and account for major share in cost of production. With protective irrigation and balanced use of nutrients, production cost gets reduced. Therefore, micro-irrigation, fertigation and renewable energy will require more attention. Use of micro- irrigation and fertigation has to be facilitated for small and marginal farmers Smart Nutrient Management System recommends the nutrient requirement of crops on the basis of general nutrient uptake by the plant and further adjusts the dose on the basis of targeted yield and the level of nutrients already available in the soil, soil pH, bulk density, organic carbon content, *etc.* by analyzing and interpreting the soil, water and tissue (leaf) analysis report of the farmers' field (Soil Health Card). It also takes the antagonistic and synergistic interaction among nutrients into consideration. Therefore, more intensive research is needed to make the system adoptable by the farmers for efficient use of soil health card, and to maximize the income.

Modified Integrated Pest Management (lPM) technology, incorporating all possible and available pest control techniques to keep pests below Economic Injury Level (ElL) is strongly needed in climate smart horticulture, having greater emphasis on weather data, crop phenology, physical and mechanical methods, agronomic techniques, use of trap and border crops, non-pesticides management, need based chemical management and economics. Intelligent Pest Management should therefore, be incorporated in climate smart horticulture. There is a need to promote and support urban and peri-urban horticulture. The carbon credit scheme should be extended to vertical gardens. Trees furnish live green technology to suffice environmental moderation with cooler, healthier and aesthetic touch in urban life. Tree plantation should be encouraged in the residential as well as private and public urban neighbourhoods. Interior-landscaping with indoor plants should be increased in homes and offices, as these are found to be linked with improved indoor air quality and better human health.

4.4 Technological Changes in Horticulture

Hydroponics/ Aeroponics is emerging as a technology to produce seeds and plants free from the diseases. This technology is also effective in quality production of high value fruits and vegetables. The technology has its application in vertical gardening also. Therefore, there is a need for promoting hydroponics/ aeroponics to provide higher income per unit area of land and water, which can help farmers to achieve the enhanced income. Nano-technology provides opportunities for the development of processes and product, which are impossible to achieve through conventional system. Therefore, use of nanotechnologies in agriculture has to be given emphasis through the appropriate investment on research and development. Diagnostic based on nanotechnology, nano-pheromone for insect, pests and nano-sheets for packing needs have to be encouraged through appropriate investment.

Cold Chain Management empowers the farmers to get better income and better price realization from their farm produce. The cold chain also improves the quality and extends the shelf-life of perishable fruits and vegetables, and it ensures that fresh produce reaches to the consumers with no negative impact. Therefore, cold chain management has to be promoted. Traceability in the food is becoming an essential part for marketing of farm produce to ensure food quality and food safety. Tracceabilty is the chain of information of the produce from production till it reaches the consumers. The food quality and safety assurance build the consumers' confidence in the product as well as brand. Therefore, there is need to create awareness about food safety and traceability of the farm produce. Linking the farmer with markets is essential for better realization for farm produce. Various models have been practiced. However, understanding the value chain and its dynamics from a small producer perspective is limited. Having the integration with farmers' producer organisation is lacking. Therefore, there is a need for strengthening farmer producer organisation in terms of skills and investment.

4.5 Initiatives Needed for Resilience

A concerted effort with identified goal involving all the stakeholders, keeping the technology at driving seat and farmers as centre of attention, would definitely help in achieving faster and inclusive growth. The extension must, focus on producer aggregation at various levels and provide forward linkages. The existing system has to be empowered with knowledge to serve the farmers better with not only technological changes but with new paradigm in marketing. Therefore, there is a need for reorienting extension system. Market reforms and value chain management system should be such, which provide access to market and better realization of price for the produce. Developing markets and access to credit will be a key to ensure that India's farmers have access to affordable institutional credit for quality agricultural inputs, as well as access to adequate remuneration for the produce. This is essential to enhance farmers' income. There is a need for change in land aggregation policies. The Govt. of India has already prepared a model act for aggregation of land, which provides opportunity for investment even on leased land. This would also help in adopting technologies and investment on infrastructure. However, it has to be implemented by the states to legalize the land leasing for promoting agriculture efficiency and for achieving needed productivity improvement in agriculture. Undoubtedly, adoption of new technology and efficient management require skills. Therefore, skill up gradation of farmers has to be done from time to time besides use of ICT for technology transfer and knowledge management.

There is a need to build a society of innovators, manufacturers and technology providers, as the development needs innovation to be at the driving seat for expected output. Therefore, it would be imperative to build atmosphere of policy framework where innovators and innovative companies make their investment in future technologies. Honeybees are the pollinator, which enhances the crop yield, from 25 to 100 percent, more so in horticultural crops, and also provides honey and other products as additional income to the farmers. Therefore, bee keeping has to be promoted more effectively in farm sector by having end to end approach. This will include bee colony, management strategies, and value addition in honey, including quality management. This would help in realising better income from unit area of farm. As horticulture provides ample opportunity for skilled employment through multiplier effect at various activities from production to consumption having the links in planting material production, input production and supply, packaging, storage, branding and its promotion, there is a strong need to address the horticulture as priority sector having the mission mode approach for value chain management to make it more competitive and responsive enterprise.

Various schemes for the promotion of horticulture have provided different kind of assistance, namely micro-irrigation, planting material, nursery production, protected cultivation, mechanization, cool chain management, branding etc., however there is a gap in needed skills and mentoring the farmers for adoptions and management of technologies. Therefore, skill development and mentoring should be a focused part of any schemes to support horticulture. The strategies should be considered to formulate innovative packages of options based on past experiences to promote improved and innovative development options. In this context, precision or smart horticulture, which has emerged as one of the options, considering that it is economically rewarding and intellectually satisfying and has potential to provide better employment and involves more skilled people in the diverse activities. Such approaches are needed to address the challenges of producing more with less.

5 Developing climate smart horticulture

In order to develop climate change smart horticultural crops, we need detailed information on physiological responses of the crops, effects on growth and development, quality and productivity. The various impacts need to be addressed in concerted and systematic manner in order to prepare the horticulture sector to face the imminent challenges of climate change. The rise in temperature would lead to higher respiration rate, alter photosynthesis rate and partitioning of photosynthates to economic parts. It could also alter the phenology, shorten the crop duration, days to flowering and fruiting, hasten fruit maturity, ripening and senescence. The sensitivity of individual crop to temperature depends on inherent tolerance and growing habits. Indeterminate crops are less sensitive to heat stress conditions due to extended flowering compared to determinate crops. The temperature rise may not be evenly distributed between day and night and between different seasons. In tropical regions even moderate warming may lead to disproportionate declines in yield. In high latitudes, crop yields may improve as a result of a small increase in temperatures. In developing countries, which are predominantly located in lower latitudes, temperatures are already closer to or beyond thresholds and further warming would reduce rather than increase productivity. The impact of climate change is likely to differ with region and type of the crop and climate variability.

6.Impact of climate change on production of horticultural crops

The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many crops. In perennial crops like mango and guava, temperature is reported to have influence on flowering. The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures. Though grape originated in temperate regions, modifications in production system, taking up two pruning and one crop, has enabled it to adapt to tropical conditions. Under climate change conditions there would be changes in availability of growing degree-days leading to hastening of the phenological processes. Cashew, which is mostly grown under rainfed conditions, is vulnerable to climatic variability and drought conditions caused due to shifts in rainfall pattern and inter seasonal variability. The temperature rise will influence the survival and distribution of pest populations. Consequently, shifting equilibrium between host plants and pests. The rise in temperature will hasten nutrient mineralization in soils, decrease fertilizer use efficiency. Increase in temperature at fruit maturity leads to fruit cracking and burning in litchi and premature ripening of mango. Low fruit set is observed due to sudden rise in day time temperature (35ºC) during peak flowering in mango. Low temperature (4 to 11.5ºC) in the month of January, accompanied by high humidity (>80%) and cloudy weather delayed panicle emergence. During peak bloom period, high temperature (35ºC) accompanied by low relative humidity (49%) and long sunshine hours resulted in excessive transpiration and dehydration injury to panicles. Untimely winter rains promote vegetative flushes in citrus instead of flowering flushes. Dry spell during flower emergence and fruit set affects flower initiation and aggravates incidence of pest (*Psylla*).

Many slow-growing fruit crops require heavy investment on establishment of orchards. Quick alteration/shifting of fruit species or varieties would be difficult and painful loss-bearing exercise under the impact of climate change, which may discourage the development. Recent studies have indicated that in Kullu district of Himachal Pradesh, farmers shifted from apple to vegetables, while in Shimla district at relatively higher altitude orchards have been replaced from high-chilling requiring apple cultivars of apple (Royal Delicious) to low-chilling requiring cultivars and other fruit crops like kiwi, pear, peach and plum and vegetables. In mid hills of Shimla district, trend is to shift from apple and potato cultivation totally. It is corroborated by declining trend in snowfall and apple productivity in Himachal Pradesh. Since many crops with chilling requirements are tree species, moving production areas is difficult. Thus, in replanting orchards and plantations over the next decade, selection of lower-chilling requiring types may be advisable. This is just an example of impending impacts of global warming and climate change.

In wine grapes anthocyanin development is influenced by difference between day and night temperatures with high variation (15-20 ºC) promoting colour development. In coconut, impact of climate change related events like consecutive droughts and cyclones adversely affected nut yields (like droughts in TN and Karnataka, cyclone in AP). Grape being a temperate crop has very well adapted to tropical regions, under climate change scenario with increase in temperature there would be change in growing degree days (GDD), which has direct bearing on phenology of the crop. Hence, under such circumstances, we would have to identify varieties and regions suitable for production of quality fruits. Excessively high temperatures for extended periods of time in grapes generally result in delayed fruit maturation and reduction in fruit quality. At 35°C pigment development was completely inhibited in Tokay and reduced in Cardinal and Pinot Noir compared to 20 or 25°C.

A linear reduction in per cent acid with increasing effective heat units was evident in Valencia and Navel orange varieties indicating the negative relationship of temperature with acid/brix ratios. Shift in varietal choice may become necessary in case of grapevines, banana, mango and other important horticultural crops. In onion, warmer temperatures shorten the duration of growth leading to lower crop yields. Any soil warming would be advantageous for cucurbits, which are generally direct seeded and have a high heat requirement. The rise in temperature will influence survival and distribution of pest population; developing new equilibrium between alternate host crops and pests; hasten nutrient mineralization in soils; decrease fertilizer-use efficiency; and increase evapo-transpiration with reduced water-use efficiency.

In severe water stress causes reduction in leaf initiation, leaf size gets reduced and leaves become leathery and thick. Root growth is adversely affected by water stress. It may lead to increased rooting depth and higher proportion of feeder roots in citrus. In, water stress reduces inflorescence initiation in conjunction with reduced shoot growth. Water stress reduces the growth of grape berries, but does not influence the characteristic double sigmoid growth curve. Water deficit during stage I (when cell division is occurring) will generally reduce berry size more than water deficits during stages II and III (growth cell expansion). Water deficit positively affected polyphenol accumulation in berry skin and anthocyanin biosynthesis was strongly induced by water stress and the wines obtained from water-stressed plants had high anthocyanin concentration resulting in a more intense colour. Impact of water stress is more influenced by stage of growth, water stress before flowering is essential to get flowering while stress at the growth stage of fruit is detrimental.

With global warming, production areas for specific crops and/or timing of planting could be changed, but for many horticultural crops, market windows and infrastructure, such as availability of local packing and distribution facilities are critical components of the production system. Locations of important production areas are often defined as much by available land, markets and infrastructure as by climatic conditions per se. Thus, as horticulturists we have to ask ourselves and our clientele whether it is realistic to move production areas in response to climate change, or whether there are other production practices that can be adjusted to compensate climate change. Climate change and CO_2 are likely to alter important interactions between horticultural plants and pollinators, insect and disease, and pests and weeds.

We need quick and clear understanding of impact of climate change on agriculture for making sound action plan because horticulture based farming systems have high potential for sequestering carbon for mitigation of climate change. The perennial trees act as carbon sinks by sequestering the atmospheric carbon. The carbon credits could be earned under the clean development mechanism (CDM). The horticultural waste could be composted locally instead of dumping in the landfills, which can reduce the release of global warming methane that is involved in global warming. The organic waste could also be used for generating biogas as an alternate energy source. There are considerable uncertainties about agronomic implications of horticultural crops. Predicting impact of climate change on horticultural crops accurately on regional scale is a big problem. It can be accomplished only by a modeling approach through well-validated robust crop simulation models. These crop simulation models incorporate the effect of various factors of growth and yield in a mathematical model processed by computers to give results quickly for specific situation. Well-validated simulation tools developed for cereal crops have been helpful in predicting of impact of climate change. The net effect of climate change on crops will depend on interaction effects of rise in temperature and CO_2 concentration in atmosphere. In general, CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperature on yield. Most importantly, the quality of produce of these crops are likely to be impacted severely.

7. Managing Climate Change for Climate Smart horticulture

The issues of climate change and solution to the problems arising out of it, requires local analysis, planning and management which could be managed through innovation, technology evaluation and refinement to provide effective solutions to the problems. Potential impacts of climate change depend not only on climate *per se*, but also on the system's ability to adapt to change. The potential depends on how well the crops adapt to the concomitant environmental stresses due to climate change. Depending on the vulnerability of individual crop in an agro-ecological region and the growing season, the crop based adaptation strategies need to be developed, integrating all available options to sustain the productivity. The scientists have already developed several technologies to cope with extreme events like high temperature, frost and limited and excess moisture stress conditions. These available technologies could be integrated and made use to reduce the adverse impacts of climate change and climate variability. Further emphasis needs to be put on developing the crop, agro-ecological region and season-based technologies to reduce the impacts and increase the resilience of horticultural production systems to climate change. To address the adverse impacts of climate change on productivity and quality of horticultural crops we need to develop sound adaptation strategies.

In Climate Smart horticulture is a production system for improved water-use efficiency and to adapt to the hot and dry conditions. Strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season. Modifying fertilizer application to enhance nutrient availability and use of soil amendments to improve soil fertility and enhance nutrient uptake. Providing irrigation during critical stages of the crop growth and conservation of soil moisture reserves are the most important interventions. The crop management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances, excessive soil moisture due to heavy rain becomes major problem and it could be overcome by growing crops on raised beds. Production of vegetables could be taken up using clear plastic rain shelters, which can reduce the direct impact on developing fruits and also reduce the field water logging during rainy season. Planting on raised beds during rainy season will increase the yield due to improved drainage and reduced anoxic stress to the root system. Use of rootstock tolerant would provide the scion cultivars with tolerance to soil related environmental stresses such as drought, salinity, low soil temperature and flooding.

In addition to employing modified crop management practices, the challenges posed by climate change could be tackled by developing tolerant varieties. Several institutions have evolved hybrids and varieties, which are tolerant to heat and drought stress conditions. They must be used very effectively to combat the effect of climate change depending upon their performance in a given agro-ecological region. Efforts should be intensified to develop new varieties suitable to different agro-ecological regions under changing climatic conditions. In comparison to annual crops, where the adaptation strategies can be realized relatively fast using a wide range of cultivars and species, changing planting dates or season, the planting and rearrangement of orchards requires a consideration of the more long-term aspects of climate change. Therefore, before resorting to any adaptation option, a detailed investigation on the impact of climate change on perennial crops is necessary.

The long-time horizon of perennial crops creates situations like; favourable areas may become unfavourable during the life of a single orchard. The choice of a variety is complicated by the risk that the best variety for the current climate may be poorly suited for future climates. Thus, while adaptations such as planting new varieties and shifting to new areas may reduce impacts in the long-term, short-term losses may largely be unavoidable. In wine grape, each grape variety grows in a range of temperatures and for each variety it is possible to define climates for premium wine production. The physiological and morphological differences between varieties (genotypes) enable production over a relatively large range of climates and depending upon the suitability to different growing areas the cultivars may be adopted. In situations, where there is a strong consumer preference for a select cultivar and also the suitable varieties are not available to adapt to the changing climate of a particular growing region, the option of using rootstocks for better performance of the scion cultivars could be explored.

An integrated approach with all available options of smart agriculture will be most effective in sustaining the productivity under climate change conditions. To achieve this end, efforts must be initiated at national and agro-ecological region level to assess the impact of climate change on different crops to develop a number of the combinations of adaptation options, in an integrated manner to tackle the impacts of climate change**.**

Technological Changes Needed for Climate Resilient horticulture

In a matter of fact, grape is a temperate fruit, which has been largely grown under cool climate, be it for table purposes or for wine-making. But the technological change in plant architecture and production system management has helped to produced grape in tropical situation, with highest productivity in the world. Likewise, the chilling will no be enough to induce flowering in apple and high temperature in the mid hill agro-climatic conditions, may cause desiccation in pollen, shriveling of fruits resulting in reduced yield and more failure of the crops. These are the likely impact which causes the concerns. But there are innumerable examples to cite that, climate has been changing and the technologies have helped in mitigating the problem. Salinity and alkalinity were a great problem for successful growing of grape but identification of suitable rootstocks has made it highly productive. If we look to potato, tomato, cauliflower and cabbage, these are thermo-sensitive crops and were productive only under long day conditions in temperate climate. But development of heat tolerant cultivars and adjustment in production system management has made it possible with very high productivity, even in subtropical and mild subtropical and warmer climates. These are the past experiences, which clearly brings home the point that through innovative research threat of climate change could be converted into the opportunity, but will need visualization of likely change, its impact and planning to mitigate it bad impact. Now, available tools of biotechnology could add for speedier delivery of research results.

Keeping in view the nature of crop, its sensitivity level and the agro-ecological region, the crop-based adaptation strategies need to be developed, integrating all available options to sustain the productivity. Developing strategies and tools to comprehensively understand the impact of climate change and evolve possible adaptation measures in horticultural crops is less understood. To enhance our preparedness for climate change and to formulate a sound action plant, we need to identify gaps in vital information, prioritize research issues from point of view of farmers, policy-planners, scientists, trade and industry. It is imperative to visualize likely changes which can happen in next 50-100 years, how these changes could affect growth, development and quality of horticultural crops, what are the technologies which shall help to mitigate the problem and what kind of innovative research should be done to overcome the challenges of climate change. Thus, policy issues, adaptation strategies and mitigation technologies could be worked out and challenges could be converted into opportunity.

SUMMARY & CONCLUSION

Climate change, a global phenomenon, is a concern for food and nutritional security of growing population, expected to be 9.6 billion at the end of 2050, and has attracted global, regional and national dialogues for mitigation and adoption strategies. The likely effects stipulated are occurrence of drought and floods, change in rainfall pattern and sudden change in temperatures, which will have impact on the growth pattern of plant, flowering, fruiting and yield and quality of produce, besides increasing vulnerabilities to pest and diseases. How to handle the challenges of climate change in terms of adaptation and mitigation strategies is a point of discussion in the programmes of the governments, globally. Adaptive mechanisms through the development of new crops, cultivars and technologies are also a priority research agenda for most of the research organisations. Since impact of climate change will largely depend on current agro-climate conditions, cropping pattern and socio-economic conditions, solution to the problems arising out of it, requires local analysis, planning and management.

Horticulture, which was a pleasantry before independence of the country has moved from the rural confine to commercialisation with the turn of the century, keeping a growth rate of 5.86 per cent with increasing demand, after 2000, referred to as **Golden Revolution**, and is projected to grow above 6 per cent, to achieve doubling of farmers' income, food and nutritional security, health care and environmental services. With wide arrays of crops, horticulture may have differential responses: some may benefit from higher amount of carbon dioxide, while flowering and fruiting may not occur, some crops may extend in area due to less occurrence of frost, while some crops may shift from mild hills to upper hills. Therefore, understanding the impacts in a given crop under specific situation becomes inevitable in horticulture as most of the horticultural crops are long duration or perennial in nature. This necessitates a thorough analysis and understanding about climate change at regional levels in relation to both annual and perennial horticultural crops, which could be managed through innovation, technology evaluation and refinement to provide effective solutions. Methodologies for analysis in many crops are now available.

Mathematical models have been developed using available basic data on the crop response to different climatic factors, which have the potential to predict likely impact as well as suggest ways to overcome the problems to some extent, suggesting that impact will differ from region to region, depending upon current ecological and climatic conditions. With a rise in temperature, shifting of apple-growing areas, altering of phonological stages of fruit trees and change in quality of horticultural produce with respect to carotenoids and anthocyanins are taking place. Growth stages are shortening, leading to early maturity and reduction in yield. Evidences also suggest that with a rise in carbon dioxide concentration, there could be an enhanced photosynthesis and ultimately higher biological yield, provided water and nutrients are managed effectively. However, increase in temperature may alter the phtosynthate partitioning and phenology of flowering. New pathogens and insect pests may emerge. Development of high-temperature tolerant cultivars, change in production systems and use of new tools and technology would help in adaption to climate change.

The potential of perennial fruit and plantation crops for higher carbon sequestration provides an opportunity to be a sink for increased carbon dioxide and, additionally, opportunity for soil carbon sequestration. Interior and exterior landscape gardening has proven benefit in reducing carbon concentration. Taking stock of current knowledge about the effect of climate variables and their synthesis for new knowledge in relation to climate change is imperative for adaptive strategies. I am sure, the conference will have critical analysis to enhance the knowledge about impact of climate change on horticultural crops and also provide a guidance to adoptive strategies for different crops in many ago-climatic conditions. In conclusion, it can be said that well planned strategies based on knowledge and technology could convert the threat into the opportunity provided we work in mission mode integrating all the efforts together, addressing the issues concurrently involving all the stakeholders. In this context, this conference assumes significance to analyze impact and develop partnership in managing the climate change for resilience in production.

The achievements in horticulture till date is attributed to infrastructure for the research, investment of government with a mission mode approach and enabling policy initiatives. With the projected growth development is happening with innovative models of technology and its adoption, and the targeted production is achievable, but, not in usual mode of approach. The mission approach, which was envisaged to address all the issues in links of the chain from production to consumption in integrated manner has proved to be more successful in achieving the goals. However, there are concerns about competitiveness, which calls for efficiency in all the activities, starting from conceptualisation to production, post-harvest and cold chain management, transportation, marketing and brand management till it reaches to consumers. This calls for value chain development and management to benefit all the players in the chain and provide the produce to the consumer as per their requirement. Therefore, it is suggested that horticulture be declared as priority sector for investment and mission for Smart horticulture be launched with focus on value chain development and management on priority, which will go in long way as a prime mover of economic growth providing employment, food and nutrition security environmental services and above all availability of produce as per the needs both for domestic and export market.

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Geomatics Applications for Climate Resilience in Horticulture

JAI SINGH PARIHAR

1 Introduction

Geomatics comprises remote sensing, geographic information system (GIS), navigation and positioning systems. Effective use of these technologies is facilitated by ICT and modelling tools. Geomatics as a technology tool is being used for natural resources and environmental monitoring and planning mitigation of natural disaster. Before going in to examples of applications in horticulture, let us first understand the elements of geomatics.

1.1 Remote Sensing

Remote sensing is the technique of gathering information about the objects without coming in physical contact of it. Such information is gathered by placing instruments in the satellites, aircrafts, UAV's (Unmanned Aerial Vehicles) or even balloons. Photography using cameras, both photographic film-based and digital, is also a form of remote sensing. Remote sensing instruments collect the reflected/emitted/backscattered energy from an object. Energy levels thus sensed by the sensor of a payload are digitally quantized and recorded. These interns are also converted to hard copy prints. The payloads collecting information in visible, near infrared, shortwave infrared and thermal infrared region of electromagnetic spectrum are called optical sensors. Whereas, the one operating in microwave region classified as microwave payloads. Remote sensing is used for collecting information about earth surface, oceans and atmosphere employing suitable payloads. It is also being used for collecting information about the planets and objects in space.

Physical basis of remote sensing is on the premise that every object has a characteristic response when the electromagnetic energy falls on it. Depending on its composition, surface roughness and orientation, energy gets absorbed, reflected/backscattered and/or transmitted. This typical response of objects to electromagnetic energy is called its spectral signature. Accordingly, when we see water as blue it means it has absorbed green and red part of energy but reflected blue which reaches to our eyes, similar is the case for green vegetation, which we see as green, because it reflected back green part of energy. Whereas red part of spectrum is absorbed and used by chlorophyll in plants for photosynthesis. Accordingly red part of spectrum is also called photosynthetically active radiation. Most of the green vegetation have high reflectance in near infrared region caused by intercellular airspaces. Plant water content determines the high absorption in short wave infrared (SWIR) region of spectrum. In multi-spectral remote sensing information collected separately for different parts of spectral region is used together to derive information about the objects.

1.2 Geographic Information System (GIS)

GIS is a software tool to collect, collate, store, retrieve, display and analyses spatial as well as non-spatial data. Information about the geographic location for which the data/information belongs to, is key to GIS. GIS facilitates integration of variety of data on large no. of parameters, these could be in the form of maps, charts and/or tables. All the data is referenced to its geographic location; thus, GIS has become a very useful tool for planning, implementation and monitoring of any activity on earth. In horticulture GIS applications on site

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suitability for crops, crop intensification, planning post-harvest processing and storage etc. have been successfully demonstrated and some of these are described in this paper.

1.3 Navigation and Positioning Systems

Field data collection is required in large variety of applications, where it is important to reach to precise location, know its geographic coordinates (Latitude and Longitudes) and be able overlay the data on a no. of parameter accurately. Satellite based navigation and positioning system are based on precise information of position of satellite in the orbit as well as time of broadcast of signal. It is used to determine precise location of a point on earth using the signals from several (three or more) such satellites and calculating the geographic coordinate of the place. There are several global positioning systems of different countries: GPS (USA), GLONASS (USSR), Galileo (European Union) and BuiDou (China). India too has launched its NAVIC or NAVigation with Indian Constellation for navigation covering the Indian region.

Using such systems with a smart phone and/or GPS device, it is possible to know your location on a map, plan a journey route, track the progress in journey, estimate area of a field by walking around it. It is important to note that using a positioning system it is possible to collect field data even on a terrain where prominent land feature (Ground Control Points) are not available and precisely overlay such data on other data layers.

1.4 ICT and Modelling Tools

Information and Communication Technology includes combined use of communication tools viz. radio, television, cell phone, satellite systems, computer and networks. It facilitates near instantaneous communication across the continents and even in space. Modelling tools are the software packages designed to use data on large no. and variety of parameters and simulate the expected process and obtain projected results using computers, provide solutions to if-then situations etc.

All the above, remote sensing, GIS, navigation and positioning systems, ICT and modelling tools put together are the geomatics technique. These have applications in earth resources, environment and natural disasters for guiding formulation of development & managements plans, monitoring progress of development as well as raising alarms and warnings etc. A large no. of applications of geomatics in agriculture in general and horticulture in particular have been developed and implemented globally as well as in India leading to adaption of digital technology in the sector.

2.Geomatics Applications in Agriculture in General

Globally crop inventory and crop production forecasting has been an area of attention right from the advent of remote sensing globally. With the advent of satellite remote sensing multi-spectral images have been used in a no. of national and international projects on crop assessment and monitoring. The most notable among these is Large Area Crop Inventory Experiment (LACIE) conducted by NASA, NOAA and USDA of USA in 1970,s covering major wheat growing countries in the world (Macdonald et al. 1975 and MacDonald 1976). LACIE aimed at in-season multiple assessment of wheat including production forecast using Landsat MSS data of 79m spatial resolution, a sample-based data selection and machine processing of data for wheat area estimation. Several national and a few regional and global programmes followed LACIE, and brief on these is given in Group on Earth Observations (GEO) brochure on Global Agricultural Monitoring (https://earthobservations.org/index.php). Assessment and monitoring of major food crops viz. wheat, rice, corn and soybean is now done regularly under the GEO G-20 Global Agricultural Monitoring (GEO-GLAM) programme (https://cropmonitor.org/) as a part of Agricultural Market Information System (AMIS) programme of Food and Agriculture Organisation (FAO) of the United Nations (UN). Currently GEO-GLAM is operational system for assessment of crop and a good example of use of geomatics in crop monitoring and international cooperation. Another nearly global agricultural monitoring programme is CropWatch of China (http://www.cropwatch.com.cn/htm/en/index.shtml). It covers major food crop producing countries in the world including India. Regular assessment of crop prospects is made using satellite remote sensing as well as weather data with digital image analysis and GIS techniques and a quarterly bulletin is issued. At regional level Monitoring Agricultural ResourceS (MARS) project of European Union is a major programme on use of space technology for deriving timely information on crop area and yield (https://joint-research-centre.ec.europa.eu/monitoring-agricultural-resources-mars_en). Monthly bulletins giving information on crop prospects are issued and made available with open access. While globally many developed and developing nations have contributed to development of geomatics techniques for applications in agriculture, India has contributed in the effort very significantly. Important landmarks are briefly described in following para.

2.1 Geomatics applications in Agriculture in India

Remote sensing programme in India began with study of horticulture crop coconut root-wilt disease detection in parts of Kerala in late 1960's (Dakshinamurthy et al. 1970). Colour infrared photographs acquired from a helicopter platform had shown distinction between root wilt disease affected coconut plant canopy and the healthy plants. Subsequently a no. of projects on use of CIR aerial photography for groundnut (Sahai et al. 1975), wheat (Dhanju et al. 1978) rice and sugarcane (Sahai et al. 1977). Satellite remote sensing for agriculture began with wheat crop acreage estimation in 1984-85 as a part of Crop Production Forecasting (CPF) project under Indian Remote Sensing Satellite Utilization Programme (IRS-UP) launched in 1983. Wheat crop area estimation was done using LANDSAT MSS digital data of 79m spatial resolution and digital image analysis (Dadhwal and Parihar, 1985). Crop Acreage and Production Estimation (CAPE) project was initiated in 1988 at the behest of Ministry of Agriculture. It addressed technique development for pre-harvest production forecast of food grains (Wheat, rice and winter-sorghum), oilseeds (Rapeseed/mustard and groundnut), sugarcane, cotton, winter-potato and onion, covering its major crop growing regions in India. Procedure and software packages were developed, validated and operationalized for using digital image analysis of remote sensing data for crop area estimation and weather-based yield modelling for making pre-harvest crop production forecasting (Dadhwal et al. 2002). Project implementation was carried out by joint teams from ISRO, State Remote Sensing Centre's, ICAR institutions, State Agricultural Departments and many other institutions working on remote sensing applications development. This resulted in creating human resource for crop assessment and production forecasting in the country.

Success of CAPE led to demand from union Ministry of Agriculture for enlarging the scope of work in terms of no. of crops and area covered also need of multiple in-season assessment of crops, from the beginning of crop season, including field preparation to harvesting. To address these requirements FASAL (Forecasting Agricultural output using Space, Agrometeorology and Land based observations) concept was developed in 1997. It envisaged integrated use of multi-source data viz. optical and microwave remote sensing, in-situ and satellite observation derived weather data, historical crop statistics on crop area, production, prices etc. and diverse range of techniques such as remote sensing, weather-based modelling, simulation modelling and econometry (Figure-1). Thus, the FASAL concept became applicable for assessment of all seasonal crop agriculture and horticulture.

Under the FASAL project wheat, rice, rabi-sorghum, rapeseed/mustard, groundnut, sugarcane, cotton, jute, winter potato, onion etc. were covered for multiple in-season assessment and production forecasting. FASAL technique and software development was initiated in Odisha state and extended to rest of states by the multi-institutional teams developed under CAPE project with further augmentation by involving more institutions in the country as required. An account of developments under FASAL project is given by Parihar and Oza (2006). Multi-spectral, temporal satellite data was the main source of remote sensing data. However, in case of cloud covered conditions in kharif season use of Synthetic Aperture Radar (SAR) data was explored for rice crop monitoring (Parihar et al. 1998 and Chakraborty et al. 2006). To institutionalize the FASAL project Mahalanobis National Crop Forecast Centre (MNCFC) was established in 2012 by Union Ministry of Agriculture and Farmers Welfare. MNCFC is working on meeting all the requirements related to geomatics application in the Ministry of Agriculture & Farmers Welfare (Ray et al. 2020 and https://www.ncfc.gov.in/).

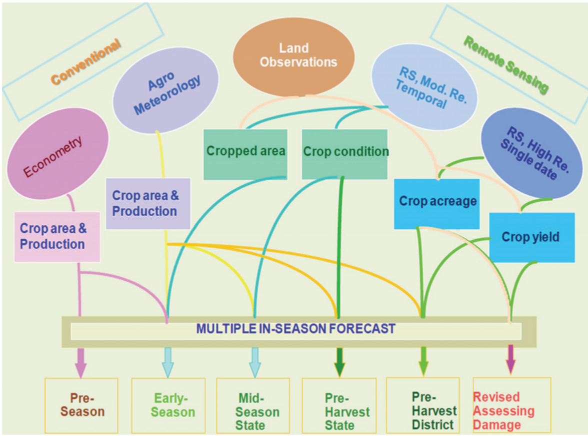

Fig. 1: FASAL concept on use of multi-source data and basket of techniques for multiple in-season assessment of crops (Parihar and Oza, 2006)

3.0 Demonstrated Applications of Geomatics in Horticulture

Horticulture segment of agriculture is vast and varied; fruits, vegetables, spices/condiments, medicinal crops to field, plantation and orchards on other hand. Geomatics applications have been developed for crop inventory and production forecasting of field crops, inventory of orchards, site suitability for crops, post-harvest infrastructure planning etc. Details of these are given in the following sections:

3.1 Inventory of field crops

Among the field crops potato and onion crop area estimation and production forecasting was the first major application of geomatics developed in India. Crop area estimation has been dome using complete area enumeration with high spatial resolution multi-spectral satellite data and digital image analysis for onion crop. The crop canopy consisting of erectile components result in relatively low ground cover with green biomass. Fields are also scattered even in case of major onion crop growing regions like parts of Maharashtra and Gujarat. An example showing onion crop in a village in a part of Gujarat is shown in figure-2 (Mehta et al. 2010). The technique for onion area estimation has been developed by Space Applications Centre, Ahmedabad and know how transferred to National Horticulture Research and Development Foundation (HHRDF), Nasik for operational use. NHRDF has been a regularly making assessment of onion under the CAPE and FASAL projects.

Fig. 2: Classified onion crop (Green) superimposed on IRS LISS-IV FCC (Jan. 2006) for a village in Talaja sub-division, Gujarat (Mehta et al. 2010)

Potato crop is grown in many states across the country. Winter potato is the major crop in India. Remote sensing-based potato area estimation procedure have been developed. Sampling based approach for selection of satellite data for analysis has been followed in order to cover large region. The project area is spread over states of Punjab, Uttar Pradesh, West Bengal and Gujarat and implemented jointly by the teams from SAC, Central Potato Research Institute, Shimla and its units in Punjab and Uttar Pradesh. In the early stages multi-spectral data of 188m spatial resolution and repeat coverage of 5-days from Wide Field Sensor (WiFS) payload of Indian Remote Sensing Satellite (IRS) was used in view of the regional nature of coverage comprising several states across the country (Panigrahy and Singh, 2001 and Singh et al. 2002). Multi-spectral images of different years and image showing area under potato after classification show the year-to-year change in the potato cropped area (Figure-3a and 3b). Subsequently AWiFS data of 55m spatial resolution and 5-day repeat coverage has been used in making multiple assessment during the season as well as to monitor changes across the seasons. In addition to providing acreage estimate and production forecast for major potato growing states year-to-year change in potato growing area were also mapped.

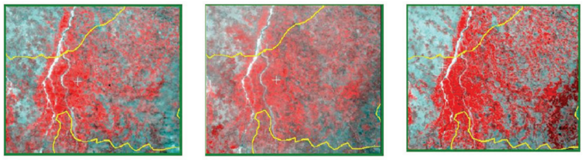

Fig. 3a: IRS WiFS FCC of the study area showing potato crop distribution in January 1996, 1999 and 2000 (Panigrahy and Singh, 2001)

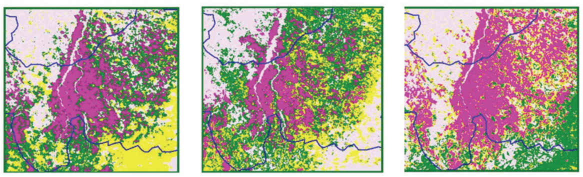

Fig. 3b: IRS WiFS classified images of the study area showing potato crop distribution (magenta) in January 1996, 1999 and 2000 (Panigrahy and Singh, 2001)

3.2 Diseased crop area mapping

Crop diseases as the yield reducing factor are a major area of concern while making crop production forecasts. Late blight affected potato crop area mapping with remote sensing data was successfully demonstrated for Jalandhar district in Punjab (Panigrahy et al. 2010). Multi-spectral data of IRS LISS-III having 23m spatial resolution was used to map the potato crop in the months of November and January. Incidence of late blight disease was reported in the month of December in parts of Jalandhar district. It was followed up with field visit for ground truth data collection. Subsequently, maximum likelihood (MXL) supervised classification of the data acquired in November month when crop was young did not indicate presence of disease, however the image acquired in January month when crop was in advance stage no. of field clusters were found disease affected (Figure- 4).

3.3 Mapping of orchard crops

A large no. of horticultural crops viz. apple, chiku, grape, oranges, mango and pear are grown as orchards. Feasibility of mapping of orchards using remote sensing data for many of such crops has been successfully demonstrated (Panigrahy and Parihar, 2010). An example of mapping the apple orchards in Shimla district, Himachal Pradesh is shown in figure-5 (Panigrahy et al. 2008). Typically, moderate spatial resolution multi-spectral data of LISS-III payload of IRS series of satellites has been used for mapping the area under Mango (Dutta et al. 2010), Grape (Panigrahy et al. 2010) and Coconut (Panigrahy et al. 2010) orchards. Details of the data used and methodology are available in Panigrahy and Parihar (2010). Orchard area maps with information about health of plants in general and plant density etc. has been found useful in rejuvenation planning and crop intensification.

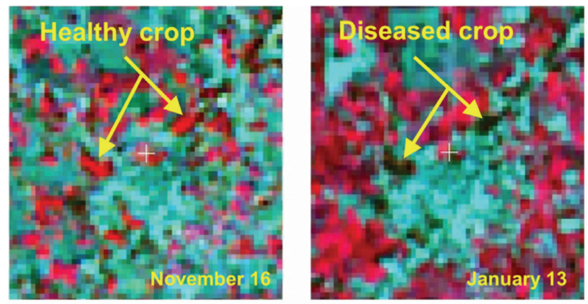

Fig. 4: LISS-III False colour composite images of November and January months showing healthy and late blight affected potato crop near Jamsher village of Jalandhar district (Panigrahy et al. 2010)

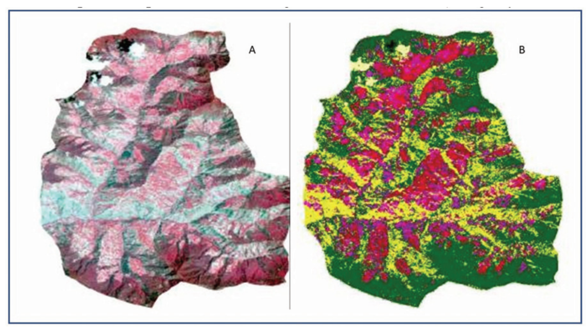

Fig. 5: IRS LISS III FCC (A) of May and classified image (B) showing apple orchard distribution and density (Dense crop in magenta and Sparse in red color) in Kotkhai block, Shimla district (Panigrahy et al. 2008)

3.4 Site suitability analysis and mapping

Site suitability for horticultural crop has been an important application of geomatics in the field of horticulture. The Technology Mission for Integrated Development of Horticulture in North Eastern India including Sikkim was main driver of this application, when in the beginning of 21st century North Eastern states were covered under the popularly known Technology Mission on Horticulture. Site suitability analysis for Apple in Arunachal Pradesh, Pineapple in Manipur and Tripura, Cashew in Meghalaya, Passion fruit in Mizoram, Mandarin in Sikkim were addressed in the project on geomatics applications developed by Space Applications Centre, Ahmedabad at the behest of Technology Mission. State Remote

Sensing Applications Centre's and State Horticulture Department were the partners in the project, guided by Technology Mission.

Most of the land in the North-Eastern states is hilly and jhum cultivation is practiced in almost all the hilly areas. One of the considerations in the Technology Mission was to promote settled agriculture which may facilitate investment in agricultural development, make it profitable to farmers, economical and environment friendly. The first task was to map the clusters of jhum lands as well as the terrain on which these jhum land are located. Accordingly multi-spectral images were used to map the area under jhum lands. The methodology developed has been continuously improved to maximize the use of satellite observation derived data on larger no. of parameters and regional coverage (Parihar and Singh, 2019). Such analysis is being done for a no. of crops in North-Eastern Region under the CHAMAN project using the updated methodology (Figure-6) (Handique et al. 2022). The digital elevation data derived from satellite observations were used to derive the slope and aspect of land. Coupling it with terrain height data the Height Above Mean Sea Level was derived. Information on soil and weather, available from published work were used. GIS analysis was done to locate the areas meeting the conditions required for a crop under consideration. This resulted in generating the site suitability map for the crop. The jhum land clusters located nearer to road network were preferred, so that transportation of produce for post-harvest processing as well as marketing is easy. The Technology Mission guided the farmers about how to grow the crops, its post-harvest processing and marketing through State Horticulture Department(s) and Krishi Vigyan Kendra(s). State horticulture department also arranged for providing quality planting material to farmers. An example of site suitability for apple in Arunachal Pradesh is shown in figure-7 (Panigrahy et al. 2004).

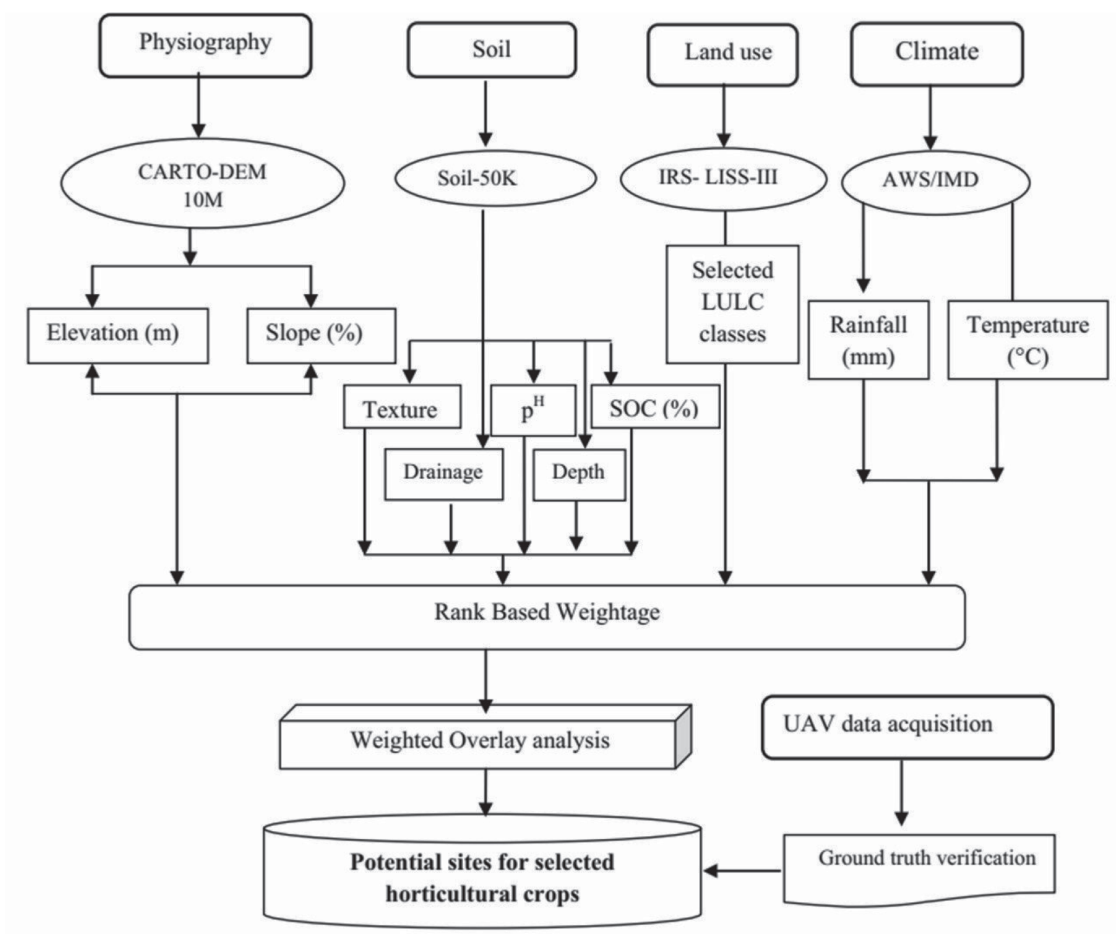

Fig. 6: Flowchart of methodology followed for site suitability analysis of horticulture crops (Handique et al. 2022)

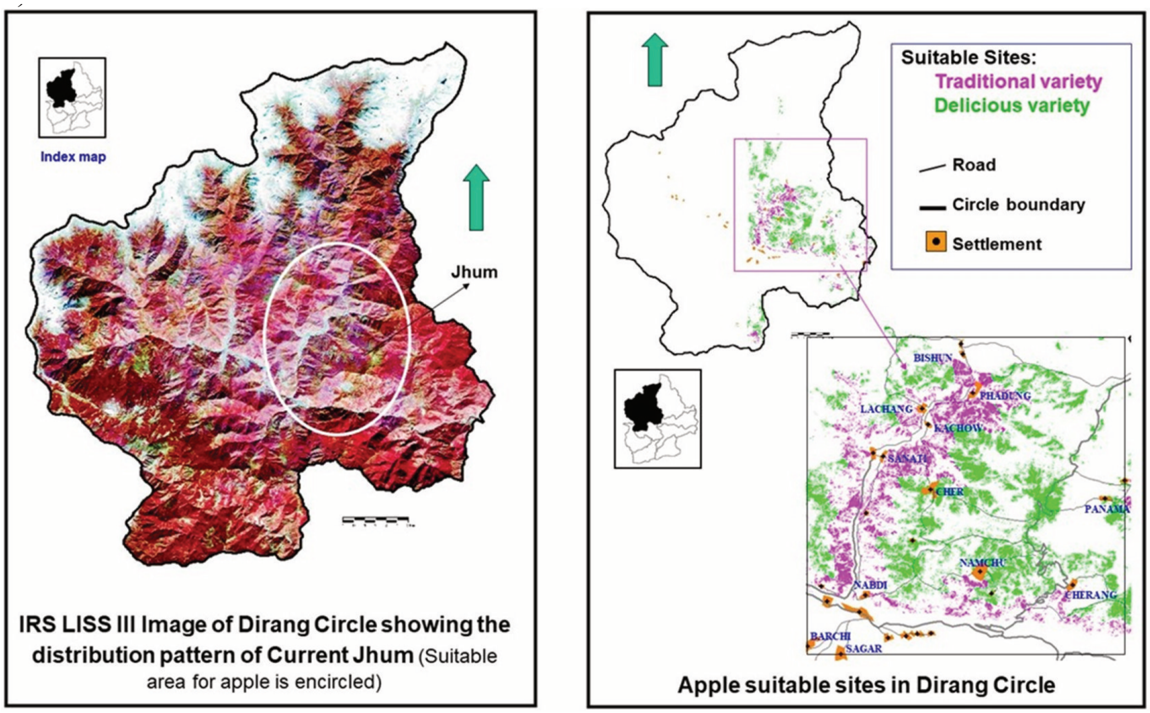

Fig. 7. LISS-III multispectral image of Dirang circle, West Kameng district, Arunachal Pradesh showing Jhum land distribution and site suitability for traditional and delicious apple varieties (Panigrahy et al. 2004)

3.5 Infrastructure development planning

Unlike the food grains and oilseeds, most of the horticultural produce particularly fruits and vegetables have shorter shelf life. If the farmer is unable to get profitable price in that short time after harvesting, the large volume gets wasted. This calls for having storage, processing and marketing infrastructure at convenient locations. Planning for development/creation of infrastructure to support post-harvest handling requires volume of produce, currently available infrastructure including its location, capacity etc. A case study of planning for cold storage facility for potato in a part of Bardhman district of West Bengal is presented (Ray et al. 2000). Areas of potato cultivation were mapped using IRS 1C WiFS images (Figure-8). Potato production forecast were made using the remote sensing and weather data-based model. A parallel activity was to map and overlay the information about existing cold storage on potato producing area map using GIS. The GIS analysis resulted in identification of areas with high, moderate and low priority as well as area with zero demand for creating cold storages (Figure-9). This type of analytical approach and objective analysis need to be followed while planning for creating any post-harvest infrastructure.

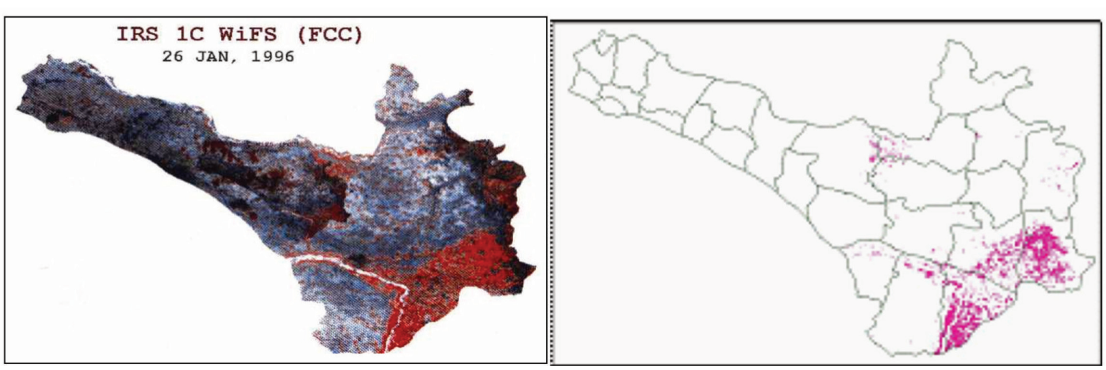

Fig. 8. IRS LISS III FCC showing distribution of potato crop and other land cover/use (left), derived Potato map of Bardhaman district (Right) with overlay of block boundaries (Ray et al. 2000)

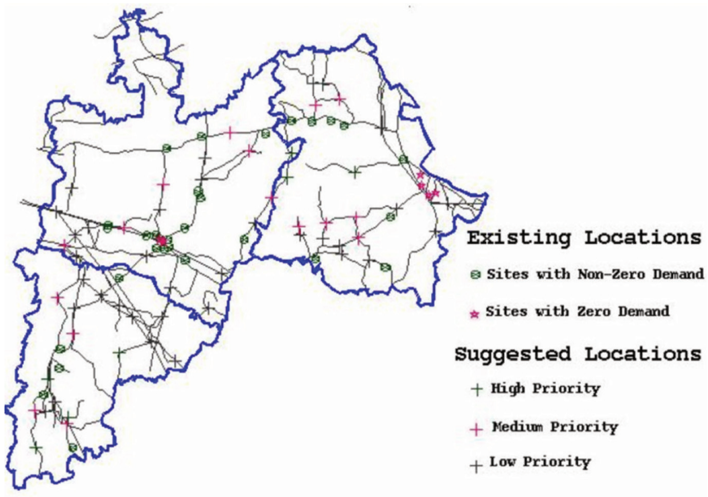

Fig. 9: Location of the existing cold storages and suggested new locations for the study area- Memari, Kalna and Jamalpur blocks of Bardhaman district (Ray et al. 2000)

3.6 Modelling impact of climate change on horticulture

Assessing the impact of climate change requires use of variety of data on land surface, soil, hydrology and environment. Methodology for analysis of large volume of spatial and non-spatial data and modelling has been developed and implemented for apple crop in India (Panigrahy et al. 2014) Observations from earth observation satellites including weather observing space missions have enabled creation of database of a large no. of biophysical and atmospheric parameters, this includes climatology of many atmospheric parameters. No. of bioclimatic indices have been developed using the satellite data. Large volume of data on climatic parameters was available as point measurement by weather agencies, techniques have been developed to convert these

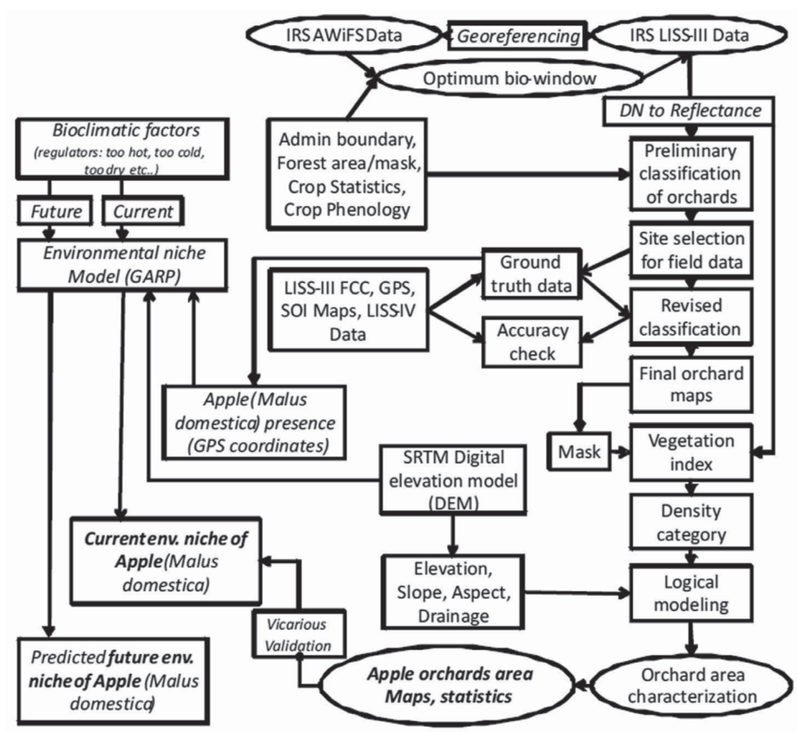

Fig. 10: Methodology for assessing impact of climate change on horticultural crops using geomatics (Panigrahy et al. 2014)

observations in spatial format covering land surface of the world (Hijmans et al. 2005). Such data available with open access is facilitating its unhindered use for applications like climate change (https://www.worldclim.org/data/index.html). An example of assessing impact of climate change on horticulture using geomatics is for the apple crop in India (Figure-10) (Panigrahy et al. 2014). Temporal multi-spectral satellite data of moderate spatial resolution of 55m were used to derive the optimum bio-window of for mapping the apple crop area. It was used to select higher spatial resolution satellite data of 23m acquired at appropriate bio-window of apple to map the area under apple. Integrated use of other relevant data and information in GIS framework has been made to generate the scenarios of climate change impacts and future environmental niche for apple crop.

3.7 Coordinated Horticulture Assessment and Management using geoiNformatics (CHAMAN) project

Realizing the importance of horticulture in Indian agriculture, need for focused attention on geomatics applications in horticulture CHAMAN project was developed by Space Applications Centre. Experience gained on geomatics applications for horticulture as described above, the requirement of Ministry on Agriculture & Farmers Welfare and the overall developments in the field were used in defining the scope or CHAMAN project. The project envisaged crop area assessment and production forecasting of seven major horticultural crops in selected districts in twelve main crop producing states resulting in covering 185 districts in the country. It also addresses geospatial applications for development and management planning in horticulture, covering; post-harvest infrastructure, aqua-horticulture, orchard rejuvenation, crop intensification, GIS database creation, site suitability assessment and detailed scientific field level studies for crop identification, yield modelling, disease assessment and precision farming. MNCFC is making regular assessment of 7 major horticulture crops viz. mango, banana, citrus, potato, onion, chilli and tomato (Ray et al. 2018 and https://www.ncfc.gov.in/chaman.html). CHAMAN project built on the legacy of earlier project Technology Mission on Integrated Development of Horticulture in North-Easterns States including Sikkim has been implemented with improved vigour in all the states of North-Eastern Region (NER) covering a large no. of horticulture crops (Handique et al. 2022). The project having been developed in consultation with user community and being jointly conducted by the technology developers and users is facilitating direct use of results by the resource managers in the states.

4.0 Way Forward in New-Normal

From the examples on geomatics applications described above it emerges that there is immense scope for use of geomatics in decision making for development and management planning of horticulture in the country. Programme like CHAMAN have potential use in improving the farmer's income and keep the balance in environment. The studies and projects carried out have resulted in development of expertise and human resource in use of geomatics. The knowledge and expertise are available for use in planning the future development. Multi-spectral and microwave satellite image of spatial resolution up to 10m are regularly available with open access and free of cost. Many agencies are providing weather data and weather climatology products which can be used with geomatics tools for modelling and decision making.

Horticulture sector provides a large variety of products, freshly harvest and after going through processing. The incidence of COVID-19 pandemic has raised concern about the need for information about the happenings in the value chain and supply chain. Concerns have been even while using fresh fruits and vegetables. This calls for induction of newer digital technology and software tools to provide relevant information from crop growing environment to package of practices, processing, transportation, storage and handling etc. Blockchain technology in association with geomatics offers solution for meeting this requirement. Country has expertise in assimilating and using every technological innovation and well prepared to integrate the use of these developments.

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Applications of Artificial Intelligence for Climate Resilient and Sustainable Development of Horticulture

NARENDRA SINGH RATHORE

1.0 Introduction

India is the second most populous country in the world having a population of about 1.39 billion, Four out of 34 global biodiversity hotspots and 15 out of 200 global eco-regions fully or partly. Horticulture accounts for 33% of Indian's agricultural GDP from a mere 18% of cropped area. Steady growth of horticulture in India is evinced from all time high estimated production of 331.05 million tonnes of horticultural crops from an area of 27.59 million hectare. These crops include fruits, vegetables, medicinal, aromatic, and ornamental plants etc having special significance in terms of high export value, more food per unit area, and best utilization of undulating and wasteland. Further, such crops are extremely useful to provide raw materials for industries, seed production, floriculture, mushroom cultivation, nursery preparation, etc. In India, the existence of physiographic, climatic and soil diversities help in growing a large variety of horticultural crops and therefore, making India as one of the world's largest producers of fruits and vegetables. The erratic climate is one of the major challenges for sustainable development of horticulture. A climate resilient approach using digital technologies can be very effective for sustainable growth of horticultural crops. The modern Climate Resilient Horticulture (CRH) is an approach that uses digital technologies for sustainable climate resilient eco system for all crops including the horticultural crops to achieve long-term higher productivity and farm incomes under erratic climatic conditions. The Indian climate has a great diversity of ecosystem that varies from humid and dry tropical to temperate alpine zones. The explosive growth in population, erratic climate changes, shrinking natural resources & farmland, migration of rural population to urban belts, and varied market demands are forcing the agricultural production system into a new paradigm. The digital technology enabled new generation agricultural system should become a more sustainably productive in output, efficient in operation and resilient to climate change. The Artificial Intelligence (AI) and a hybrid of other digital technologies hold possibility and promise in addressing the challenges of this new paradigm.

2.0 Digital Agriculture for Climate Resilience: Climate Smart Horticulture

The variations in statistical patterns of environmental parameters like temperature, water evaporation, rain fall, drought, green house gases etc. are the major quantitative symptoms of a drastic climate change. The rise in earth's temperature causes more evaporation of surface water leading to drought or unpredictable precipitation in terms of rain patterns leading to floods. The increase in green house gases leads to rise in atmospheric temperature, what we call global warming. The anthropogenic factors i.e. human impact on earth's climate, are the key contributors for climate change and global warming. Such factors include explosive growth in industrialization, radiations of radio waves, carbon emissions, electricity generation etc. The agricultural sector, particularly the horticultural crops are more sensitive towards climate changes and adversely affect its prospects for farmers. Climate-Smart Horticulture (CSH) is need of the hour to combat the adversities caused due to erratic climate and its

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effects on horticultural crops. It is an approach for transforming agricultural systems to ensure large crop production under the new realities of climate change. Widespread changes in rainfall and temperature patterns threaten agricultural production and increase the vulnerability of people dependent on agriculture for their livelihoods, which includes most of the world's poor. Climate change disrupts food markets, posing population-wide risks to food supply. Threats can be reduced by increasing the adaptive capacity of farmers as well as increasing resilience and resource use efficiency in agricultural production systems.

The CRH approach is therefore, required to achieve long term higher productivity and farm incomes under climate variability. There are three categories of digital agriculture solutions that have the greatest potential to impact the farmers, such as weather and climate services, data-driven agricultural services and digital agricultural financial services. A digital climate resilient agricultural system can provide data-driven agriculture services and agri digital financial services for creating a sustainable climate resilient horticulture eco system to overcome the challenges presented by climate change. The real time information of crop microclimate and immediate measures and real time needs of the crop can be determined with the help of installing different sensors in the fields measuring real time environmental conditions like temperature, humidity, rainfall, carbon dioxide, oxygen, wind speed etc. Besides, soil health parameters can simultaneously be monitored using suitable sensors. These sensor data can be combined with that of satellite imaging and local weather data. The deep learning and machine learning algorithms can analyze such big data and quickly generate application oriented results to help farmers make better operational decisions.

2.1 AI applications in Horticulture

Artificial Intelligence (AI) is a technolgy which can store, compute, retrieve, manipulate, analyze and transform a big set of digital information and can apply machine vision for increasing efficiency, speed and workability of the system. The AI permits systematically scope of '3S' i.e. Safety, Security and Survillence, which is also known as manmade intelligence. In fact it needs more reliable and accurate data or information for processing and correction for predicting performance of any system and devices. The artificial intelligence in a machine or computer is achieved through powerful mathematical algorithms and its implementation with programming tools, known as machine learning and deep learning approaches to create a sophisticated intelligent machine that performs given human functions. The Artificial Intelligence can also bring a paradigm shift in all perspectives of agriculture and the conventional farming techniques. The future of farming depends largely on adoption of digital technologies with AI enabled cognitive solutions. As a result, the farmers need not to rely only on intuition for the agriculture and crop production but use of AI technology will help them to increase their incomes and the way they grow and sell the crop produce. All decision what, how, when and where can be easily answered by decision proved by AI algorithms. A cloud based AI and Machine Learning tools and app can help farmers to advise the exact time of sowing and the depth of sowing. Further, it helps farmers in land preparation, soil test-based fertilization and the seed treatment. A hybrid of technologies using AI and Deep learning can detect the type of plant or flower in order for providing favourable environment and a sustainable growth of plant. As a result, the production of more customized fruits and plants will grow, and this will increase the diversity of products and production method. Further, it can be used to detect presence of weeds and diseases of plants. In green house farming of horticultural crops, the sensor and IoT based technological solutions embedded with AI, ML and DL algorithms can be very effective in increasing crop production under controlled climatic conditions as prevailing in green house farming. Although, the green house farming can provide a controlled environment to the plants however, with human intervention. Here, wireless technology and IoT plays important role. By using the latest communication protocols and sensors we can implement weather monitoring and control the green house climate without human presence in the farm. The determination of maturity indices of the fruits and vegetables can be done with sensor and deep learning techniques to ensure the harvesting of fruits and crops at right stage. The major advantage of focusing on AI based methods is that these technologies tackle each problem separately and rather than generalizing, provide customized solutions to a specific problem of individual farm.

2.1.1 Climate Smart Farming Using AI

The Artificial Intelligence (AI) and cloud computing play an important role in the enhancement of overall agricultural produce i.e. crop yield. The smart sensors and data analytics based farming activities can be planned, monitored and controlled remotely in real time environment. The AI technology can also be used to determine history of climate, optimal sowing period, and the real time Moisture Adequacy data (MAI) with the help of soil sensor and meteorological sensors. These technologies provide daily rainfall, rain forecast, and soil moisture. These data help to build predictability and provide inputs to farmers on ideal sowing time. Further, an early warning of pest attack is provided using spectral imaging sensors to predict pest attack. The deep learning algorithms are capable of generating risk factors of pest attack as high, medium, or low depending upon the weather data and the crop growth stage. The AI technology can be used by farmers in their smart phone to see projected seasonal forecasting patterns so that he can take corrective measures in advance for improving agricultural accuracy and also to increase productivity under varied climatic conditions. These DL models are capable of predicting upcoming weather patterns months ahead to assist decisions of farmers. This may result into significant increase in average crop yield per hectare.

3.0 Machine Learning and Deep Learning in Horticulture

Machine learning and Deeplearning are the sub-domains of artificial intelligence to providemultifunctional computationtool forprocessing big data including imaging data of thermal, near-infrared and RGB images. The deep learning can process and provide reliable prediction results for large amounts of heterogeneous, complex and uncertain patterns of data. The use of machine learning and deep learning algorithms is increasing in horticulturalresearch for makingsenseofthe large data sets producedduring planting and postharvestprocesses. Further, it is extensively used by horticultural researchers to analyze huge data produced during planting, crop monitoring and postharvest processes. Deep-learning technologies have been success fully applied in the horticultural do main with promising results such asvariety recognition, yieldestim ation, qualitydetection, stress phenotypingdetection, growth monitoring and others. Such approaches can help modelling of crop micro climate and early detection of plant diseases. It can also help in quantifying the abiotic/biotic stress, real time need of the crop in terms of fertilizers, irrigation, insecticides and maturity indices of the crop. The deep-learningtechnologies areapplied in the horticultural do main for variety recognition, yield estimation, quality detection, stress phenotyping detection, growth monitoring and other tasks.

Crop Surveillance & Monitoring: One of the major goals in horticultural crop management is to achieve maximum yield with minimum investment while maintaining a good quality of the crop produce. Crop infestation due to insects, diseases, and weeds are some of the major factors responsible for crop yield losses. Further, an efficient Precision Agriculture Crop Management System is one, which is capable of precisely detecting the crop yield indicators (or crop health parameters) at an early stage and can predict the yield at any point of time of the crop cycle. The early detection of crop infestations followed by instant remedial and correcting measures to counter the factors can minimize yield losses. This can help to increase crop yield and hence subsequent profit.

In crop health assessment, the drone embedded with multi spectral sensors on board, scans the complete crop area in a very short time. The multi spectral sensors provide sensor data in visible and near-infrared band, revealing changes in plants and indicate their health and alert farmers for any type of disease or insect attack. The high-resolution precision field images are passed through convolution neural network image processing algorithm to identify areas with weeds, pests, and crop counting. Also it gives alert for areas having useful crops that need water, and also the plant stress level in mid-growth stage. In terms of infected plants, by scanning crops in both RGB and near-infra red light, it is possible to generate multispectral images using drone devices. With this, it is possible to specify which plants have been infected including their location in a vast field to apply remedies, instantly. The multi spectral images combine hyper spectral images with 3D scanning techniques to define the spatial information system that is used for acres of land. The temporal component provides the guidance for the entire lifecycle of the plant. In combination with soil sensors, drones can give a 3D GPS accurate model of field and data that the human eye cannot pickup. Many times average farm size is in hundreds of acres, drone monitoring is much faster. Drones are able to cover far more land in much less time than humans, allowing for large farms to be monitored more frequently. High precision aerial images of the crops provide much better view of crop, towards pest detection, leakage detection in water supplies and in crop counting.

Soil & Field Analysis: The soil analysis and determination of fertility is an important exercise to decide the crop type and its cultivation. The unmanned aerial vehicle (UAV) or drones can be instrumental for accurate soil mapping before the planting. The sensor enabled drone produce precise 3-D maps for early soil analysis, useful in planning seed planting patterns. Before the crop cycle, drone produces 3-D field map of detailed terrain, drainage, soil viability and irrigation. Nitrogen-level management can also be made by drone solutions. After planting, drone-driven soil analysis provides data for irrigation and nitrogen-level management. In planting, drone-planting systems can significantly decrease planting costs. It is a step forward for optimum utilisation of agriculture inputs and thud reduces cost of cultivation drastically.

Crop Spraying: Aerial spraying of pods with seeds and plant nutrients into the soil provides necessary supplements for plants for growth at right time. The aerial spraying drone that flies at lower altitude typically 3-5 meters from surface, shoot pods with seeds and nutrients into the soil, providing all the nutrients necessary for growing crops as per requirement. In crop spraying, drones can scan the ground, spraying in real time for even coverage. The experiments have established that aerial spraying is five times faster with drones than traditional machinery. Apart from that, drones can be programmed to spray liquids by modulating distance from the ground depending on the terrain. It can be used for customised fertilisation and help to reduce excessive doses of chemical fertilizer.

Genomic Prediction (GP): Machine learning and deep learning tools can also be effectively used in GenomicPrediction(GP). It is processinwhichun tested good genetic attributes are predicted by employing genome-wide marker information. Recently, deep-learning and machine learning algorithms have been applied as powerful tools to quantitatively predict phenotypes to analyze the increasing amount of available genetic and genomic data. Although numerous examples of GP have been widely utilized toimprovethebreeding efficiency ofplantsandanimals, there is a great scope for such applications in horticultural crops.

3.0 Conclusion

The artificial intelligence can play a major role for smart horticulture which is climate resilient and sustainable. The smallholder farmers of horticultural crops can be helped in decision making, yield predictions and crop surveillance. The modern AI and cloud computing techmiques can create technologies related to digital horticulture to improve the overall farm management operations of the fields. The drone technology is giving agriculture a high-tech makeover with the help of vertical capturing of field and monitoring crop accordingly. The AI based drones in horticulture are used for soil and field analysis, planting, crop spraying, crop monitoring, irrigation, and health assessment and finally prediction yield. The adoption of modern agricultural practices can improve crop productivity and quality of produce. Further, it may attract the technology friendly young generations of the country to opt agriculture and horticulture as a preferred profession, distracting them to migrate towards urban belts.

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Technological Options for Sustainable Horticultural Production Management System in Wastelands

D.R. SINGH

Introduction

Land represents an important component of natural resources for survival and sustenance of continental life directly. The land degradation is a temporary or permanent decline in the productive capacity of the land or its potential for environmental management. The Inter-Governmental Panel on Climate Change (IPCC) defined land degradation as 'a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans'. In total, 146.8 m ha land is degraded land in India (NBSS&LUP, 2004). The share of different kinds of degraded lands as reported by Sehgal and Abrol (1994) are given in Fig. 1.

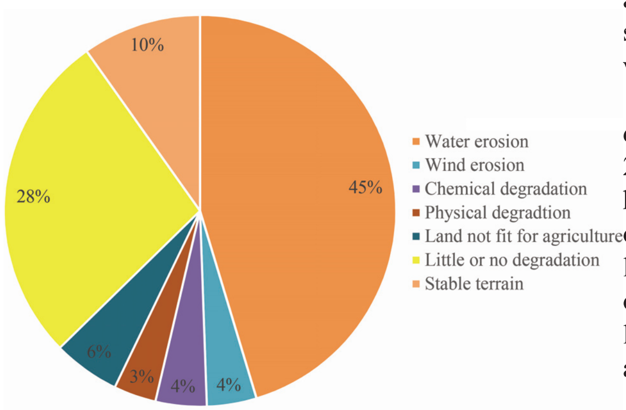

Fig. 1: Extent of soil degradation in India (Sehgal and Abrol, 1994).

The sub-grouping of the degraded land is considered as water erosion (73.27 m ha), wind erosion (12.4 m ha), chemical degradation (salt affected 5.44 m ha, salt affected & water eroded soils 1.20 m ha, exclusive acidic 5.09 m ha and acidic water eroded soils 5.72 m ha), physical degradations 1.07 m ha. Based on the principal factors, the different kinds of land degradations are given in Fig. 2. Since the land is a non-renewable resource at human time scale and therefore, the adverse effects of degradative processes, man-made or natural on land quality are irreversible. It has emerged as one of the most pressing environmental problems, which like climate change will worse due to land-insensitive activities.

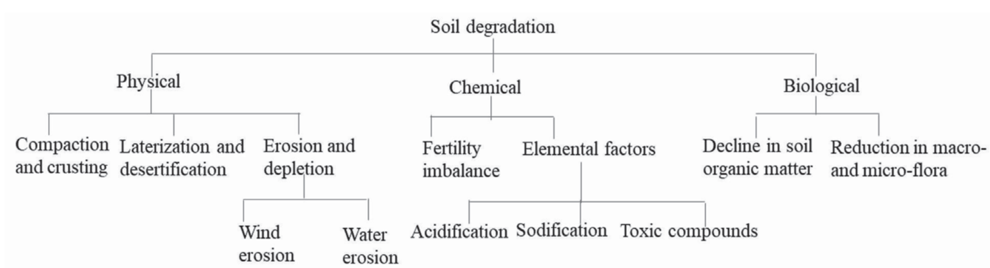

Fig. 2: Different kinds of land degradation (Source: Reddy, 1999)

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Globally, about 25 % of the total land area has been degraded. It has been estimated that nearly 24 billion tons of fertile soil was being lost per year, largely due to unsustainable agriculture practices. If this trend continues, 95 percent of the Earth's land areas could become degraded by 2050. This impact nearly 3.2 billion people globally especially those engaged in primary productivity i.e. agriculture, forestry, animal husbandry, fisheries etc. The marginal people in rural communities, smallholder farmers, landless labours are most vulnerable to land degradation. The situation will worse if not tackled adequately since the world population will be increasing by about 35 percent to 9.7 billion in 2050, with rising demands for agricultural products including food, feed, fiber, and fuel. Expending human settlements, increasing industries, piling up of waste and expanding transport ways (roads, railway network) worldwide making the land in poor situation. Even in agricultural fields, the indiscriminate use of nutrients and poor-quality water causing great threat to the basic quality of a reproductive land. The land degradation has direct effect on productivity, food insecurity, economic depletion and land degradation remains an important subject of the twenty-first century. This will press serious challenge to meet the food and nutritional needs of the rising population particularly in regions have prevalence of degraded lands. Thus, the restoration of degraded land and slow down the pace of degradative forces are crucial for human sustenance.

Technological options for restoration and utilization of degraded lands

The researchers have developed a number of improved technologies in agriculture and horticulture for restoring the degraded land and crop cultivation. Since, the problem has large scale and dimensions, therefore, a system approach needs to be followed to attain the sustainability in the production system of horticultural plants in the degraded land. Ecologically none of the land is degraded but it is a succession process which make it more productive by restoration process.

Sustainable land management (SLM) is most effective approach on present day to tackle the problem of land degradation. The SLM is defined as 'the stewardship and use of land resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions' (WOCAT n.d., IPCC.cp).

The major technological options available present day for sustainable restoration of horticultural crops are given below:

1. Management of degraded lands

In case of physical degraded lands, the soil erosion is most important factor for land degradation and of that, water erosion in semiarid region and wind erosion in arid region is a serious problem. There are various measures now available for management of water erosion including agronomic, mechanical, forestry measures; and for wind erosion including minimum tillage with rough soil surface, stubble mulching, strip mulching, cover crops, mulching, wind break and shelterbelts, nano-clay etc. Agroforestry include both forestry and crop component and watershed development consider the region as a unit of management thereby effective in managing both kinds of erosion.

In chemical degraded lands, salt affected soils, acid soils and waterlogged soils are the result of chemical degradation under different ecosystems. Thus, it is essential to check or reduce the process of chemical degradation to reclaim/convert the soils. Biological amelioration, chemical amelioration crops, cropping system and crop management practices, proper drainage etc. are common practices suggested for management of land degradation. The biological degradation is primarily depending on soil organic matter because this makes the soil a living dynamic system. For this, adding bulky organic manusres, promotion of green manuring, adoption of agro-forestry measures, intermittent cycles of fallow or agro-forestry, natural farming etc. are suggested options. In these options, the integration of suitable perennial horticultural crops serves dual purple of land reclamation and also provide economic activity to the farmers engaged in the process.

2. Suitable farming systems

Land degradation is not a new problem like climate change because the soil carbon loss is estimated to have been ongoing for at least 12,000 years, however, it increased exponentially in the last 200 years (Sanderman et al. 2017). The farmers opted contemporary solution to maintain and improve soil fertility through the prevention of runoff and erosion, and management of nutrients through vegetation residues and manure. Many ancient sustainable farming systems were highlighted by IPCC namely raised-field agriculture in Mexico, homegardens in tropical island regions, tropical forest gardens in Southeast Asia and Central America, terraced agriculture in East Africa, Central America, Southeast Asia and the Mediterranean basin, and integrated rice–fish cultivation in East Asia. The horticultural crops are integral part of these customized farming systems which not only served the food and nutritional needs of people but also provided livelihood support.

3. Integrated farming system (IFS) for degraded lands

The IFS approach is an interdependent, interrelated often interlocking production systems based on few crops, animals and related subsidiary enterprises in such a way that maximize the utilization of nutrients of each system and minimize the negative effect of these enterprises on environment. However, it has diverse regionally fitting components such as agriculture, horticulture, livestock, poultry, pig farming, duckery, fish, rabbit, honey bee etc. Such components are now well identified in different regions of the country. Government agencies can facilitate farmers to adopt such economic measures to reclaim the degraded soils. Promotion of suitable horticultural crops in IFS is essential to economize the interventions and also provide livelihood support to the farmers during the gestation period of land reclamation.

4. Suitable horticultural crops

The horticultural crops represent a large number of botanically diverse crop species originated from different agroclimatic regions. For eroded soils, the suitable crops are mentioned hereunder (Aishwath, 2019):

Fruit crops: Almond, Aonla, Apricot, Avocado, Aple, Beal, Ber, Breadfruit, Khrni, Mahua, Mulberry, Sharifa, Tamarind etc.

Vegetable crops: Ash gourd, Cowpea, Drumstick, Kachra, Pointed gourd, Pointed gourd, Sponge gourd, Teasle gourd.

Plantation Crop: Arecanut, Cashew, Cocoa, Coffee, Tea.

Ornamental crops: Orchid, Palmyrapalm.

Medicinal and aromatic plants: Bajradanti, Chitrak, Dill, Eucalyptus, Giloy, Indian bdellium, Kalihari, Ketki, Lavender, Musli, Rosa grass, Rose, Tulsi, Velvet bean.

Salinity tolerant vegetable crops: Beet, Kale, Turnip, Palak, Asparagus, Bitter gourd, Ash gourd, Lettuce.

Soil acidity tolerant vegetables: Potato, Sweet potato, Watermelon

Soil alkalinity: Brinjal, spinach and sugar beet.

5. Organic farming

Technically, the 'Organic farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, genetically modified organisms and livestock food additives'.Since it uses organic supplements derivative of animals and plant residues such as poultry manure, farmyard manure, vermicompost, hair and wool waste, cow dung with rice, wheat straw, sorghum stalks, pigeon pea, chickpea, sugarcane trash, etc. This is not only an effective measure of prevention of land degradation but also more effective in reclamation of degraded lands. Organic supplements are usually the derivative of animals and plant residues such as poultry manure, farmyard manure, vermi compost, hair and wool waste, cow dung with crop residues etc. (Singh et al. 2020).These compounds increases microbial activity in the soil which releases various substances to effect soil biochemical properties and improve the soil health. Since, organic farming is a crop production system in particular but its extension agroforestry (with horticultural crops) will enhance to speed of recovery of degraded lands.

6. Natural farming

Neither land degradation is a new phenomenon nor the management options. Earlier the traditional ways were common among the farmers to restore the fertility or remove the causes of land degradation. One of such option is Natural Farming. This is a chemical-free alias traditional farming method which is being considered as an agroecology based diversified farming system that integrates crops, trees and livestock with functional biodiversity. This is almost like integrated farming system with only input or crop management option of organic farming practices. Promotion of natural farming in degraded lands is another option however, ephesis should be given to promote perennial hardy horticultural crops in these areas with natural farming so that it can contribute to the country demand supply for horticultural crops.

7. Crop plant succession for restoration of degraded lands

Since there is no land without value and there is no land where plant can't be grown provided proper light and water is available. However, the mineral matrix of soil is an issues which need proper management. This is an edaphic factor which mostly associated with soil carbon or organic matter in particular. The barren or degraded land can be restored by keeping the concept of plant succession in front. In this, a chain of crop systems: Forestry-agroforestry-perennial fruits-annual horticultural/ agronomic crops should be followed. For this the time frame for each component during restoration process is a matter of research. Since, such efforts need long-term experiments and investments however, these are essential to generate scientific database for restoration process. There are some measures available which can enhance the process of restoration but these need to be tested in different agro-ecological regions.

8. Land management practices

Land manipulation techniques such as broad bed and furrow (BBF), broad bed system for low land areas, trench system for annuals, soil mount techniques, deep pit for perennials, polybags or pot culture in problem soils in uplands are common techniques for crop growing in degradation or poor soils. Among these the broad bed and furrow is very effective for growing paddy + vegetables/flowers/ fodder etc in low land areas water logging is serious problem for prolonged period such as Andaman and Nicobar Islands, tropical coastal regions etc. In case of trench system, the trenches of 1 feet depth and 30-45 cm wide deep trenches of appropriate length are made and filled with good quality soil: organic manures to grow vegetables, flowers and other agronomical crops. Similarly, in raised beds, the organic manure is added adequately and 30 cm height beds are made to grow crops. This save crops from intermittent water logging and help to utilize the otherwise degraded lands effectively. In case of soil mount techniques, in low land areas near costal region, the soil mount of 0.5-1 cm x 0.5-1.0 m x 0.5-1.0 m size are made and in centre of these sufficient quantity of organic manures or vermicompost are added to raise the crops. Suitable crops are annuals vine type like cucurbits, pole type beans; fruits like lemon, Noni (Morinda) etc. Similarly, in problem rocky soils, the deep pit technique can be explored in that the deep pits of different size can be made and short to medium growing fruit trees can be grown. Polybag or pot culture is another good option for the growers and policy makers to promote agriculture in degraded uplands. This will avoid soil erosion and help rapid adoption of economic activities from the region.

9. Biodiversity conservation and land restoration

The biodiversity represents Rapid expansion and unsustainable management of croplands and grazing lands is the most extensive global direct driver of land degradation, causing significant loss of biodiversity and ecosystem services – food security, water purification, the provision of energy and other contributions of nature essential to people. Conse3rvation of biodiversity in agriculturally wastelands or transit lands is important option to utilize and restore the degraded lands.

10. Noni for tapping wastelands

Noni (*Morindacitrifolia*) is a medicinal fruit plant which is used for preparation diverse health refreshing drinks and cosmetic items. This is very commonly seen wild tree in tropical regions. It was found to be very effective solution for utilization of sea water encroached degraded lands in islands and coastal regions (Singh et al. 2009). The soil mount technique was found to be effective for growing Noni in these salts affected lands. Further, in sloppy lands or hilly terrain in tropical islands, the soils are usually unfit for commercial cultivation but noni was found to be very suitable for such situation. Drought tolerance and strong root system make this as an ideal crop for cultivation in wasteland (Singh et al. 2012).

Land policy Formulation in India

In India, the land is an important consideration in national planning since it has limited scale but most in demand. Because India, has only 2.4 per cent of the world's geographical area but supports over 16 per cent of the world's population. It has 0.5 per cent of the world's grazing area but has over 18 per cent of world's cattle population (NITI Ayog). Intensive agricultural practices that rely heavily on water, chemical fertilisers and pesticides have caused waterlogging and salinity in many parts of the country. The plan-wise issues and policies for land management are given in Table 1.

Policy issues

- Promotion of farm-forestry and agroforestry on marginal lands has to be encouraged. The marginal lands and lands with slopes of more than one degree are ideally suited for tree crops. Hence, the farmers and local communities should be sensitized for tree plantations in these regions.
- Watershed approach has significant impact on land restoration and effective use of wastelands for diverse agricultural and forestry practices. Therefore, it should be prompted at large scale with appropriate technological support.
- Since, effective water management is an integral part of land restoration and utilization for agri-horticultural crops, therefore, rainwater harvesting and conservation would be the focus of development planning in this context. Use of indigenous technology and local materials would be promoted.
- Resource-poor areas such as having degraded land support activities that provide low-wage refuge employment. Therefore, adequate credit and training facilities and additional livelihood activities should be provided in the region for promotion of human activities which also contribute in land restoration.
- Water, fodder and fuel have always been the responsibility of women in the rural areas.Training programmes that impart skills,

Table 1: Land policy formulation through planning period.

Plant period	Issues	Policy focus
First 1951–56	To increase area under cultivation	Land reform for efficient use of land and tenancy rights to cultivate land and abolition of intermediaries
Second 1956–61	Low productivity in dry land	Soil conservation, irrigation development, strengthen extension services
Third 1961–66	Food security, reclaiming cultiwable waste land and ways to tackle low growth regions to increase the growth	Intensive area development program, conducting soil surveys
Fourth 1969–74	Food security, ways to shifting land towards food crops, tackle allocation and technical inefficiency in production	Focus on soil and water conservation in dry regions, technological change, land ceiling Act, institutional changes
Fifth 1974–79	Irrigated land management, Drought-prone areas	Drought prone area and desert area development programs, focus on dry farming
Sixth 1980–85	Underutilisation of land resources	Land and water management programs
Seventh 1985–90	Soil erosion and land degradation, deforestation, degradation of forest land	Specific attention to soil and water conservation
Eighth 1992–97	Dryland and rainfed areas, importance of peoples participation in land management in villages recognised	Soil conservation integrated with watershed programs. Agroclimatic regional planning approach
Ninth 1997–2002	Faster rate of land degradation, revisit of Land reforms, tackling technical inefficiency, long term policy needed	Maintenance of village commons, Decentralised land management, Panchayat Raj institutions
Tenth 2002–2007	Groundwater depletion and water logging	Rainwater harvesting, groundwater recharging measures and controlling groundwater exploitation, treatment of waterlogged areas
Eleventh 2007–2012	In addition to erosion, salinity and alkalinity, soils losing soil carbon and micronutrients due to irrational and unbalanced fertilizer use	Rationalise subsidies across nutrients, reform delivery method of subsidies, agriculture extension

(Source: Despande, 2003; Mythili and Goedecke, 2016) improve access to credit and marketing facilities and other support service would have to be arranged for them.

- A National Policy on Land Resources Management would be formulated for optimum management of land resources to meet socio-economic demands.
- Programmes relating to conservation, development and management of land resources are handled by different Central Ministries and Departments
- To tackle the rapidly declining water table and prevalence of dry conditions in many parts of the country, traditional methods of harvesting and conservation of water will be encouraged.
- Land and forest regeneration programmes need to be appropriately planned on a microwatershed basis.
- Capacity building is needed for Government and user communities through training programmes and awareness campaigns.
- A comprehensive regional land use database would be created and made accessible.
- In setting priorities for land use planning and management, it may be useful to identify and assess 'hot spots' of land degradation so that they get maximum benefits from the limited resources available.
- Promotion of research activities in agroforestry and horticultural crops for proper utilization of degraded lands of land in transition.
- Research need to be done on effective land manipulation techniques for growing horticultural crops with limited external inputs in the degraded lands, since the farmers in these regions are resource poor.

Conclusion

Land degradation is a serious issue which affect food and nutritional security of the country. There is need to intensify the efforts for restoration of degraded lands to ensure food security and livelihood support to people. Different technological options are available now for restoration and reclamation of degraded lands. However, most of these are costly and time taking measures. Thus, there is need for systematic and long-term research programmes for understanding the most effective land management option. Use of region specific and problem specific crops, irrigation management options, land management practices, microbial consortia etc. have shown promise. Organic farming and natural farming are new dimensions in agriculture & horticulture which great potential not only in enhancing the income but also utilize the degraded wastelands.

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Challenges and Opportunities in Horticulture

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Horticulture (fruits including nuts; vegetables including potato, tuber crops, mushroom; ornamental plants including cut flowers; spices; plantation crops and medicinal & aromatic plants) play important role in Indian agriculture. It has become a key driver for economic development in many of the states in the country. Presently, horticulture alone contributes about 30.4 per cent to GDP of agriculture. India has emerged as the second largest producer of fruits and vegetables in the world and largest producer of crops like mango, banana, coconut, cashew, papaya, and pomegranate. Many states in India like Maharashtra, Andhra Pradesh, Himachal Pradesh, Jammu Kashmir, Uttrakhand, etc. are focusing on horticulture to improve the productivity and farm income. India is the largest producer and exporter of spices at global level and also has recorded highest productivity in the world in many crops like grape, banana, cassava, peas and pomegranate. Keeping the future challenging issues in mind, such as fast increasing global population, food & nutritional security, reducing land & water resources, ill effects of climate change & pollution, unemployment etc., horticulture has enormous potential to address such challenging issues. However, there will be urgent need to focus on key factors, in order to succeed in future. Top ten issues, as felt by the author, are listed below with brief description.

Quality Planting Material: Seeds and planting material play an important role in horticultural produce and profitability of farmers. Non-availability of quality seeds and planting material has been a perpetual issue for the growers. It has been observed that number of research findings and papers are available in open domain to address almost every issue that exist on the topic today. However, timely availability of desired seeds and planting material for commercial horticulture is like waging war. A large number of imports are being made in India, especially of vegetables and flowers seeds. Our public funded institutions like universities, research institutions and state machineries etc. cannot address the challenge. There is readily available market which can be tapped for business development in support with start-ups and private entrepreneurs.

Alternate Production Technologies: Fast raising population, reducing per capita availability of cultivable land & water resources, degradation of land and ill effects of climate change, etc. are mega challenges before us. Such issues are going to affect expansion of horticulture in days to come. A number of publications have been made to find alternate strategies to these issues. Protected cultivation, soilless cultivation, vertical farming, indoor horticulture, etc. are some classical examples which need to be studied, customised and developed as per the need of the time and location. Till now only limited and scattered information are available. To make break through, there is need to develop complete package & practises and proper support system in order to popularise these technologies. Secondly, such technologies need not be considered as alternative to open field and orchard cultivation, but to be used as supplementary technologies for specific crops and different environments, also under extreme conditions.

Efficient Input Management: Timely availability and efficient use of resources is one of the most important limiting factor in horticultural production. It not only affects yield, quality and profitability of the farmers but also play important role in pollution control and, environmental & product safety. Major resources like water, fertilizers/ ago-chemicals, seeds/ planting material, manpower, etc. need to be used in judicious manner, at right time and at right dose. Caution may be prepared and highlighted on the issues. This will improve farm efficiency and quality of produce, thereby increasing profitability of the farmers.

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Toxin free & quality of Produce: Safety of the horticultural produce is going to be a major market issue since consumers are becoming aware about the ill effects of toxicity. Heavy metal contaminations and pathogenic contamination are two major concerns on the subject. Various SOPs, testing kits/ facilities and certification, etc. are blooming to address the issue. The importing countries are framing stringent rules and strong monitoring mechanism. Ignoring / relaxing any such issue will drastically damage the horticulture industry, as it is directly affecting the global and domestic market and related to health of the people.

Effective Post Harvest Management: Post harvest losses in horticultural crops are very high and share major component in farmers' income/ profit. At every step from harvest till it reaches consumer's table, there are substantial loss at several points. Though many technologies are available to handle the issue, but still it will remain as one of the most important challenge in future also. Effective mechanisation, storage, transport and value addition with proper supply chain management techniques only will minimise the losses and improve the profit of the famers, with least input. This also has potential to improve our export to the other countries.

Mechanisation, Tools/ Equipment and Artificial Intelligence: Till now horticultural engineering support has been very weak and poor. The tools and equipments used at various stages of production, harvesting, post-harvest/ processing are very primitive and not users' friendly. It is predicted that most of orchard and post-harvest operations will now be mechanised and supported with Artificial intelligence, related data and past experience. This will not only conserve time and resources, but also reduce losses and damages, which will enable to make right decisions at faster pace.

Successful Models and Stories: In diverse country like India, transferring technology to the farmers'field is really challenging. Indian farmers are very apprehensive about the change to new technologies/practices, because of small land holding, poor resources and lack of strong support system, which challenge their livelihood in case of failure. The most effective and successful means of technology transfer is our country has been through models and success stories. There is need to develop more and more models and success stories in various zones on different technologies which can easily be replicated by others. This will make our technology programme more fast and effective.

Farmers friendly market link: Marketing of horticultural produce is the most important but weak link affecting farmers' profitability. Horticultural produce being highly soft and perishable, poses special challenges in marketing. Poor marketing infrastructures, link between producers and consumer and too many but inefficient middle agents are some key factors which need to be improved. With revolution of information technologies, marketing can be developed directly between producer and consumer and hurdles need to be removed to make effective transfer of produce farm to plate. This only has the potential to double famers profit.

Knowledge management with focused R& D and Education: Knowledge is ultimate power and key to success in any business. Lot of knowledge has been created by researchers, farmers, industry, scholars, entrepreneurs, etc. which lies *in silo* and in different forms. It is not only difficult to retrieve them but also to understand and further translate into reality. With the use of modern tools, such experience/ knowledge need to be made available in easy to understand and usable by the framers, keeping their requirement in mind. Many such initiatives have been made in the form of mobile App and farmers advisory services, etc which caters the need of the farmers, based on crop, soil region, climate, forecasting and market information services, etc. On the other hand, our academic and R&D institutions need to be more focused on real ground problems faced by the growers and take up as research issues. Quality of our education also need to be improved with more focus on skill development, rather on the current process of knowledge based education/ testing.

Innovations in Horticulture: There are number of agencies, universities and institutions etc. which are excellent seat of knowledge for horticultural science. Number of new concepts are developed, proven with data & experimentation. However, when it comes to address the challenges, or solve any problem on ground, most of our findings prove to be either a failure or not sustainable. This happens because our approach to tackle the problem is only in bits and pieces. There is strong need to switch over to technology development, from science development approach. This will give complete solution package to the challenges, and also help to boost innovation in horticulture.

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Climate Resilient Sustainable Technologies of Dryland Fruits for Economic and Health Security

A.K. SINGH

Introduction

Fruits are undoubtedly known as protective as they are rich in vitamins, phyto-chemicals and minerals. Fruits are excellent source of soluble dietary fiber, which helps in lowering the cholesterol level and fats from the body and also helps in smooth bowel movements. Generally, when fruits are compared with vegetables, pulses and cereals possess very high anti-oxidant values. Antioxidant properties help in removal of free radicals from the body, and thus provide protection against many chronicle and infectious disease. Since time immemorial, edible wild fruits have played a very vital role in supplementing the diet to the poor masses especially tribes of country. Apart from customary use as food, wild edible fruits have various health advantages as it potentially give immunity to many diseases (Singh and Singh, 2016). Accordingly, *Ayurveda*, the Indian Folk medicine was developed from wild fruits and plants. It was recognized that a high consumption of fruits can help to prevent several non-communicable diseases such as cardiovascular diseases, the diabetes type II and some cancer. Most of the important semi-arid fruits are indigenous and it is easily available. In India most common underutilized fruits are aonla (*Emblica officinalis*), ber (*Zigyphus mauritiana*) bael (*Aegle marmelos*), chironji (*Buchanania lanzan*), karonda (*Carissa congesta*), ker (*Capparis decidua)*, phalsa (*Grewia asiatica*), pilu (*Salvadora oleoides*), jamun (*Syzygium cuminii*), kokam (*Garcina indica*), malabar tamarind (*G. cambogia*) and tamarind (*Tamarindus indica*), monkey jack *(Atrocarpus lakoocha)*, ber (*Ziziphus mauritiana*), lasoda (*Cordia dichotoma*), wood apple (*Feronia limonia*), custard apple (*Annona squamosa*),fig (*Ficus carica*), cape gooseberry *(Physalis peruviana)* phalsa (*Grewia subinaequalis*), mulberry (*Morus nigra*), manila tamarind (*Pithecellobium dulce*), timru (*Diospyrus melenoxylon*), mahua (*Madhuca indica*)and palmyra palm (*Borassus flabellifer*), Sugar date palm (*Phoenix sylvestris,),* mahua *(Bassia* latifolia) etc. These fruits are rich source of vitamins (ascorbic acid, thiamine, niacin, pyridoxine and folacin), minerals, fat, protein, and dietary fiber. These crops can be grown with minimal management under aberrant agro-climatic conditions (Singh *et al.* 2011, 2016 and Singh, 2001). The semi-arid zone is a transition zone between desert and dense forests of Western Ghats. The semi-arid zone comprises 970,530 km2, which is 37% of the total geographical area of the country. The semi-arid zone is distributed in the states of Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu (Table 1). In the semi-arid zones, the crops and cropping systems are quite diverse depending upon soil types and length of growing season.

Table 1: Area under hot arid and semi-arid zones in India

States	Semi-arid zone km^2	Semi-arid zone (%)	Arid Zone km^2	Arid Zone (%)
Rajasthan	121020	13	196150	61.00
Gujarat	90520	9	62180	19.60
Punjab & Haryana	58650	6	27350	9.00
Maharashtra	189580	19	1290	0.40
Karnataka	139360	15	8570	03.70
Andhra Pradesh	138670	15	21550	-
Tamil Nadu	95250	10	-	-
Uttar Pradesh	64230	7	-	-
Madhya Pradesh	59470	6	-	-

Nutritional significance

Fruit crops can be "bridge crops," filling nutritional gaps in the annual dietary cycle. These crops can be continuously harvested over weeks or

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months and act as a long-term nutritional supplement. A farm or garden diverse in both species and cultivars will produce over an extended period and will provide a diversity of nutrients. Seasonal variation in food supply affects livelihoods as well. Times of abundance, such as during the harvest and sale of crops, alternate with periods during which savings dwindle. Underutilized fruit crops can improve livelihoods in two ways. First, income can be increased through specialty markets that pay a premium for unusual products or items available somewhat out of season. Second, money can be saved, and thus livelihoods improved, if underutilized crops feed the family during periods when food might otherwise need to be purchased. Specific nutrient deficiency, malnutrition, and under weight of children are significant challenge inrural/ tribal areas of India. The intake of nutrients in daily diet is far from satisfactory and largely less than 50% RDA is consumed by over 70% of Indian population. Vitamin A, iron, and zinc deficiency when combined constitute the second largest risk factor in the global burden of diseases; 330,000 child deaths are precipitated every year in India due to VAD; 22,000 people, mainly pregnant women, die every year in India from severe anemia; 6.6 million children are born mentally impaired every year in India due to iodine deficiency; intellectual capacity is reduced by 15% across India due to iodine deficiency; and 200,000 babies are born every year with neural tube defects in India due to folic acid deficiency. It increases the risk of premature delivery and low birth weight. The maximum children of tribals are suffering from IDA, retarded growth, impaired cognitive performance, and reduced physical activity. Nutrient deficiency also accelerates the mortality and morbidity rate in women. Fruits play a significant role in tribal/rural population nutrition, especially as sources of vitamins ascorbic acid (C), carotenoids (A), thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6), and folacin, minerals, fat, protein, and dietary fibre. Other important nutrients supplied by fruits and vegetables include riboflavin (B2), zinc, calcium, potassium, and phosphorus. Most of the food resource is available in plenty during a particular season but all have not been utilized to desired extent due to many reasons. Thus, people residing in tribal areas hardly get considerable advantage from the abundantly available resources. The solution of the problem lies only in evolving the techniques of value addition, providing market, and creating awareness about nutritional quality of underutilized commodities. Processing and value addition of underutilized fruits into more useful, digestive, tasteful, and convenient products ultimately improves the economic value of underutilized commodities and develop nutritional security to the people of country particularly poor ones.

Medicinal significance

Most of the underutilized indigenous fruit crops used as medicinal formulations throughout India, and popular in various indigenous system of medicine like *Unani, Ayurveda* and Homoeopathy owing to rich in minerals, vitamins and phytochemicals. These fruits are rich in flavour and aroma. Beside their importance for nutritional, therapeutical and economic value, diversity of these fruits also has cultural and social value, contributing to the stability of ecosystem. Cultivation and consumption of these crops may be helpful in overcoming the nutritional deficiencies predominant in rural/tribal areas. They also improve socio-economic conditions of poor masses of the country. In addition to socio-economic and ecological advantage, such fruits have numerous medicinal properties as its different plant parts have pharmacological activities. Therefore, these fruits are rich in minerals, vitamins and phyto-chemicals which need to be harvested for commercialization and utilization of wasteland simultaneously (Singh *et al.* 2014). Biological activities of minor fruits are presented in Table2.

Table 2: Biological activities of dryland fruits

Crops	Biological activities
Bael	Anticancer, sedative, hypnotic, analgesic, anticonvulsive, hypothermic, antimalarial, antipyretic, antidiuretic, antitumor, cardioactive, antihyperglycemic, antidislipidemic, antiinflammatory, antiulcer, antiseptic, antiallergic, antidirrhoea, astringent, antibacterial, antihelminthic, antispasmodic, artiemicide, cytotoxicanti-diabetic, antidiabetic
Aonla	Analgesic, anti-tussive, hypoglycaemic, antidiabetic anti-atherogenic, adaptogenic, cardioprotective, gastro, nephron, neuro protective, anticancer, anti-mutagenic, anti-inflammator, chemo preventive, immune modulatory properties.
Ber	Anti-inflammatory, anti-microbial Agent, Anti-allergic, anti-histaminic, anti cancer, anti-diarrheal , antiaging
Jamun	Antidiabetic, antihyperglycemic, antifungal, anti-inflammatory, neuropsycho-pharmacological, antimicrobial, antibacterial, radioprotectiv,

(*Contd.*)

	gastroprotective, antifertility, anorexigenic, antidiarrheal, ulcerogenic and anti-HIV.
Custard apple	Antiviral, antioxidant activity, respiratory stimulant, antimalarial, antihelmintic, antiulcer hepatoprotective, anti-arthritic, antiinflammatory and analgesic, anti-HIV, hypoglycemic
Mulberry	Antidiabetes, hypertension, anaemia, and arthritis antioxidant, antimicrobial, and neuro-protective, anti-inflammatory.
Wood apple	Antimutagenic, hypoglycemic and hyperlipidemic vomiting and hiccups, dysentry, indigestion and induce bowel boils and amoebiosis, diuretic activity, anti-bacterial, antifungal.
Tamarind	Cardioprotective, gastric, jaundice, fever,
Khirni	Aphrodisiac, appetizer, arthritis, jaundice, blood purifier
Mahua	anti-inflammatory, hematoprotective, antitumor, analgesic, rheumatism, ulcer, tonsillitis ulcers, dyspepsia, opcity of the cornea, bronchitis, urethrorrhea, leprosy
Chironji	Antidiarrhoea, intercostals, rheumatic pains and skin diseases
Phalsa	Astringent, stomachic, demulcent,rheumatism, antiinflammation, administered in respiratory, cardiac and blood disorders, antimicrobial, anti-platelet, antiemetic, anti-cancer properties anticancer, antioxidant, radioprotective and antihyperglycemic properties
Karonda	astringent, appetizer, antipyretic, antidiabetic scabies, intestinal worms, diarrhoea antipyretic, appetizer, antiscorbutic, antihelmintic
Manila tamarind	Abortifacient, anodyne, astringent, larvicidal, guamachil is a folk remedy for convulsions, dysentery, dyspepsia, earache, leprosy, peptic ulcers, sores, toothache, and venereal disease eczema, sore throat, acne and pimples
Wild noni	Antibacterial, antiviral, antifungal, antitumor, antihelmin, analgesic, hypotensive, anti inflammatory and immune enhancing effects.
Fig	Metabolic, cardiovascular, respiratory, antispasmodic, anti-inflammatory, antidiarrhoea, respiratory haemorrhage, diuretic, diabetics, anthelmintic tuberculosis, anticancer, antidiarrheal
Timru	Antimicrobial , antiplasmodial, antidiabetic, antimaleria
Gonda	Antihelminthic, diuretic,,demulcent

Sources: Maity *et al.* 2009, Singh *et al.* 2014, 2019a, Sharma *et al.* 2007, Yadav *et al.* 2018, Shyam Sunder 2010, Qureshi *et al.* 2010, Chauhan *et al.* 2012 and Maridass *et al.* 2008

Genetic resources

India, the centre of origin for many tropical and sub-tropical fruit tree species, most of them are not commercially cultivated but they are significant source of livelihood support for many local communities. The local inhabitants of Western Ghats, Maharashtra, Gujarat, Rajasthan and North Eastern States of India were traditionally reliant on local fruit species like tamarind, aonla, ber, chironji, custard apple etc., apart from mango and other major fruit crops for their livelihoods. Due to unsustainable market pressures and rapid urbanization, majority of these species have come to near extinction. Therefore, cconservation of genetic resources of underutilized fruits through holistic approach is required which includes both *in-situ* and *ex-situ* conservation strategies (Singh *et al*., 2020). The diversity of some of the underutilized fruits is well studied while for other underutilized fruits relatively less attention has been given so far. In this connection, crop specific surveys in targeted diversity rich areas were undertaken in arid and semi-arid regions of Gujarat, Madhya Pradesh, Uttar Pradesh, Chhattishgarh, Haryana, Punjab, etc. and a large number of germplasm of semi-arid fruits were collected over the years for systematic evaluation, characterization and conservation of indigenous germplasm at CHES, Godhra (Singh *et al*., 2020). Germplasm of various underutilized fruit crops were evaluated for development of varieties at CHES, Godhra on the basis of desirable horticultural traits. Out of which varieties like Goma Yashi (bael), Goma Priyanka (jamun), and tamarind (Goma Prateek) have been become popular at national level as evidenced by commercial scale plantation at the farmer's field (Singh *et al.* 2018c, Singh *et al.* 2010a). A wide range of variability with regard to yield, qualitative and quantitative character in different semi-arid fruit crops (Singh and Singh, 2005a, 2012b and 2019d, Singh *et al*., 2020). At

Table 3: Germplasm conservation of semi-arid at National Field Repository of CIAH, Bikaner

Crop	Scientific name	No.	Crop	Scientific name	No.
Bael	*Aegle marmelos*	21	Manila tamarind	*Pythocelobium dulcae*	03
Ber	*Ziziphus mauritiana*	318	Jharber	*Ziziphus rotundifolia*	22
Cactus pear	Opuntia ficus-indica	24	Jamun	*Syzygigium cuminii*	2
Phalsa	*Grewia subenaequalis*	05	Lasora	*Cordya myxa*	15
Pomegranate	*Punica granatum*	154	Kair	*Capparis decidua*	06
Fig	*Ficus carica*	02	Karonda	*Carissa carandus*	05
Mulberry	*Morus* spp.	15	Wood apple	*Feronia limonia*	03

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Table 4: Germplasm conservation of semi-arid fruit at National Field Repository of CHES, Godhra

Crop	Scientific name	No.	Crop	Scientific name	No.
Aonla (Indian gooseberry)	*Emblica officinalis G.*	26	Manila tamarind	*Pythocelubium dulcae*	25
Bael	*Aegle marmelos*	215	Jamun	*Syzygium cuminii*	68
Capegooseberry	*Physalis peruviana*	06	Palmyra palm	*Borassus flabellifer*	2
Phalsa	*Grewia subanaequalis*	25	Karonda	*Carissa carandus*	40
Badhal	*Artocarpus lacucha*	04	Fig	*Ficus carica*	07
Mulberry	*Morus* spp.	15	Chironji	*Buchanania lanzan*	30
Mahua	*Bassia latifolia*	30	Wood Apple	*Feronia limonia*	65
Tamarind	*Tamarindus indica*	25	Khirni	*Monilkara hexendra*	30
Custard apple	*Annona squamosa*	70	Lasoda	*Cordia myxa*	04
Ber	*Ziziphus mauritiana*	64	Barhal	*Artocarpus lakoocha*	3

Singh *et al.*, 2020

present, ICAR-CIAH (Table 3) and its regional Centre CHES, Godhra are maintaining a large number of diverse germplasm of semi-arid fruits in field repository (Table 4).

Wide range of variability in leaf morphology, flower characters and phenology has been reported in different germplasm of minor fruits under rainfed semi-arid condition (Singh *et al*. 2013a). Singh *et al.* (2015a) observed inter-varietal morphological variability in terms of leaf base margin and apex in bael varieties under central Gujarat conditions. Morphological variations in terms of vivipary, metaxenia and cauliflory in bael germplasm have also been recorded (Singh *et al.*, 2018b) under dryland conditions of western India.Morphological, floral, phenological and pollination behaviour in different germplasm of hot semi-arid fruits have been studied in detail, viz. bael (Singh *et al.* 2008, 2011a, 2011b, 2012a), jamun (Singh and Singh 2012b), khirni (Singh and Singh 2005d, Singh *et al.* 2016b and 2019c), tamarind (Singh and Singh 2005b, Singh *et al.* 2010), chironji (Singh *et al.* 2006 and 2010), phalsa (Singh *et al.* 2019a), karonda (Singh *et al.* 2014), custard apple (Vikas *et al.* 2017 and 2018), wood apple (Yadav *et al.* 2018), mahua (Singh *et al.* 2005 and 2008) and wild noni (Singh and Singh 2018, Singh *et al.* 2014b and 2016b) under rainfed hot environment of western India.

Varietal wealth

Selection of plant species and their varieties for production is important. The crop must have one or another characters like deep root system, summer dormancy, high 'bound water' in tissues, reduced leaf area, sunken stomata, thick cuticle, wax coating of pubescence, presence of latex, and ability to adopt shallow, rocky, gravelly and undulated wasteland. Some semi-arid fruit crops are widely grown and used in their centers of origin, but are "neglected" by regional and international markets (Singh *et al.*2019a). Crops not suited to long distance transport and commoditization are often ignored by plant breeders and agricultural researchers, which limits the number of named cultivars and the creation of new varieties with traits suited to a broader range of growing conditions (Singh *et al.* 2013).Some highly nutritious plants could play a larger role in reducing malnutrition if they were eaten over a longer period of the year or if cultivars were available for different growing conditions. At present, research work on collection, characterization, evaluation and conservation of underutilized fruits have been initiated at several Agricultural Universities and ICAR institutes and their regional centre and high yielding quality varieties were developed. Varietal wealth underexploited fruits is given in Table 5.

Table 5: Different promising varieties dryland fruits

Crops	Varieties
Bael	Goma Yashi, Thar Divya, Thar Neelkanth, Thar Srishti, Thar Prakriti, Thar Shivangi, NB-7, NB-9, NB-5, CISHB-1, CISHB-2, Pant Aparna, Pant Shivani, Pant Sujata and Pant Urvashi
Aonla	Banarasi, Chakaiya, Francis, NA-4, NA-5, NA-6, NA-7, NA-10,Anand-1, Anand-2, BSR-1 and BSR-2 and laxmi-52
Ber	Gola, Umran, Goma Kirti, Thar Sevika, Thar Bhubhraj, Seb, Apple ber, Mundia, Banarsi Kadaka
Jamun	Goma Priyanka, Thar Kranti, Konkan Bahadoli, Jamwant,Paras,Rajamun, Rajendra Jamun-1, Jamwant

(*Contd.*)

Custard apple	Washington PI 98797, Washington PI 107005,British Guinea, Barbados seedling, Island Gem, Bullocks Heart, Pink Mammoth,Balanagar, Mammoth, Red Sitaphal, Yellow Sitaphal, Phule Janki and Sindhan
Mulberry	Thar Lohit, Thar Harit, Victoria-1, China White, Saharanpur Local-1, Saharanpur Local-2, S-13, S-34, S-146, S-7999, S-1635, Chak Majra
Karonda	Pant Manohar, Pant Sudarshn, Pant Suverna, Konkan Bold, Thar Kamal
Tamarind	Goma Prateek, Prathisthan, PKM-1, T 263, Urigam, Ajanta, Yogeshwari, DTS 1 and DTS 2, Anant Rudhira
Lasoda	Thar Gold, Paras Gonda, Puskar Local, Maru Samridhi, Karn Lasoda
Khirni	Thar Rituraj
Phalsa	Thar Pragati
Chironj	Thar Priya
Mahua	Thar Madhu, NM-2, NM- 4, NM-7, NM- 9
Manila tamarind	PKM (MT) 1
Fig	Poona Fig, Dianna, Dinkar, Conadria, Excel, Chalisgaon
Wood apple	Thar Gaurav

Saroj *et al.* 2018, Singh *et al.* 2019, Hiwale 2015, Singh *et al.* 2010, Yadav*et al.* 2018a and 2018b.

High Density Planting

Planting density mainly depends upon the plant type, soil fertility, varieties, growth habit of tree, rootstock used and management practices. These are the deciding factors for optimum spacing in an orchard. Different systems of planting, viz. square, rectangular, traiangular (alternate), quincunx, hexagonal, contour,double hedgerow, cluster, pair and hedgerow system of planting may be adopted. Generally, adjacent planting is followed in arid regions and in poorly fertile soils. In this system, two plants are placed closely keeping double space between rows. In the plains, planting, is generally done in square or rectangular system while on slopy lands, fruit trees are planted on contour terraces, half moon terraces, trenches and bunds, and micro-catchments. On marshy and wet areas mounding and ridge-ditch method of planting have been suggested. The trenches and bunds made across the slope are staggered (Saroj *et al.,* 1994). In a micro-catchment, which may be triangular or rectangular, trees are planted at the lowest point where runoff accumulates. In a micro-catchment, which may be triangular or rectangular, trees are planted at the lowest point where runoff accumulates (Shrma *et al.,* 2013). The planting distance 6 x 6 m or 8 x 8 m for ber cultivation is optimum. Date palm, bael and aonla are planted at 5 x 5 m or 8 x 8 m distance. High density planting studies in pomegranate revealed that the maximum plant height was recorded at 2m x 2 m spacing, whereas plant height, stem girth, average number of fruits, average weight of fruit and yield was obtained under 4.5m x 3.0 m spacing under Rahuri conditions. High density planting is also beneficial in aonla (Singh *et al.,* 2010, Singh *et al.,* 2018) and ber, bael, chironji (Singh *et al.,* 2016) and jamun (Singh *et al.,* 2018) fruit trees to achieve high yield under semi-arid conditions.

The high density planting of Bhagwa pomegranate at spacing of 5m x 3m (666 plants ha^{-1}) and 4m x 2.5 m (1000 plants ha^{-1}) under drip irrigation and fertigation has been adopted by the farmers of Rajasthan with a fruit yield of 15t ha^{-1} and net income of 1.5-2.0 lakh ha^{-1}. However, farmers are facing the problem of fruit cracking and nematode infestation in hot arid region of Rajasthan (Saroj, 2018). ICAR-CIAH, RS, CHES, Godhra has released a semi dwarf bael variety Goma Yashi can be planted at 5m x 5m, accommodated 400 plants ha^{-1} which can yield 25t ha^{-1} at the age of 8th of plantation with net return of 1.5 lakh/ha under rainfed and waste land conditions of Gujarat (Singh *et al*., 2019).Under rainfed semi-arid conditions of Gujarat, aonla cv. NA-7 was planted in double hedge row system of planting by accommodating 260 plants ha^{-1} has given the fruit yield of 23t/ha with a net return of 2.43 lakh/ha at 11th year of planting (Saroj, 2018). High density planting systems has been successfully demonstrated for earliness, improved yield, smooth handling and cultural practices using double hedge row system of planting in aonla (Singh *et al*., 2011). Moreover, by manipulating plant spacing using different planting systems like rectangular planting in hedge row, double hedge row, paired planting and cluster planting proved to be an important tool to achieve high quality produce.

Value added products

A large quantity of dryland fruits produce goes waste due to unavailability of adequate storage facility and lack of knowledge about value added products. Proper storage facility like cool storage, CA and ZECC storage can reduce the post harvest loss to greater extent and can improve the farm income (Singh *et al.* 2019b, Singh and Singh 2012).

Various processed products are being made by the people utilizing their acquired traditional knowledge like sun drying, pickling etc. However, with the application of modern techniques, the quality of products could be improved considerably. The pre-treatment of many fruits with hormone and harmless chemicals results in better quality end products (Meghwal, 2016). Solar drying and electric tray dehydration of fruits and vegetable help to reduce dust load on the product and retain natural colour. Techniques for preparation of different products from semi-arid fruits have been standardized (Mishra 2018).Mal nutrition in resource poor areas of semi-arid region is a major problem particularly in women and children. Fruits like tamarind, custard apple, bael, khirni, karonda, phalsa, mulberry, wild noni, wood apple etc. are a rich source of vitamins, minerals and dietary fibres These fruits are highly perishable in nature, the marketing of which is a major problem, e.g. custard apple gets spoiled within 2–3 days of harvesting, if not consumed (Vikas, 2018). Also with the glut in the market, the prices of these fruits drop down drastically making it uneconomical for the farmers to sustain production; the result is that the farmers uproot the trees owing to low price in the market. To avoid the situation, there is a need to extend shelf-life of these fruits and to develop post-harvest value addition technologies which are simple and adaptable at the farm level. This will not only result in developing small-scale industry but it will also provide employment to the rural masses throughout the year resulting in increased income of both farmers and workers. Efforts made at the CIAH Bikaner and region research Centre CHES, Godhra were successful and many products viz., dried and dehydrated fruits, RTS, squash, fruit bars, candies, fruit concentrates, powders, wines, and condensed fruit juices through solar drying, were prepared and demonstrated to stakeholders for further commercialization (Singh *et al.* 2013).There is tremendous scope for preparing beverages from ripened fruit of chironji. Kernels are being used for the preparation of different kinds of sweets. The products like squash, RTS, and nectar may be prepared from the pulp of the fruits. The value added products of these fruits have expected to catch the national and international markets, if it is properly focused (Table 6).

Table 6: Value-added products of dryland fruits

Semi-arid fruit crop	Value-added products
Bael	Preserve, RTS, nectar, ice cream, slab, squash, cider, canned slices, pickles and powder
Aonla	Jam Sauce, chutney, preserve, candy, powder, pickle, supari, pills and shreds
Ber	Juice, RTS, candy, jam, jelly, powder, wine
Chironji	Dried kernels, fruit bar
Karonda	Pickle, candy, jelly, jam, preserve, wine,Chutney
Wood apple	Squash, powder, pickle, chutney, jelly, fruit bar
Khirni	Dehydrated fruits, fruit bar, RTS, jam
Jamun	Juice, RTS, squash, syrup, carbonated drink and wine
Phalsa	Juice, squash, syrup
Lasoda	Pickle, culinary
Custard apple	Jam, beverages, ice cream
Tamarind	Tokku (chutney), panipuri masala, Juice concentrate, pulp powder, jam, syrup, candy toffee, tamarind karnel powder
Timru	Bidi, dried fruit
Pilu	Squash, dried *peelu*, wines
Kair	Pickle, dried fruits
Mulberry	Juice, squash and syrup
Mahua	Biscuits, cakes dried powder, seed oil and wine
Manila tamarind	Biscuits, squash and syrup
Aloe	Candy, jelly, pickle, cold cream, crack cream, moisturizer, gel
Fig	Fig paste, concentrate, powder, nuggets, jam

Sources: Singh *et al.* 2016, 2019a, Singh *et al.* 2010 andMishra, 2018

Conclusion

The fruit crops mentioned in this article possess tremendous nutritional and medicinal values. These fruit crops are present around us in unsystematic manner. So, cultivation of these crops in systematic manner and efficient utilization of marketing systems and channels for fresh fruits and processed products can motivate the growers towards growing these crops and can uplift the economy of country. There is tremendous scope of utilizing these crops in different promising value added products to the food and nutraceutical industry. The value added product can meet the dearth of new product in the market and serve the purpose of health security along with economic security. Use of these fruit crops often declines due to changes in farming practices, changes in market forces, and cultural erosion that results from modernization, migration, urbanization, and land degradation.

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Fruit Breeding in India: Achievements and Way Forward

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1. Introduction

Fruit crop improvement is more than one hundred years old today. It was in 1905 that varietal improvement work was initiated in guava by late Dr. G.S. Cheema & Deshmukh and followed by Burns and Prayag,1921 on mango at Ganesh Khind Fruit Experiment Station, Pune. As a result, L-49 guava (Sardar Guava) was developed through a selection from cv. Allahabad Safeda in 1927. These initiatives set the tone for emphasis on fruit crop improvement in India. After that, fruit crop improvement has been carried out in a number of crops through introduction, selection, hybridisation and mutation breeding. Similarly, the exotic germplasm was also introduced. These activities performed by local growers, often patronized by the then rulers and some enthusiastic horticulturist continued over the years and resulted in the development of several popular varietiesof different fruits. After independence of India fruit crop improvement got a fillip with the setting up of a network of Institutes/Project Directorates/ National Research Centres and Regional Station of Institutes in different regions of thecountry. Today we have institutes devoted to Tropical Fruits (IIHR, Bengaluru), Sub-tropical Fruits (CISH, Lucknow), Temperate Fruits (CITH, Srinagar), Arid Fruits (CIAH, Bikaner) and Citrus (CCRI, Nagpur). Besides, there are Project Directorates/ NRCs for Banana (NRCB, Trichi), Grape (NRCG, Pune), Litchi (NRCL, Muzaffarpur), Pomegranate (NRCP, Solapur). Several Department of Horticulture/ Fruit crops instate Agri/ Horti Universities also took up crop improvement work on a number of crops, e.g., mango, guava, grape, aonla, pomegranate, etc. which has resulted in a number of superior varieties.

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2. Problems in fruit breeding

Fruit crop breeding is a long drawn and difficult process due to distinct floral biology, out crossing high heterozygosity, sterility, parthenocarpy, apomixes, polyembryony, poor fruit set, excessive fruit drop. Low rate of sexual propagation with mostly one seed from one fruit, lack of selection procedures for isolation of desired hybrids and long pre-bearing age. Although the breeding methods are the same as for other group or crops, resulting off springs in fruit breeding require huge space for evaluation. There is also need to refine the selection procedure in different crops coming in the way of improvements as understanding of the genetics and inheritance pattern of the quantitative traits in fruit crops has been extremely difficult. Hence, the selection of parents in a breeding programme based on the phenotype becomes difficult and progeny performance or manifestation of hybrid vigour becomes unpredictable. The progenies are also influenced to a great extentby environment. One of the advantages of the heterozygosity is that in the F, generation itself segregation is maximum and the desirable traits in the progenies can be fixed by vegetative propagation. However, a time has come to shift our emphasis from conventional breeding to modern methods of breeding based on biotechnological intervention.

3. Crop improvement through conventional methods

Plant genetics resources form basic raw material to meet current and future needs of crop improvement. Diversity comprises of native land races, selections, elite cultivars and wild relatives of plants. There is also lotof diversity due to seedling population and spontaneous mutations. In fact, unlike other crops where there isneed to create variability in fruit crops it is the management of diversity which is more challenging. Significant achievement made through the above method is discussed below:

3.1. Introduction, evaluation and conservation of gene pool

India is an important centre of diversity and has rich variability of several fruits. There is a large diversity of several native but underutilized fruits namely aonla, bael, jackfruit, jamun, karonda and phalsa. Simultaneously; exotic introduction of new fruit species and varieties have been made in several fruits adding to the existing variability. As a result, a rich reservoir of species and cultivars of several fruit crops has been built up at various research centres (table 1) listed below:

Table 1: National Active Germplasm sites for tropical fruits in India

S.No	Crop	No. of accession	Total accessions across India	NAGS
1	Banana	375+	1213	NRCB, Trichy
2	Citrus	430+	435	CCRI. Nagpur
3	Grapes	299+	458	NRCG, Pune
4	Guava	120+	287	CISH, Lucknow
5	Jackfruit	100+	281	IIHR, Bengaluru
6	Litchi	40+	40	NRCL, Muzaffarpur
7	Mango	750+	1382	IIHR, Bengaluru, CISH, Lucknow
8	Papaya	89+	89 (30+)	TNAU/IIHR
9	Sapota	57+	57	Arabhavi, Karnataka
		Total	4242	

Source: https://aicrp.icar.gov.in/fruits/achievements/plant-genetic-resources/

Table 2: Fruit genetic resources available under IIHR, Bengaluru

Crops	IIHR, Bangalore	CHES, Bhubaneshwar	CHES, Chettalli	CHES, Hirehalli	Total
Mango	767	105	0	0	872
Papaya	38	0	0	0	38
Guava	62	0	0	0	62
Sapota	41	0	0	0	41
Pomegranate	271	0	0	0	271
Jackfruit	67	27	0	25	119
Custard apple	27	4	0	0	31
Grapes	72	0	0	0	72
Strawberry	123	0	0	0	123
Jamun	131	0	41	0	172
Pummello	27	0	65	0	92
Minor fruits	47	35	0	13	95
Bael	0	11	0	0	11
Mangosteen	0	0	17	0	17
Rambutan	0	0	200	0	200
Avocado	6	0	50	16	72
Malabar tamarind *(Garcinia gummigutta)*	0	0	85	0	85
Yellow mangosteen *(Garcinia xanthochymus)*	0	0	106	0	106
Total					2479

Conservation, evaluation & utilisation of biodiversity, which is an important genetic wealth is very important. Many species & varieties in different fruits are rapidly being lost. There are several methods of conservation, which include pollen storage, conservation at haploid stage (accomplished through pollen) and *in situ* conservation, while evaluation of these collections have resulted in identification of several vs suited to different agro-climatic regions of the country much remains to be done in respect of evaluation & utilization oflarge varietal wealth in India (Table 2). Some of the prominent exotic introductions are listed below:

Apple: One of the most significant contributions in the temperate fruits was made by Mr. Samuel Evan Stokes, a resident of Philara, USA who settled in Kotgarh and introduced Delicious group of apples in 1916. It is from these first few saplings that the sweet Delicious group of apple e.g. the Golden Delicious, Red Delicious, were introduced in the area. A large number of new apple cultivars namely Fuji, Oregon Spur. Neil Chief, Red Gold, Red Spur, Royal Gala, Scarlett Gala, Staking Delicious, Top Red and Vance Delicious were introduced from Denmark, Japan, Yugoslavia, West Germany, Europe and USA keeping in view our preference for red coloured, spur bearing and apple scab tolerant varieties.

Banana: Some of the prominent introduction in banana include varieties like Lady Finger having resistance to buncy top virus from Australia; Grand Naine from France and Valery from West Indies. Of these varieties, Grand tone is now extremely popular and is grown commercially all over the country. Some accessions introduced in India and released as Kaveri Saba, Kaveri Kalki and Kaveri Kanya (NRCB, Trichy).

Citrus: Several varieties and rootstocks of citrus have been introduced from USA and Japan. These include: Kinnow- Blood Red and Washington, Naval oranges; grapefruits- March Seedless, Foster, Duncan, Starking Ruby, Red Blush; and lemon-Lisbon and Eureka.

Grape: A large number of varieties have been introduced in grape from different countries. Some of the notable introductions are Thompson Seedless, Perlette, Beauty Seedless, Delight, Himrod cultivars from USA and Kismish Chorni and Kismish Beli cultivars from erstwhile USSR. Other commercial grape cultivars introduced are Red Globe, Crimsom Seedless, Ruby Seedless, Riesling, Centennial Seedless, Flame Seedless, Fantasy Seedless, Rose, Pinot Noir, Shiraz, Chenin Blanc, Cabernet Sauvignon, Chardonnay, Merlot, Sauvignon, Blanc, and Cabernet Blanc from USA and European countries. Many of these varieties are now under commercial cultivation for table, raisin and wine purposes.

Mango: Many exotic cultivars of mango such as Tommy Atkins, Haden, Sensation, Keitt, Zill, Carabao and Julie have been introduced from Florida (USA) and Peru. Sensation and Tommy Atkins have been used in hybridisation programme for imparting red peel colour to indigenous varieties.

Papaya: In papaya Solo, Sunrise, Sunset varieties have been introduced.

Pineapple: Almost all commercial varieties of pineapple grown in India, e.g. Kew, Giant Kew, Queen, Mauritius, and Spanish are exotic introduction.

Arid Zone Fruits: While a large number of arid zone fruits are indigenous to India, several cultivars were introduced in date palm, from Sultanate of Oman, Saudi Arabia and Egypt, fig from USA and Iran and mulberry varieties, Black English, California Giant, Large Black, and Wellington etc. have been introduced.

Temperate Fruits: A number of varieties were also introduced in other temperate fruits. These include William's Bartlett, Conference, Keiffer, Baggugosha, Chinese sand pear in pear, New Castle, Royal, Kaisha, Charamgz in apricot; Early Rivers, July Elberta, JH Hale in peach and Allison, Bruno, Abbott, Hayward, Monty etc. in kiwifruit. Besides, a number of low chilling peach varieties namely Flordasun, Floradred, SunRed and 16-33 were introduced from USA in subtropical regions by PAU Ludhiana. In olive, varieties like Cortina, Apression, Pendotino, and Lessino introduced in Jammu & Kashmir and UP hills produced good quality oil yield (Table 3).

Table 3. Temperate fruits genetic resources conserved at CITH, Srinagar

S.No.	Germplasm	Germplasm Status in 2014-15	Present Status
1.	Fruits	1010	1323
	Pome	321	445
	Stone	162	246
	Nuts	359	398
	others	168	224
	Total		2636

Source: https://cith.icar.gov.in/Researchachievements.aspx?

3.2. Selection of Seedling & Elite Clones

Clonal selection is an important tool in fruit crop improvement. While the exact basis of clonal variants is still not known, seedlings resulting from spontaneous mutations may be the reason for such variants. India is an important centre of diversity of crop plants and has rich variability in several fruits. This gene pool has provided cvs of several fruits grown commercially. Lot of emphasis has been laid on variety improvement in fruit crops through selection of superior chance seedlings and elite clones and their use through vegetative propagation. Clonal selections from commercial varieties are of great value as they differ from the parental material only in few important characteristics. Superior clones have been selected in a number of almost twodozen fruit crops and many of them are now being grown commercially. Some of the seedling and clonal selections which have become commercial in different crops are listed below:

Table 4: Clonal selections in different fruit crops

Aonla	Krishna Kanchan (Faizabad); Goma Aishwarya (Godhra)
Bael	Banarasi and Kagzi (UP); Pant Shivani (Pant Nagar)
Banana	Udayam, NRC-7, Bhat manohar, Kaveri Harita (Trichy)
Ber	Goma Kirti (Godhra), Thar Bhubharaj (Bikaner)
CitrusAcid lime	Vikram, Pramalini (Parbhani), Sai Sarbati (Rahuri), Jai Devi (Tamil Nadu), Tenali (AP), Pusa Udit, Pusa Abhinav (IARI, New Delhi)
Lemon	Pant Lemon-1 (Pantnagar)
Mandarin	Mudkhed Seedless (Maharashtra)
Pummelo	Arka Ananta, Arka Chandra (Bengaluru)
Sweet orange	Yuvraj Blood Red (Ludhiana), Pusa Sharad, Pusa Round (IARI, New Delhi)
Custard Apple	NKM-1&2 (Maharashtra), Arka Neelachal Vikram (Bengaluru)

(*Contd.*)

Grape	Dilkhush (Andhra Pradesh), Manjari Kishmish, (Pune) Manjari Naveen (Pune), Sharad Seedless, Cheema Sahebi (Maharashtra); Pusa Seedless (New Delhi), Tas-e-Ganesh, Manik Chaman,Sonaka (Maharashtra)
Jackfruit	Palur-1 Jack, Siddu, Shankara (Bengaluru), Swarna Chandra, Swarna Halasu (UAS, Bengaluru, Karnataka)
Jamun	Konkan Bhadoli (Vengurle), CISH-J42 (Lucknow), Narendra Jamun (Faizabad)and Goma Priyanka (Gujarat)
Karonda	Pant Manohar, Pant Sudarshan,Pant Suvarna (Pantnagar)
Mango	Niranjan, off season bearing (Parbhani);Sunderraja, a red blushed selection (Rewa), Dashehari-51, regular bearing and high yielding (Lucknow);Cardoz Mankhurd, (Goa); Paiyur-1, a clonal selection (Paiyur); Maneka (Sabour)Arka Neelachal Kesari clonal selection from Gulabkhas (CHES, Bhubaneshwar)
Pomegranate	G-137 , Ganesh (Pune) and Jyothi (Bengaluru)
Rambhutan	Arka Coorg Arun, Arka Coorg Peetab (Karnataka)
Sapota	PKM-1 (Periyakulum); CO-1,2 & 3 (Coimbatore)
Strawberry	Shimla delicious, Jutogh Special (CITH- Srinagar), Pusa early dwarf, Pusa Pride, Pusa sweet (IARI, Shimla)
Tamarind	Goma Prateek (CIAH, Bikaner)
Walnut	Series of clones selected CITH, Pusa Khor (IARI, Shimla)

One of the drawbacks in clonal selection is that if the mother clone is susceptible, the selection is also susceptible. However, some clonal selections can be used as pre-breeding lines for traits different than their mother clones.

Mutation

Gandevi, tall mutant of Dwarf Cavendish (FRS, Gujarat)

Pusa Seedless Pummelo-1, India's first seedless white fleshed pummelo mutant having juice recovery of 41.13% (IARI, New Delhi, Annula Report 2020)

Pusa Arun, a natural mutant from IARI, New Delhi.

3.3. Fruit Breeding

Developments of fruit varieties through hybridisation has also been underway in some fruit crops at differentcentres under National Agriculture Research system in the country and have resulted in several varieties ofwhich many are grown commercially. Some of these are as follows:

A**pple:** Breeding work has been in progress at Regional Horticultural Research Station, Mashobra, Shimla; Fruit Research Station, Shalimar, Kashmir, and Horticultural Experiment and Training Centre, Chaubatia, Uttarakhand with the objectives of developing varieties with better shelf-life, early maturity, high dessert quality and resistance to scab. Hybridization work initiated at Kashmir during 1956 resulted in the releaseof two hybrids namely Lal Ambri and Sunehari. Similar work started at Mashobra, Himachal Pradesh in1960 resulted in four hybrids, namely, Ambstarking, Ambroyal, Ambred and Ambrich. To evolve low chilling varieties having coloured and sweet fruits with good keeping quality, work was initiated at Chaubatia in 1970. As a result, Chaubatia Princess, Chaubatia Agrim, Chaubatia Swarnima and Chaubatia Anupam were released for cultivation. Further, systematic breeding aimed at development of scab resistant apple varieties at SKUAST, Srinagar resulted in the release of Firdaus and Shireen varieties. IARI, regional station Shimla has released two hybrids namely Pusa Gold (Golden Delicious X Tydeman early Worcester) and Pusa Amartara Pride (Royal Delicious x Prima) which are resistant to Powdery mildew and apple scab (Verma.M.K.,2014).

Almond hybridization programme aimed at developing low chilling varieties resulted in development of Hybrid-15, Hybrid A-258 and H-98 with high productivity and quality at PAU, Ludhiana.

Apricot: The major objective in apricot improvement has been climatic adaptation to help it escape spring frost. As a result, work at RFRS, Chaubatia (Uttarakhand) taken up in 1969 resulted in the release of three varieties namely, Chaubatia Madhu (early ripening and highly productive), Chaubatia Kesri (Mid-season variety), and Chaubatia Alankar (low chilling and early ripening).

Ber: Thar Sevika (Seb X Katha) (CIAH, Bikaner)

Custard Apple: A variety of custard apple, Arka Sahan (Gem x Mammoth) has been released from IIHR, Bengaluru and has gained popularity throughout the country and now in the production chain.

Grape: Hybridization work in grape was taken up by IIHR, Bengaluru and IARI, New Delhi. eleven hybrids namely Arkavati, Arka Kanchan, Arka Shyam and Arka Hans were released from IIHR, which have fruitful basal buds and could be trained on head system. Subsequently, seven more grape hybrids namely Arka Neelmani, Arka Sweta, Arka Majestic, Arka Chitra, Arka Soma, Arka Trishna and Arka Krishna have been developed fortable, juice and wine purposes. At IARI, New Delhi, two promising hybrids namely Pusa Urvashi and Pusa Navrang (tenturier) have been released during mid-nineties while, two more hybrids (Pusa Aditi, Pusa Trissar and Pusa Swarnika) have also been identified for release in 2014. Recently Pusa Purple Seedless, a cross of Pearl of Casaba and Beauty seedless was obtained through embryo rescue technique (IARI, New Delhi, 2020 annual report). In 2017, NRC on grape, Pune has developed Manjari Medika (Pusa Navrang * Flame Sedless) (NRC grapes, Pune) Some of these hybrids namely Arkavati from IIHR, Bengaluru and Pusa Navrang from IARI, New Delhi have given good performance and are under adoption bygrape growers in certain states.

Guava: Improvement through hybridization has been undertaken at various centres has resulted in the development and release of soft seeded and large fruited varieties Safed Jam and Kohir Safed (Sangareddy,A.P.), soft seeded white fleshed Arka Amulya, Arka Poorna and soft seeded red blushed Hybrid, Arka Kiran, Arka Rashmi, Hybrid 16-1 (IIHR, Bengaluru); Hisar Safeda and red dotted peel and pink fleshed Hisar Surkha (CCS HAU, Hisar), besides a dwarfing rootstock Pusa Srijan from IARI, New Delhi.Lalit, Shweta, Dhawal and Lalima are the promising selections of guava from CISH, Luknow.

Mango: Systematic hybridization work in India started at Sabour in Bihar and resulted in two hybrids Mahmood Bahar and Prabha Shankar by crossing Bombai and Kalapady varieites. Subsequently, work at Ananthrajupet, Andhra Pradesh resulted in the release of four mango hybrids namely Neeleshan, Neelgoa, Neeludin and Swarnjehangir. Subsequently mango hybridization was taken up at New Delhi (IARI), Vengurla (MPKV) and Bengaluru (IIHR). Major emphasis has been given to development of regular and precocious bearing, dwarf, and large fruited varieties with red blush, good keeping quality and freedom from spongy tissue disorder. Morethan 30 hybrid cultivars have been released by various institutes which include:

Andhra Pradesh:	AU Rumai (Sangareddy)
Bihar:	Sundar Langra, Alfazli, Sabori and Jawahar (BAU, Sabour);
Gujarat:	Neelphanso, Neeleshan and Neeleshwari from Paria;
Karnataka:	Arka Arun and Arka Puneet, (spongy tissue disorder free) Arka Anmol (having goodquality) and Arka Neelkiran (attractive red blush) (IIHR, Bengaluru)Arka Udaya and Arka Suprabath are the double cross hybrids of same parent, Early and Bunch bearing habit;
Maharashtra:	Ratna (free from spongy tissue disorder), Sindhu (seedless) and Konkan Ruchi fromKKV, Dapoli; Sai Sugandh from Rahuri, Ratna released from Vengurla,
New Delhi:	Mallika, (High TSS, regular bearing, semi-vigorous with wider adaptability); Amrapali, (regular bearingvariety, suitable for HDP); Pusa Arunima (red coloured peel andexcellent shelf life), PusaShresth, Pusa Lalima, PusaPratibha and Pusa Peetamber (IARI, New Delhi)Pusa Manohari (Amrapali X Lal sundari) and PusaDeepshika (Amrapali X Sensation) regular bearer,
Tamil Nadu:	PKM-1 and PKM-2 (Periyakulum);
Uttar Pradesh:	Ambika and Arunika from CISH, Lucknow

Papaya: Systematic work on breeding of papaya varieties with high yield and good quality for wider adaptability was taken up at IARI, Regional Station, Pusa, Bihar in 1966. Among the collections Ranchi variety was foundto be most promising. As a result of inbreeding and selection for eight generations during 1966-82, uniform gyno-dioceious lines Pusa Delicious, Pusa Dwarf, Pusa Giant and Pusa Majesty with desirable attributes were developed. Development of papaya cultivars with good quality and high papain content was also taken up atTNAU, Coimbatore resulting in release of CO-1 to CO-7 series through inbred selection and hybridization. Papaya improvement work carried out at IIHR, Bengaluru has resulted in the development of two hybrids IIHR-39 named as Surya and IIHR-54 which have superior fruit quality. Another promising hybrid HPSC-3 has been developed at ICAR Research Complex, Tripura for high yield potential and resistance to mosaic virus.

Passion Fruit: Kaveri, a hybrid passion fruit bred at IIHR, Chethalli by crossing green and purple varieties can endure rains and has better keeping quality. It is now extensively cultivated in the N.E. region.

Peach: In peach, hybridization work at Saharanpur resulted in release of Saharanpur Prabhat, while that at CITH, Srinagar of variety CITH P-1 and Pant Peach at Pantnagar (Uttarakhand).

Pomegranate: Hybridization work in pomegranate in Karnataka and Maharashtra has resulted in thedevelopment of a number of new varieties. This includes selections No. 61 namely, Mridula from Rahuri, Maharashtra and Ruby-dark red non sticky arils with soft seeds from IIHR, Bengaluru from F2 populations.

3.4. Ploidy Breeding

A fascinating phenomenon in fruit plant has provided an important pathway for evolution and speciation. Innature, somatic mutations, union of unreduced gametes, irregularities of mitosis or meiosis produce polyploids. Attempts have been made to exploit polyploidy in fruit crop improvement through use of physical and chemical mutagenesis. Using colchicines or orizalam, fusion of protoplast upto different species or genera to form hybrids. Somatic hybridisation is an important tool or polyploidy manipulation resulting in allotetraploids and autotetraploids.

Polyploidy is important in conferring desirable characteristic in fruit crops e.g.see dlessness and increased fruitsize in guava, pear, apple and has provided advantages ovular fertility in banana. Similarly tetraploid grapes produce distinctly large berries e.g. Mawal Seedless, Perle, Case, Early Niabel, etc. Difference in ploidy levels of parents of some species adversely affect desirable crosses. Such crosses lead to development of abnormal endosperm; poor pollen tube growth and embryo abortion at different development stages. Manipulating ploidy level of one of the parents may help to overcome these barriers in hybridisation. Treatments with colchicine have helped to some extent in such situations.

In cases where interspecific or intergenric hybridisation is to be carried out studies dealing with somatic chromosome number determination (cytogenetic) and its ploidy level are of fundamental consideration. Success of such crosses depends on genomic relatedness particularly chromosome structural similarity, meiotichomology, genetic compatibility and recombination. Thus, comparative genetic and Karyotopic characterisation of such taxa is an important step towards perspective in gene introgassion.

4. SCION *VS.* ROOTSTOCK BREEDING

The important point which has been evading attention of fruit breeders in India is the recognition of the fact that in most fruit crops there are two parts requiring improvement i.e., scion and rootstock. The objectives in both cases are different. The objectives in scion breeding include attractive colour and high yield; Dwarfing for amicability to high density planting; Precocity & regularity in bearing; Seedlessness, soft seeds and betterpulp quality; richness in nutrients. Much of the work on fruit crop breeding carried out so far has been related to these objectives.

On the other hand, rootstock in fruit crops is primarily used either because of their capability to impart dwarfness or their ability to utilise nutrients from soil and water efficiently or their resistance for abiotic andbiotic stresses. They can be used either directly or in breeding programmes in their vital role in production and productivity. Selecting or breeding rootstocks is more difficult than selecting a scion variety. Evaluation of rootstocks for desirable characters and stionic effects on candidate fruit crops also requires much time.

5. REDEFINING TRAIT PRIORITIES

5.1. Exploitation of Wild Species

Wild species can play an important role in developing genetically superior varieties particularly as donor for vigour and of disease pest resistance. Unfortunately, most wild species have neither been systematically collected nor evaluated either by morphological or molecular means. Some wild species of mango are already in danger of extinction while many others grow wild even to-day e.g. *M. sylvatica* (NE) and *M. andaminica* (Andaman group of Islands). Hybrid population of *Carica papaya* cv. Arka Surya X*Vasconcealla cauliflora* have found tolerant to papaya ring spot viral disease (Jimenz and Horovitz, 1967; Veena and Dinesh, 2014). In case of guava, the wilt resitant hybrid population were obtained by crossing the *Psidium molle* x *P. guajava* (Rajan and Negi, 2005).

Incidentally wild species have been extensively used for breeding scions and rootstocks in citrus, banana, grape, papaya, blueberries and raspberries in other countries. We have not even taken full advantage of information generated from this work by foreign institutions or introduced promising materials requiringpriority in different crops. Exploitation of wild species and incorporating their desirable genes in cultivated species however is different task as quantitative traits are harder to transfer. Also, resultant hybrids are sterile with low yield and poor quality. Further mechanical isolation, chromosomal aberration and genetic & cytoplasmic incompatibilities hinder hybridization between wild and cultivated species.

Some of the recently identified Banana wild species are *Musa indoandamanesis* (Singh 2014)*, M paramjitiana* (Singh 2017, Bohra 2019)*, M arunachalensis* (Sreejith *et. al.,* 2015), *M nanensis* (Swangpol *et. al.,*2015).

5.2. Breeding of Scion Varieties

Yield & Quality Improvement: Some of the traits of commercial importance in scion varieties include fruitsize, colour, yield and quality components. Efforts have been made to improve these in a number of crops e.g., mango, guava, papaya, grape, pomegranate through conventional breeding. However, polyploidy breeding is a potential tool for improving yield and quality, which are critical commercial traits. Even large fruit size is an important trait to fetch premium price in certain fruits like grapeand kiwi besides size, novel colour and nutrient content adds value to the crop variety. While tetraploid varieties resulting in larger berries and early ripening have been developed in grape, certain defects like poor growth habit, irregular flower setting andreduced yield prevent their commercial acceptability. Many fruit crops play an important role in nutritional security, being important sources of vitamins, mineral and antioxidants compounds like anthocyanims, flavonoids and procyanadins. Some wild species of *Vitis*(grape), strawberry and *Rubus* and cultivated varieties of apple, grape, kiwi, orange, peach, pear and *Rubus*are rich in antioxidants. These genes can be introduced through hybridisation. Source of some antioxidants reported elsewhere are listed below:

Anthocyanins	Grape	*V.vinifera x V. labrusca; V.labrusca x V. riperia*
	Raspberry	*R.innominates*
Anti-oxidants	Strawberry	Wild spp. *F.virginiana, spp. glaca*
	Grape	*V. amurensis*
	Raspberry	Red & black raspberries of genus *Rubus*
Total Phenolics	Raspberry	*R.caucasicus*
Ascorbic Acid	Raspberry	*R.idaus*

Seedlessness: Seedlessness is an important trait in commercial fruit crops. It can be induced through mutation and polyploidy breeding by crossing tetraploids x diploids. Autopolyploids play a crucial role in development of triploids. Triploids are generally mere vigorous than diploids and sterile which features helps in producing seedless cultivars. Triploidy has been commercially exploited in citrus, banana, grape & guava. Some seedless varieties produced through Mutation/ Hybridisation are listed below:

Fruit	Hybridisation	Mutation
Grape	Pearlette, Beauty Seedless, Pusa purple seedless	
Grapefruit		Duncan, Star Ruby, Ray Ruby, Flame and Nel Ruby (Vuuren and Vyver 2000)
Lemon		Eureka
Mandarin	Gold Nugget, Pixie, Winola	Shiyueju
Orange	Clara, Tacle	Hongju 418, 420, Pineapple
Pummelo x Grapefruit	Oroblanco, Melogold	

5.3. Breeding of Rootstocks

Tree Architecture: Rootstocks have the ability to modify the vegetative growth and affect scion vigour resulting in dramatic change in planting systems of fruit crops by their ability in tree size control making it possible to go for high density planting system leading to meadow orchards. Emphasis therefore needs to belaid on selection of dwarf trees/ rootstocks for close spacing. Spacing distance will however, vary based on scion vigour i.e., high, medium & dwarf; fertility status and water holding capacity of the soil. Some work in this regard has been carried out successfully in UK in apple, where a number of dwarfing, semi-dwarfing and standard rootstocks have been developed and are being successfully exploited commercially are listed below:

Dwarfing Rootstocks	Semi-Dwarfing Rootstocks	Standard Size Rootstocks
B.9, B.10, B146, B49, Bemani, G.16, G.41, G.65, G.214, G.935, M.9, M.27, Mark, MAC39, Ottawa 3, P.2, P.22, Supporter 1, Supporter 4, V.3	B.118, B.490, G.11, G.30, G.202, G.210, G.890, G.969,J-TE-H, M.26, M.27, M.4, M.7 EMLA, M.9 (interstem)/ MM.106rootstock, M.27, M.9(interstem)/ MM.111 rootstock, MM.106 EMLA, V.1	Antonovka 313, MM.111EMLA, P.18, Seedling

5.4. Breeding for Abiotic stress tolerance

As climate changes become more severe, several abiotic stresses e.g. high temperature, drought, cold and salinity limit plant growth, yield and fruit quality. Losses are often inter-related and hinder normal, physiological, biochemical and molecular processes in plants. There is also severe cellular damage impairing plant development and fruit set. Work done in breeding of varieties for abiotic stress tolerance is briefly givenbelow:

Drought Tolerance: Water scarcity is becoming a key limiting factor in fruit crop production. It is being caused due to decline in rainfall pattern and increase in number of warmer days. Drought plays an important role in scion growth and yield during water scarcity period. With the drought incidence becoming frequent inthe country, it has become important to identify drought tolerant varieties and species and developing drought tolerant hybrids has assumed significant importance. The mechanism involved in drought tolerance include, drought escape, dehydration, avoidance, drought tolerance, recovery and resistance besides increasing water uptake and reducing water loss. Blueberry, a fruit not grown commercially in India is highly susceptible to drought. A number of drought tolerance species/ hybrids have been identified in different crops. These include *C. reshni, C. aurantium, C. limonia, C. jambhiri and P. trifoliata* of Citrus and *V. arboretum, V. dorrowi* of Raspberry. Some highly, moderately drought tolerant species/ hybrids are listed below:

Reaction to drought	Crop	Rootstock
Highly tolerant	Citrus	Flying Sunki
	Grape	110 R, Ramsey, 1103 Paulsen, 140 Ruggeri, Kober 5BB
Moderately tolerant	Apple	M 9, M 26, M 111
	Citrus	Carrizo Citrange, Swingle Citrumelo
	Grape	Teleki 5C, SO4
Moderately tolerant to drought	Peach	4247T1
Tolerant	Citrus	SSW 1

Thus, breeding of rootstocks adapted to different drought conditions in important fruit crops is the best option available to manage drought.

Cold Tolerance: Cold stress is a major limiting factor that affects productivity of many fruit crops. While severe cold restricts growth, freezing temperatures injure plants and kill trees. Many commercial fruits namely apple, citrus, guava, grape, papaya, blueberry and pear are susceptible to cold and freezing temperature. Low temperatures often affect plant growth and crop productivity. Plants differ in tolerance to chilling (0-15°C) and freezing (0°C) temperatures. Continuous effort is required to breed *cvs*, which is cold hardy and escape severe cold climate. However, resistance to cold is complex, quantitatively inherited and controlled by polygene infruit crops. Vast germplasm is available in different fruit crops possessing genes for cold hardness as below:

Apple: On the basis of evaluation, the following cold tolerant rootstocks have been identified:

Temperature	Rootstocks
-16°C to -19°C	G 935
-12°C to -14°C	G 11, G 30, G 41, B 9, P 2 and M 26, B 9, Ottawa 3, P.2
-08°C to -11°C	-M 26, MM 106, MM 111, and M 7, Jork 9, Alnarp 2, M 26
-06°C to -08°C	M.7, MM 106

Grape: American grape species such as *V. labrusca, V. aestivalis*, and *V. riparia* are potential sources of cold hardiness. *V. riparia* species have been reported to withstand up to -40°C. Rootstocks like *V. riparia, Glorie, St. George,* and 1103P are tolerant to cold injury. Even though resistant sources are available, selection of cold hardy progenies from hybrid populations by lengthy screening and evaluation makes breeding difficult. Furtherthe study of cold hardiness and inheritance pattern is challenging. Such studies are also few. Inheritance pattern of cold tolerance has been studied in a few crops is given below:

Crop	Trait	Heritability
Blueberry	Bud freezing tolerance	High
Apple	Winter survival	Mid – high
Peach	Dormant flower buds	Mid – high
	Cambium, xylem and bud injury	0.65 – 0.96
Plum	Winter survival	>0.0

Salt tolerance: Salinity is one of the most serious environmental factors that affect the crop productivity worldwide. Most crops are sensitive to high salt concentrations in the soil. Sodium and chloride ions in thesoils are the dominating factors in adversely affecting yield of fruit crops. More than 800 million hectares of land are affected by soil salinity throughout the world. Fruit crops like citrus, grape, apple, pear, peach, cherry, apricot, strawberry, plum, etc. are susceptible to soil salinity. There is thus need to give priority to breeding salt tolerant rootstocks. The level of susceptiblity to salinity has been worked out in some fruit crops and the threshold levels are given below:

Crop	Threshold level
	(dS/m)
Grape fruit	1.2
Sweet orange	1.3
Almond, Apple, Black berry, Grape, Lemon, Mandarin	1.5
Apricot, Avocado	1.6
Peach	1.7
Plum	2.6

There are three types of salinity tolerance mechanism in crops e.g.; tolerance to osmotic stress, salt exclusion, tissue tolerance. Citrus is one of the most sensitive crops for salinity. A large number of citrus orchards in India are getting affected by salinity every year. The ability of citrus trees to tolerate root zone salinity is mainly dependent on rootstocks. Citrus rootstocks vary in their degree of tolerance for salinity. The Cl- excluding ability of Rangpur lime and Na+ excluding ability of *P. trifoliata* can be transferred to their hybrid derivatives. Work done in Australia, Canada, Spain & USA has resulted in development of several hybrids, namely Swingle, Citrumelo, Troyer, Risk and Carrizo Citranges besides US-897 and X637. Evaluation of different Citrus species, relatives and hybrid rootstocks for salinity tolerance has indicated that Cleopatra mandarin is salt tolerant and Sour orange is susceptible. The rootstocks US-897 and X639 have also been shown to be highly salt tolerant than Cleopatra mandarin. Some of the salt tolerant citrus rootstocks are listed below:

Rootstock	Remarks
Swingle Citrumelo	Moderately tolerant to salinity
Troyer Citrange	Tolerant to salinity
Rusk Citrange	Tolerant to salinity
Us-897	Highly tolerant to salinity
X 639	Highly tolerant to salinity
Carrizo Citrange	Moderately tolerant to salinity

Salinity is a serious concern in grape production also because of its moderate sensitiveness in saline soils. *Vitisvinifera*, the commonly cultivated grape is a poor Cl- excluder and rapidly absorbs and accumulates salts in the plant system leading to poor vegetative growth, burning of leaves and low yields in contrast to *Vitis* specieslike *V. rupestris, V. cinerea, V. champini*and *V. berlandieri* which are good chloride ion excluders. Results of different rootstocks have revealed that Salt Creek and Freedom have high level of tolerance to salinity. Some of the commonly used grape rootstocks tolerant to salinity are listed below:

Rootstock	Parents
Salt Creek	*V. champinii*
Freedom	Complex hybrid of *V. champinii, V. riparia, V. labrusca, V. vinifera, V. solonis*
140Ru	*V. berlandieri*x *V. rupestris*
1103P	*V. berlandieri*x *V. rupestris*
SO4	*V. berlandieri*x *V. riparia*
41B	*V. vinefera*x *V. berlandieri*

Salinity causes yield loss in citrus, mango, avocado, stone fruits etc. The mango rootstock Gomera-1 is reported to be was a Cl- excluder. Similarly, 13-1, Olour and Kurukan are also reported for salt tolerance. The inter specific *Prunus* rootstocks like HS-314 and GF-677 have proved to be good source of salinity resistance. The extent of salinity has been on the increase in India rendering several suitable areas unfit for fruit cultivationparticularly for lack of salt tolerant rootstocks. It therefore calls for priority attention to this aspect.

5.5. Breeding for Biotic Stress Tolerance

Resistance to biotic stresses is a major objective in any crop breeding programme world over. Resistance is the ability of host plant to reduce the infestation or damage or both by an insect or disease or any of the external force. Resistance level may vary from only slight plant tolerance to stress or total immunity. It canbe result of one or more mechanism. Both vertical and horizontal mechanisms have been used by breedersfor development of new varieties. Building desirable resistance is the only permanent solution to control pest incidence. Further, with call for organic farming and making food safer a priority, resistance breeding has assumed great importance. In this regard, development of rootstocks for certain biotic and abiotic stress is extremely important in fruit crops.

5.5.1. Pest Resistance

A number of pests adversely affects the productivity & quality of different crops. Important pest which has attracted attention of breeders worldwide include the following:

Economically important pests in some fruit crops.

Crop	Pests
Apple	Wooly Apple Aphids
Banana	Corm Borer, Pseudostem Weevil
Citrus	Aphids, Citrus Butterfly, Leaf Miner, Psyllids, Stem Borer, Thrips, Whitefly
Grape	Phylloxera
Guava	Fruit Fly
Mango	Fruit Fly, Hopper, Stone Weevil
Papaya	Papaya Mealy Bug, White Fly
Pomegranate	Anar Butterfly

Besides nematodes (in citrus, banana & grape) and borers in certain fruit crops cause huge economic losses. Since chemical control of these pests can be a major hazard to the environment, breeding of pest resistant rootstocks becomes important. Several wild species have been identified as sources of resistance as discussed below:

Apple: The woolly apple aphid (WAA), (*Eriosomalanigerum*, Hausmann) is the primary pest of apple worldwide. It affects roots and aerial parts of the plant. It causes more damage by feeding the roots. The control of this pest when feeding of roots under soil is very difficult either chemically or culturally. As a result, rootstock breeding programmes were started globally and Northern Spy was used as a source of resistance along with Malling series. The Malling-Merton rootstock series e.g. MM 104 (M2 x Northern Spy), MM 106(M1 x Northern Spy), and MM 111 (Merton 793 x Northern Spy) derived from Northern Spy were resistantto WAA. However, they were not immune. The immunity to WAA was identified in *M. robusta*accessionRobusta 5 which has *Er*2 resistant gene.

A breeding programme aimed at Cornell University, Geneva campus for combining multiple resistance and tree size control using different Merton series, *M. domestica* and *M. robusta*has resulted in release of *s*everal rootstocks with multiple level of tolerance and varying degree of tree size control listed below:

Grape: In grapes, Phylloxera, *Daktulosphair avitifoliae* (Fitch) is the most devastating pest of grape and it invaded Europe during the late 1860s and caused severe economic losses in grape vine industries. Intensive grape breeding programme was initiated by several breeders resulting in development of hybrid rootstocks likeSO4, 5BB and 5C derived from *Vitis berlandieri* Planch. X *V. riparia* Michx. resistant to phylloxera. However, this pest is fortunately not available in India.

Nematodes: Nematodes constitute one of the major limiting factors in fruit crop production. They cause extensive root necrosis resulting in serious economic consequences that drastically reduce the

Sl.No	Rootstock	Tree Vigour	Resistance to	Tolerant
1	G 41	Dwarf	WAA and fire blight	
2	G 214	Dwarfing	WAA, fire blight, and crown rot.	
3	G 202	Semi dwarf	WAA and fire blight, replant disease andcrown rot	
4	G 222	Semi dwarf, precocious	WAA and fire blight, replant disease andcrown rot	
5	G 210	Semi dwarf	WAA and fire blight,	cold hardy
6	G 890	Semi dwarf, precocious	WAA and fire blight	cold hardy
7	G 969	Semi dwarf, precocious	WAA, fire blight and crown rot	cold hardy
8	G 4210	Semi dwarf	WAA and fire blight	

yield. The roots damaged by nematodes are easy prey to fungi which invade the roots and accelerate root decay. Important nematode species which threaten the global fruit industry and cause huge economic losses are listed below:

- root-knot nematodes (*Meloidogyne incognita* and *M. arenaria*),
- burrowing nematode (*Radopholussimilis*),
- citrus nematode (*Tylenchulussemipentrans*),
- dagger nematode (*Xiphinema index*) and lesion nematodes (*Pratylenchusspp*) are the major nematode pests that infest commercial fruit crops in general

Work on breeding of nematode resistant rootstocks in citrus, grape & banana has resulted in the developmentof following rootstocks elsewhere:

Rootstocks resistant to nematodes

Grape	Degree of Resistance to Root knot Nematodeand Dagger Nematode
O39-16	Highly resistant to Dagger
Schwarzmann, Freedom, Boerner	Highly resistant to both
1616C	Highly resistant & Moderately resistant respectively
Ramsey	Highly resistant
101-14 Mgt	Moderately resistant to both
Fercal	Moderately resistant
Banana	
H 21, H 59, H 65, H 74, H 84, H 95, H 109 and H 201 (Triploids)	Burrowing nematode
NARITA-1 (Triploid)	*Helicotylenchusmulticinctus*
H 212, H-02-19, H-02-21, H-02-22, H-02-23, H-02-36; FHIA 01 (Tetraploid)	*R. Similis*
H 61, H 74 and H 95, BRS 1 andBRS 2 (Triploids)	Other nematodes

The Citrus nematode (*Tylenchulussemipenetrans*) is a worldwide problem that leads to poor growth of young plants and is responsible for poor performance of mature trees. The important source of resistance is *Poncirustrifoliata* and its derivatives. Although *P. trifoliata* is resistant to citrus nematode, its performance is very poor in alkaline and calcareous soils. It has been reported that the hybrid rootstocks of *C. reshni*x *P. trifoliata* and*C. volkameriana*x *P. trifoliata* are highly resistant to citrus nematodes. Further, some hybrid rootstocks of *C.reshni*x *P. trifoliata,* King mandarin x *P. trifoliata,* and *C. volkameriana*x *P. trifoliata* also showed very little incidence of nematodes and are moderately resistant**.**

5.5.2. Disease resistance

A number of bacteria, fungi, virus, and mycoplasma like organisms affect fruit crop production severely. The major diseases which affect production and quality of fruits drastically are listed below:

Fruit	Diseases
Apple	Scab, crowned rot, fireblight and powdery mildew
Banana	Fusarium wilt, sigatoka and leaf spot
Grape	Powdery & downy mildew
Guava	Wilt
Mango	Anthracnose, Powdery Mildew
Papaya	Mosaic, ring spot, phytopthora
Strawberry	Crinkle virus, mottle virus and red steel virus

Identification and utilisation of source of resistance is a basic requisite for incorporating disease resistance through breeding programmes. It requires screening and evaluation of germplasm to determine the magnitude of genetic variation of resistance. Several sources of resistance to major diseases have been identified in different fruit crops. These are as under:

Resistant wild species used as rootstocks in different fruit crops

Crop	Diseases	Resistant wild species rootstocks
Apple	Fire blight	*Malus robusta*
	Scab	*M. floribunda* (vf resistant gene)
Banana	Black sigatoka	*M. acumita*
	Fusarium Wilt (Race 1,2,4)	*M. acumita, spp. malaccensis*
Citrus	Phytophthora	*Trifoliate orange, swingle citrumello, Bento cintrange (hybrid)*
	Tristeza virus	*Rangpur lime, rough lemon, Cleopatra mandarin, Trifoliateorange*
Grape	Downy mildew	*V. Muscadinia, V. rotendifobia, V. amorensis*
Guava	Wilt	*Psidium friedricsthalianum*
Papaya	Ring spot	*Vasconcillecauliflora, Quercifoliapubscence*
Pear	Fire blight	*Pyrus communis*

A number of efforts have been made in different fruit crops to develop disease resistant/tolerant hybrids as listed below:

Fruit	Hybrids	Resistance
Apple	Borovinka, Hagloe Crab, Tita Zetei, Braburn, Britegold, Delicious, Empire Red, Enterprise, Fuji, Goldstar, Jonafree, Nittany and wealthy red, Pusa Gold, Pusaamartara pride	Powdery mildew Scab
	Prima, Primula, Sir Prize, Jonafree, Dayton	Scab
Banana	Diploids- SH2095, H109 andTriploid- NARITA-1Tetraploids - FHIA 01, 07 & 23	Fusarium wilt Resistant to Sigatoka Sigatoka Race 4
	FHIA 01, 17 & 18 & PITA 17	Sigatoka
Guava	Peipa, TS-G1, TS-G2	Wilt
	TS-G3	Wilt
Mango	Hybrid progenies, CISH-2035 and 1734	
Papaya	Cinta L 41, L 90	Moderately

6. STRATEGIES FOR FRUIT BREEDING

6.1. Haploids and double haploids

In fruit crops, high heterozygosity, long generation cycle with long juvenile period and often self-incompatibility do not allow the haploid development easily through the conventional methods. The haploids and double haploids can make a significant contribution in shortening the time taken for fruit breeding. Using DH technology, completely homozygous plants can be established in one generation thus saving several generations of selfing required in conventional methods. Development of homozygous lines through gametic embryogenesis resultsin single step improvement of the crop.

In a conventional breeding programme, a pure line is developed after several generations of selfing. However, in fruit crops, there is no way of obtaining homozygous lines through conventional methods. Hence, fixationby doubling the chromosome complement presents a possibility of using haploids. In many of the importantfruit crops mango, citrus, banana, grape, papaya, sapota, pomegranate, custard apple, apple, peach, pear, plum, apricot, kiwi fruit etc. it can be a very handy tool in the improvement.

6.2. Role of bio-technology in fruit breeding

Marker assisted breeding (MAB): Fruit crops being perennial and heterozygous remain juvenile for a long period, when propagated through seeds. Since seed production is indispensable in a breeding programme, shortening of juvenile period or finding alternate ways to induce early fruiting in seedlings is very importantto achieve early assessment at seedling stage and avoiding evaluation of unwanted seedlings. A number ofmethods like top working, induction of flowering by chemicals, shortening of juvenile phase by grafting havebeen employed. Using a combination of above techniques, a number of superior varieties have been developed.

These include:

- Blood red guava
- Pink pulped papaya
- Early maturing seedless grape
- Seedless mango
- Vitamin rich peach & plum
- Regular bearing mango hybrids

Assessment of genetic diversity of fruit crops is an important step in breeding. A diverse range of plant material including land races, modern cultivars, wild relatives and other wild species are available as the starting material. Conservation of germplasm is of little importance without characterisation and further utilization of concerned plant material. To intensify these activities DNA finger printing has been implemented in the characterisation of germplasm. The molecular markers are being used for maintenance of core collection for the assessment of genetic diversity and finger printing. However, phenotyping is still advantageous to validate performance. Development of molecular markers for different traits should continue to receive priority attention. A large number of molecular markers have been developed and applied for analysis of genetic diversity and relatedness and all markers have their strengths and weaknesses. In general, two main groups of molecular markers have been utilised for PGR characterisation:

- Markers for identification of accessions detection of structure of genetic reserves collection & Relatedness of available plant material.

- Gene specific markers, applicable for Marked assisted selections (MAS).

The last two decades have witnessed initiatives to a transition from traditional phenotype to genotype assisted breeding. This has become possible due to availability of wide array of molecular markers, transcriptome and whole genome sequence data in many woody fruit plants.

A marker is a tag of identification of any trait of an organism which can be identified with confidence and relative ease and can be followed in a mapping population. DNA marker is a small region of DNA that shows sequence polymorphism among genotypes. Such DNA/ molecular markers have contributed numerously inbreeding of many crops due to their reliability and tight linkage to the trait of interest. Mapping and tagging ofgenes controlling important agronomic traits have been facilitated by an array of molecular markers. Marker assisted breeding in fruit crops is given considerable importance as it would improve the breeding efficiency in fruit crops.

Genomics in Fruit Crops: Genomics are the next generation sequencing technologies being used to generate whole genome sequences for a wide range of crop species. It helps to understand genome structures, to make use of quantum of data produced and to describe their function and interactions. With the significant advancement in sequencing technologies in recent years, efforts have been made to release whole genome sequences ofmany fruit crops. Many more whole genome sequencing projects of fruit crops are also in progress. The biggest challenge in genomics of perennial fruit trees is the development of bio-informatic tools to manage huge volume of data generated by next generation sequencing technologies. There is a need to create genome resource platforms for the benefit of academician and researchers. A few crops whose genomes have been sequenced are discussed below:

Apple: Genes have been identified for scab, fire blight fungal disease resistance, and induction of anthocyanin accumulation.

Grape: Genome sequence (size 457 Mbp) has been studied in variety Pinot Noir which was bred close to full homozygosity.

Mango: A draft genome based on transcriptome and whole genome sequence data of Dashehari, Neelum and Amrapalli (403) (Singh *et al.,* 2021) cultivars has been reported.

Musa: A global Musa genomic consortium, an international network with 40 institutions in 24 countries has worked for sequencing the banana genome. All available markers have been used to study phylogenetic relationships, diversity, evaluation, parentage analysis differentiation of A&B genomes and to develop trait specific markers.

A few genes and markers identified in fruit crops linked to various traits are given below:

Crop	Trait	Gene	Marker
Apple	Fruit colour	*Rf*	BC226
	Fruit acidity	*Ma*	OPT16-1000
	Mildew resistance	*Pl-1, Pl-2, Pl-w,Pl-d, Pl-m*	LAP – 2
	Scab	*Hcrvf2, Rvi6*	*nptII* (Belfanti *et al.,* 2004)
	Fire blight resistance	*FB_MR5*	SCAR/SSR
Citrus	Fruit acidity	Ac	RFZ20
	Seedless fruit	Fs	OPMO6r
	Citrus leprosis virus resistance		AFLP and RAPD
Peach	Flesh adhesion	F/f	OPB5a
Pear	Incompatibility		AFLP/SSR
Banana	Sugar content		RFLP
Grapes	Seedlessness, berry size, andripening date		AFLP, SSR RAPDs, ISSR and SCAR
	Fungal disease resistance	*vvtl-1*	22-kDa (Jayashankar*et al.,* 2003)
Strawberry	Day neutrality		AFLP
	Anthracnose Fruit rot resistance	*FaRCa1*	SNP and SCAR (Salinas *et al.,* 2019)
Apricot	Plum Pox virus		SSR

Papaya: Papaya with a small genome size (372Mbp), is having only a few disease resistant genes besides fruit ripening skin colour change and sugar accumulation genes. The transgenic female *Sun Up* variety was chosenfor sequencing genes.

The genome size of different fruit species is given below:

Sl.No.	Fruit Crop	Scientific name	Genome size (Mbp)
	Almond	*Prunus amygdalus*	238 (Alioto *et. al.*, 2020)
1	Apple	*Malus domestica*	742.3
2	Banana	*Musa acuminataspmalacensis*	523.0
	Date	*Phoenix dactylifera*	605.4 (Sharma *et al.*, 2016)
3	Grape	*Vitis vinifera*	487.0
	Guava	*Psidium guajava*	443.8 (www.ncbi.nlm.nih.gov.in)
4	Kiwifruit	*Actinidia chinensis*	616.1
5	Mango	*Mangifera indica*	439.0
6	Papaya	*Carica papaya*	372.0
7	Peach	*Prunus persica*	265.0
8	Pear	*Pyrus bretschneideri* Rehd	600.0
	Pineapple	*Ananas comosus*	381.9 (www.ncbi.nlm.nih.gov.in)
9	Sweet Orange	*Citrus sinensis*	452.0
10	Wild Banana	*Musa balbisiana*	438.0
11	Woodland Strawberry	*Fragaria vesca*	240.0

7. CONCLUSION

Breeding of perennial fruit trees is quite different than breeding of annual crops. Besides, there are several constraints impeding fast testing and release of varieties. In addition, there are several inherent problems in some fruit crops such as structural differences in floral biology, apomixes, parthenocarpy, cross incompatibility, number of seeds per fruit and large acreage required for meaningful assessment. While a lot of genetic variability has been collected and maintained in a number of fruit crops, major emphasis in fruit breeding has so far been laid only on developing varieties with high yield and superior fruit quality. Time has come tohave a fresh look on breeding priorities and strategies to harness the full potential of fruit breeding. Following recommendations are made to achieve the desired objectives: While a lot of genetic variability has been collected and maintained in a number of fruit crops, major emphasis in fruit breeding should be given for systematic evaluation of germplasm of fruit crops. Collection of wild germplasm, endangered species and other gene sources should be taken on priority and their descriptive evaluation is of utmost importance. There is urgent need to do basic research on inheritance of characters which will ease the choice of parents in hybridization programmes. There is need to clearly define objectives and priorities of breeding of fruit crops for different regions. Furthermore, the work should be assigned to different centres on the basis of their human resource capabilities and available facilities. Rootstock breeding of commercial fruits like mango, citrus, grape, pomegranate etc; indigenous fruits like Bael, jamun should be taken up at priority. In view of climate change, breeding work should be taken at priority for developing climate resilient varieties and rootstocks. There should be integrated breeding approaches involving traditional and modern molecular methods for the improvement of fruit crops. Marker aided selection and enriching the genome resources of fruit crops should be taken on priority. There is dearth of manpower for fruit breeding programmes keeping in view the number of crops and aspects requiring attention.

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Climate Resilient and Sustainable Production of Mango and Guava in India

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1. INTRODUCTION

India bestowed with diverse soil and climate comprising several agro-ecological regions provides ample opportunity to grow wide range of horticultural crops comprising of fruits, vegetables, root and tuber crops, flowers and other ornamentals, medicinal and aromatic plants, spices, condiments, plantation crops and mushrooms, which form a significant part of total agricultural produce in the country. Climate change impacts on agriculture are being witnessed across the world, but countries like India are more vulnerable in view of the huge population dependent on agriculture, excessive pressure on natural resources and poor coping mechanisms. The warming trend in India over the past 100 years has indicated on increase of 0.60°C. The projected impacts are likely to further aggravate field fluctuations of many crops thus impacting food security. There are already evidences of negative impacts on yield of wheat and paddy in parts of India due to increased temperature, water stress and reduction in number of rainy days. Significant negative impacts have been projected with medium-term (2010-2039) climate change, eg. yield reduction by 4.5 to 9%, depending on the magnitude and distribution of warming. Since agriculture makes up roughly 15% of India's GDP, a 4.5 to 9.0% negative impact on production implies cost of climate change to be roughly at 1.5% of GDP per year. Enhancing agricultural productivity, therefore, is critical for ensuring food and nutritional security for all, particularly the resource poor small and marginal farmers who would be affected most. Several improved agricultural practices evolved over time for diverse agro-ecological regions in India have potential to enhance climate change adaptation, if deployed prudently. Perennial tropical fruit trees species in nature are important mitigation and adaptation strategies for enhancing resilience **(Scherr and Sthapit 2009)** to adverse impacts of rainfall and temperature variability depending on the place where they grow. Although perennial fruit trees have a number of survival mechanisms that allow them to cope with stressful environments, these come at a considerable energy cost thereby potentially reducing fruit productivity. Management practices that increase agricultural production under adverse climatic conditions also tend to support climate change adaptation because they increase resilience and reduce yield variability under variable climate and extreme events.

2. AREA AND PRODUCTION SCENARIO OF GUAVA AND MANGO

The area and production trend shows that there has been a record production in horticultural crops with production during the year 2017-18(Final) reaching 311.7 million tonnes, which is 3.7% higher than the previous year and 10% higher than the past 5 years' average production. Production of fruits is estimated at 97.35 million tonnes which is 4.8% higher than previous year and has been increased to 102.03 million tonnes during 2018-19. The area, production and productivity of guava has been increased from 1998 with 0.15 million ha, 1.61 million tonnes and 10.7 t/ha to 0.28 million ha, 4.30 million tonnes and 15.0 t/ha during 2019-2020, respectively. Similarly, the area, production and productivity of mango has been increased from 1998 with 1.30 million ha, 10.23 million tonnes and 7.40 t/ha to 2.29 million ha, 20.44 million tonnes and 8.90 t/ha during 2019-2020, respectively. The above data clearly suggests that there has been increasing trend

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Table 1. Area, Production and Productivity of guava and mango in India

Year	Guava			Mango		
	Area('000 ha)	Production ('000MT)	Productivity (t/ha)	Area('000 ha)	Production ('000MT)	Productivity (t/ha)
1997-98	151.0	1614.0	10.7	1385	10234	7.4
1998-99	151.0	1801.0	11.9	1401	9782	7.0
1999-2000	151.0	1711.0	11.3	1487	10504	7.1
2000-01	148.0	1632.0	11.0	1519	10057	6.6
2001-02	154.6	1715.5	11.1	1575.8	10020.2	6.4
2002-03	154.6	1793.0	11.6	1623.4	12733.2	7.8
2003-04	166.4	1830.7	11.0	1906.7	11490	6.0
2004-05	161.0	1682.8	10.5	1970.4	11829.7	6.0
2005-06	166.5	1736.6	10.4	2080.7	12663.1	6.1
2006-07	176.0	1831.0	10.4	2154	13734	6.4
2007-08	179.0	1981.0	11.1	2201	13997	6.4
2008-09	204.0	2270.0	11.1	2309	12750	5.5
2009-10	219.7	2571.5	11.7	2312.3	15026.7	6.5
2010-11	205.0	2462.0	12.0	2297	15188	6.6
2011-12	219.9	2510.4	11.4	2378.1	16196.4	6.8
2012-13	235.6	3198.3	13.6	2500	18002.4	7.2
2013-14	268.2	3667.9	13.7	2516	18431.3	7.3
2014-15	246.2	3993.5	16.2	2163.5	18527	8.6
2015-16	254.9	4047.8	15.9	2208.6	18642.5	8.4
2016-17	260.1	3826.4	14.7	2212.2	19506.2	8.8
2017-18	264.9	4053.5	15.3	2258.1	21822.3	9.7
2018-19	276.0	4253	15.4	2296	21378	9.3
2019-20	287.0	4304	15.0	2291	20444	8.9

(NHB,2021)

of area of guava (53%) and mango (56%), production has been increased by 37.44% (guava) and 50 % (mango) (Table 1.).

The development and identification of climate resilient crop varieties, with enhanced tolerance to heat, drought, flooding, chilling and salinity stresses are essential in order to sustain and improve crop yields to cope with the challenges of climate change. The abiotic stresses such drought, heat or cold may trigger a series of responses in guava and mango that include changes in gene expression, signal transduction pathways, metabolic and molecular mechanisms as well as cumulative manifestations of these in terms of source and sink relations for adaptation. The major biotic and abiotic stresses affecting crops that limit crop productivity is given in the following figure. Among various abiotic stresses, drought, heat, salinity, cold and flooding are the major factors that adversely affect plant growth and productivity **(Maheswari et al., 2012).**

3.0. Climate Variables and Their Impact on Flowering and Fruitng

3.1. Mango

The climatic factors such as rainfall, temperature, humidity, wind and sunshine affect the growth, flowering, fruiting and quality of mango. It has been reported that low temperatures (10–15 °C or below 15 °C) during flowering increase the proportion of staminate flowers while high temperatures increase hermaphrodite flowers **(Singh, 1990;Ramirez and Davenport, 2010).** Low temperature during floral morphogenesis period which is much before the flower emergence is critical for the proportion of hermaphrodite flowers in mango (**Whiley *et al*., 1995**). **Whiley *et.al* (1991)** reported that for vegetative induction day temperature of 30ºC and night temperature of 25ºC is required. For floral induction at 15ºC day and 10ºC night temperatures are critical in mono and polyembrionic cultivars. Low temperature after a period of drought has been shown to be beneficial for floral induction. The most suitable temperature for the growth of mango is 22 to 27ºC. Temperature also has a negative effect on inflorescence size (**Dambreville *et al*., 2013)** and on the number of flowers per inflorescence (**Sukhvibul *et al.*, 1999).** In Australia, the estimated duration of mango fruit development decreased by 12-16 days (7-8%) as a consequence of the 1.5°C increase of winter temperatures over the last 45 **years (Olesen, 2011).** High temperature could also have a positive effect on fruit quality because of stress-induced synthesis of secondary compounds, some of them being of nutritional value. Similarly, the floral induction also requires the exposure of mature leaves to light, and higher levels of light intensity could have a positive effect on mango flowering. Higher light intensity enhances skin color for colored cultivars **(Lechaudel *et al*., 2013).** Since excessive light could be a stress factor, it could, as high temperature, enhance fruit quality. It could also have a positive effect on fruit size through improved photosynthesis **(Urban *et al*., 2003).** Mango requires good rainfall during its growing season (June to October) and rainless dry weather from October 2nd fortnight onwards. Rains during pre-flowering and flowering period lead to delayed flowering and increase vegetative growth. Cloudy weather during flowering results in heavy flower drop mainly due to increased population of plant hoppers. Flowering was found more dependent on moisture stress, which takes place earlier than unstressed trees. In tropical conditions flowering occurs after a period of drought **(Scholefield *etal*. 1986).** Rains at fruit maturity are beneficial for the improvement of fruit size and quality. Drought could also have an indirect positive effect on floral induction by promoting early growth cessation and vegetative rest required for floral induction. The higher CO2 concentration enhances photosynthesis and could therefore have a positive effect on fruit quality. Fruit grown at higher CO2 concentration have a larger fruit dry mass, mainly due to an increase of the pulp dry mass.

In Andhra Pradesh during 2016 season the flowering phenomena in mango was observed very different from normal flowering pattern, more particularly in Rayalaseema districts. There were four to five staggered flowering frequencies i.e., during September, 2016, October, November, December and January 2017 and February as normal flowering season in Andhra Pradesh. The changes in flowering pattern are attributed to off year during 2015 for the Banganapalli variety and combined effect of cyclonic rains received during November and December 2015. The total annual rainfall during 2015 was 1802 mm, which is 75 per cent more than average rainfall of last 26 years (1024 mm). As a result of cyclonic rains mango trees did not experience stress due to excess moisture or severe winter. Therefore, vegetative growth was abundant during January and February (2016) due to excess moisture. Without much flowering lead to accumulation of sufficient nutrients in the terminal twigs and with the advantages of rains received during July and August 2016, and moisture stress from September onwards induced staggered flowering from October, November, December 2016 (due to winter stress), again normal flowering occurred in January and February 2017. (**Naidu *et al*., 2018).** Changes in rainfall distribution pattern, occurrence of mid season drought conditions and prevalence of low temperature caused staggered flowering, fruiting and maturity, which resulted in multiple harvests starting from March to July, extended availability of mango fruits in the market. Similar phenomenon has been observed in Tamil Nadu, Karnataka, Telangana and Kerala for the past 5 years.

3.1.1. Climate change, mango production and cultivation in South-Asia

The predicted climate for the end of the 21st century, with respect to the mean climate of the last 20 years of the 20th century, will be warmer and wetter, with a mean annual increase of 3.3°C for temperature and of 11% for precipitation. The temperature and precipitation increase will not be uniform among seasons, with the largest temperature increase during the flowering season (+3.6°C) and the lowest during the harvest and vegetative growth season (+2.7°C). Precipitation is expected to be lower during flowering (-5%) and higher during the other seasons, particularly during the end of vegetative growth and vegetative rest (+15%). The frequency of extremely warm season and extremely wet season are high, for warm season, more frequent and intense hurricanes are also expected.

These seasonal climate projections are the basis to outline the expected effects of climate change on mango production in this region. The warmer climate during flowering and the warmer and wetter climate during the season of vegetative rest will probably lead to a lower floral induction. On the opposite, the hot and wet climate during fruit growth and vegetative growth will promote good fruit growth and important vegetative growth after harvest. But fruit quality could be reduced, and pests and diseases problems could be accentuated. Damages by hurricanes and flooding will increase in coastal areas.

The probable consequences of these effects on mango cultivation in South-Asia would be a shift of mango cultivation toward the North or in altitude to find cooler places allowing good floral induction. Mango orchards would also probably be established on the slopes rather than in the valleys or lowlands to avoid the risk of flooding. Irrigation could become facultative because of higher precipitation during fruit growth and vegetative development. Pruning will probably require more labor because of the warmer and wetter climate promoting vegetative growth.

3.1.2. Climate variables and their impact on pest and disease incidence in mango

In case of mango malformation, which is supposed to be caused by *Fusarium moniliforme* and supposed to be endemic in cooler climate, i.e., Northwest regions (Delhi, Punjab and western UP) may become disease of minor importance in the region due to increasing temperature. **Varma *et al.* (1969)** studied the seasonal variation at the time of flowering with the prevailing temperatures. They observed 60 per cent diseased panicles in cv. Neelum during the flowering of February-March, whereas the same plant had only 4-5 per cent malformation during off season flowering in June when the average minimum and maximum temperatures were higher than those of February-March, which resulted in decrease in disease incidence. The disease is serious in the north-west region where temperature lies between 10-150C during December-January (winter) before flowering. The disease is mild in the areas where temperatures lie from 15-20ºC, sporadic from 20-25°C and nil beyond 25°C. Hence, with the increase in temperature the incidence of malformation will decrease.

The powdery mildew (PM) caused by *Oidium mangiferae* is a common problem of mango. We **(Misra and Prakash, 1988)** found that predominance of susceptible cultivar 'Dashehari', high wind velocity for 3-4 days with maximum temperature around 35°C, minimum temperature around 17°C, relative humidity of minimum 23.4-25.5 per cent and maximum 73.3- 83.9 per cent (means dryer climate) are conducive for the rapid spread of mildew pathogen in Kakori-Malihabad mango belt of U.P. We further found that maximum temperature of 35°C play crucial role in the epidemic of PM. If maximum. temperature does not reach 35°C during the later half of March in northern plains, the epidemic of PM does not assume **(Misra and Prakash, 1997).** We **(Misra and Prakash, 1998)** also found that PM (floral) start disappearing from panicle during April-May, when minimum and maximum temperature and RH start increasing. Higher temperature above 35°C may result into non-occurrence of PM. In recent years we are observing that the epidemic of powdery mildew has not occurred. This may be the positive effect of less disease due to higher temperature, however, the higher temperature may adversely affect the flowering and fruit setting.

Anthacnose of mango is an important disease of mango. it is found that the optimum temperature for infection of anthracnose is around 25°C. Moist conditions or high RH, frequent rains with temperature around 30-35ºC favour the disease development **(Misra and Prakash 1997).** Continuous wet weather during flowering causes serious blossom blight. Relative humidity above 95 per cent for 12 hr is essential for infection and development of *C. gloeosporioides* on mango fruit. Infection progresses faster in wounded tissues, and in ripe fruits. In the present contest with the decreasing rainfall resulting lower humidity will also be unfavourable for the anthracnose disease of mango.

Bacterial canker of mango is another disease which is important and is greatly influenced by weather factors. Development of the pathogen in the field is favoured by high relative humidity (above 90%) and temperatures between 25-30°C **(Kishun and Sohi, 1983).** At Lucknow, disease was found to be severe on fruits during MayJune. Maximum and minimum temperatures, respectively, between 30-40ºC and 17.3-26.0ºC, morning per cent RH 68-100 per cent, evening RH 25-68 per cent and high wind velocity during the month (April-May) have been found favourable for the disease build up. Hence, lower rain and humidity will not be favourable for the bacterial canker of mango.

Several other diseases such as red rust, blossom blight, leaf spots, fruit rots, which are favoured by higher humidity and rain may decrease due to less rain pattern. In other hand the diseases like wilt of mango and decline may increase due to higher temperature and dryer climate. In recent years, it is observed that the incidence of wilt in mango is increasing, which may pose threatening proportion.

4.0. GUAVA

The productivity has not increased concurrently with its area and production, mainly because of biotic stresses such as wilt, root-knot nematode, anthracnose, canker and several root pathogens **(Edward and Shankar, 1964)** and abiotic stresses *viz*., drought, salinity and cold **(Mishra, 2005).** In the recent years, guava wilt (*Fusarium oxysporum* f. sp. *psidii*, root-knot nematode (*Meloidogyne incognita*) and salinity stress are emerging as a major threat to guava cultivation in India **(Hodda *et al*., 2012).** The wilt and root-knot nematode causing more than 80% loss of production. Worldwide about 1 billion ha of land is affected by salinity while in India, 6.73 million hectares (2.1% of total geographical area) affected by salinity (**Annual report, CSSRI, 2019).** The wild relatives are recognized as a potential source of useful genes to cope up with climate change scenario and emergence of new biotypes (viz. nematode and wilt) and abiotic stresses (salinity, drought and cold). Hence, to mitigate the biotic and abiotic stresses, recombination breeding between cultivated and wild species is one of the major approaches of guava improvement **(Ribeiro *et al.,* 2019**; **Usman *et al*., 2013)** because chemical methods are unsafe for environment **(Onder *et al*., 2011).** Among biotic stresses guava wilt and nematode can be control the bio-inoculants, viz. *Aspergillus niger* strain AN 17, *Trichoderma harzianum* and *Penicillium citrinum*, intercropping with *Curcuma domestica* or *Tageteserecta*, separate basin irrigation, and avoidance of tillage during July to November **(Gupta *et al*., 2010**) and the use of resistant root stock viz., *P. molle*, *P. friedrichsthalianum, P. cattleianum var. cattleianum* and *P. cattleianum var. lucidum* (**Edward and Shankar, 1964; Casassa *et al*., 1997, 1998; Moleroet *al.,* 2010, Chiamolera *et al.*, 2018).**

The wild *Psidium* species viz., *P. cattleianum var. cattleianum* and *P. cattleianum var. lucidum* can adopt to many soil types and is quite cold resistant **(Normand, 1994),** tolerates shade (**Cronk and Fuller 1995),** has good salt tolerance (**Wunderlin, 1982).**

The use of resistant rootstock is better than other methods of controlling biotic and abiotic stresses. *P. cattleianum* var. *cattleianum* and *P. cattleianum* var. *lucidum* were found were found to be immune to nematode, resistant to wilt (**Freitas *et al*., 2014** and **Lozano *et al*., 2008)** and tolerant to salt stress (**Souza *et al*., 2020**). *P. friedrichsthalianum* was found to be resistant to wilt and nematode, while *P. molle* was resistant to wilt **(Edward and Shankar, 1964).** These resistant rootstocks successfully able to tackle the problem of biotic and abiotic stresses in the era of climate change.

5.0. Adaptation and Mitigation Measures

Various adaptation and mitigation strategies including use of climate resilient crops and cultivars for different regions are most essential for agriculture to successfully cope with climate variability. Improved agricultural practices evolved over time for diverse agro-ecological regions in India have potential to enhance climate change adaptation, if deployed carefully (**Venkateswarlu *et al.,* 2011).** Management practices that improve agricultural production under adverse climatic conditions enhance resilience under variable climate and extreme events. Major strategies of adaptation to climate change include water saving technologies such as in-situ and ex-situ moisture conservation, water harvesting for supplemental irrigation, residue incorporation (to avoid it's burning), growing tolerant varieties, conservation agriculture, site specific nutrient management practices etc.

5.1. High Yielding Varieties in Mango and Guava

Systematic hybridization work started in several centres in India and across globe resulted in as many as 53 hybrids. Several of these hybrids are gaining

Table 2. Mango hybrids released in India and abroad

S.No	Hybrid	Parents	Place of release
1	ArkaArun	BanganpalliXAplhonso	ICAR-IIHR, Bangalore
2	ArkaPuneet	AlphonsoXBangapalli	ICAR-IIHR, Bangalore
3	ArkaAnmol	AlphonsoXJanardhanpasand	ICAR-IIHR, Bangalore
4	ArkaNeelkiran	AlphonsoXNeelum	ICAR-IIHR, Bangalore
5	Arka Udaya	AmrapaliXArkaAnmol	ICAR-IIHR, Bangalore
6	SwarnaJehangir	Chinnasuvarnarekha x Jehangir	FRS, Kodur
7	Neeluddin	NeelumXHimayuddin	A.P.A.U.
8	AuRumani	Rumanix Yerramulgoa	A.P.A.U.
9	Manjeera	RumaniXneelum	A.P.A.U.
10	KMH -1	CherukurasamXKhader	A.P.A.U.
11	Neelgoa	Neelum X Yerramulgoa	A.P.A.U.
12	Neeleshan	NeelumXBaneshan	A.P.A.U.
13	Neelphonso	NeelumXAplhonso	GAU, PARIA
14	Neeleshwari	NeelumXDashehari	GAU, PARIA
15	Neeleshan	NeelumXBaneshan	GAU, PARIA
16	MahmoodBahar	BombayXKalepad	FRS, Sabour
17	Prabhashankar	BombayXKalepad	FRS, Sabour
18	Al Fazli	Alphoso X Fazli	FRS, Sabour
19	Sundar langra	SardarPasandXLangra	FRS, Sabour
20	Sabri	Gulab Khas X Bombai	FRS, Sabour
21	Jawahar	GulabKhasXM.Bahar	FRS, Sabour
22	MahmoodBahar	BombayXKalepad	FRS, Sabour
23	Ratna	NeelumXAlphonso	FRS, Vengurla
24	Sindu	Ratna X Alphonso	FRS, Vengurla
25	PKM-1	ChinnaswarnarekhaXNeelum	Periyakulam,T.N.A.U.
26	PKM-2	Neelum X Mulgoa	Periyakulam,T.N.A.U.
27	Mallika	NeelumXDashehari	IARI,N.Delhi
28	Amrapali	Dashehari X Neelum	IARI,N.Delhi
29	PusaArunima	AmrapalixSensation	IARI,N.Delhi
30	PusaSurya	AmrapalixSensation	IARI,N.Delhi
31	PusaPratibha	AmrapalixSensation	IARI,N.Delhi
32	PusaShreshth	AmrapalixSensation	IARI,N.Delhi
33	PusaPeetamber	AmrapalixLalSundari	IARI,N.Delhi
34	Pusa Lalima	Dushehari x Sensation	IARI,N.Delhi
35	Ambika	AmrapaliX Janardhan pasand	CISH
36	Arunika	Amrapali x Vanraj	CISH
37	Sai sugandh	Totapuri x Kesar	-
38	CISH-M-2	Dasheharixchausa	CISH
39	CISH –M-1	Amraphalix janardhan pasand	CISH
40	Konkan Samrat	Alphonso x Tomy Atkins	BSSKKV
41	Suvarna	Alphonso x Neelum	DAPOLI
42	NMBP-1243	Irwin x Kensington Pride	Australia
43	Neeleshan Gujarat	Neelam x Baneshan	AES, Paria
44	Sonpari	Alphonso x Baneshan	AES, Paria
45	NMBP-1201	Irwin x Kensington Pride	Australia
46	NMBP-4069	Van Dyke and Kensington Pride	Australia
47	hybrid-949	Amrapalli x Vanraj	ICAR-CISH
48	hybrid-1084	Amrapalix Vanardhan pasand	ICAR-CISH
49	GMH-1	Alphonso X Baneshan	GAU
50	Hybrid 45	(Bennet Alphonso x Himayuddin),	ICAR-CISH
51	Hybrid 87	(Kalapady x Alampur Benishan)	ICAR-CISH
52	Hybrid 151	(Kalapady x Neelum)	ICAR-CISH
53	Arka Suprabhath	Amrapali X Arka Anmol	IIHR, Bengaluru

the popularity among the growers.

Table 2a: Important Guava varieties

State	Varieties/hybrids
Andhra Pradesh	Allahabad Safeda, Anakapalli Banarasi, Chittidar, Hafsi (Red Fleshed), Lucknow-46, Sardar, Seedless, Smooth Green, Smooth White.
Assam	Amsophri, Madhuriam, Safrior payele.
Bihar	Allahabad Safeda, Chittidar, Hafsi (Red Fleshed), Harijha, Seedless.
Maharashtra	Dharwar, Dholka, Kothrud, Lucknow-24, Sardar,
Gujarat	Nasik, Seedless, Sindh.
Tamil Nadu	Anakapalli, Banarasi, Bangalore, Chittidar, Hafsi, Nagpur Seedless, Smooth Green.
Uttar Pradesh	Allahabad Safeda, Apple Colour, Chittidar, Red Fleshed, Banarasi Surkha, Sardar, Mirzapuri Seedless & Lalit
West Bengal	Behrampur and cvs. of Uttar Pradesh.
Karnataka	Purple Local. Kamsari, A.Mridula, A.Amulya, A.Kiran, A.Rashmi, A.Poorna

5.2. High Density Planting in Mango and Guava

High density means to increase the plant population per unit area for increasing the production of fruit crops or HDP is one of the novel methods to achieve high productivity per unit area both in short duration and perennial horticultural crops. In mango, HDP at 1111 trees /ha on 'Olour' rootstock with Paclobutrazol application from 4thyear at 0.125g / tree/ year of age, stabilized by the 10th year resulted in 6fold increase in productivity. Similarly, cv. Amrapali at 2.5x 2.5m in triangular system accommodation of 1600 and cv. Dashehari at 3.0 X 2.5 m in square system -1333 plants per hectare. Increase in yield per hectare was 2.5 times in Amrapali than that of the low-density orchards of vigorous cultivar. In cv. Dashehari, the average yield in high density is reportedly 9.6 tonnes compared to 0.2 tonnes in low density planting. The increased yield in guava per unit area can be made possible by increasing the plant population **(Mitra *et al*., 1984).** Ultra high density planting not only provides higher yield but also provides higher net economic returns per unit area in the initial years and also facilitates more efficient use of inputs **(Reddy, 2004).** One of the ways used for efficient and profitable land use is to work on tree spacing. Its basic function is to confine the exploitation zone of the plant with regard to light, water and nutrients so that the highest total yield potential can be reached in the smallest possible area (**Singh, 2005; Lal *et al.* (1996) and Singh (2004).**As guava responds very well to pruning, the following plant densities have been recommended by Central Institute for Subtropical Horticulture, Lucknow for early, higher and quality guava production: A. 3.0m (row to row) x 1.5m (plant to plant) accommodating 2222 plants ha-1, B. 3.0m (row to row) x 3.0m (plant to plant) accommodating 1111plantsha-1 and C. 6.0m (rowto row) x 3.0m (plant to plant) accommodating 555plants ha-1. Singh *et al*. (2007) studied the performance of guava (*Psidium guajava* L.) cv. Allahabad Safeda were planted at 1.5 × 3.0, 3.0 × 3.0, 3.0 × 6.0 and 6.0 × 6.0 m spacing for growth, yield, fruit quality and light penetration. Tree growth was significantly influenced by different tree densities and the total yield was highest (79.5 kg tree^{-1}) from the tree planted at the distance of 3.0 × 6.0 m, while it was only 32.60 kg tree^{-1} from the planting distance of 1.5 × 3.0 m. However, the yield of per unit area was more (7.24 kg) at the planting distance of 1.5 × 3.0 m (2222 trees ha^{-1}).

5.3. Drip Fertigation and Mulching

The new technologies of micro-irrigation now include drip/trickle systems, surface and subsurface drip tapes, micro-sprinklers, sprayers, micro- jets, spinners, rotors, bubblers, etc. Despite wide promotion, only about 10 million ha of land is currently under micro-irrigation in India as against the total potential of 63 million ha. Maharashtra is the leading state under micro-irrigation followed by Karnataka, Andhra Pradesh and Tamil Nadu. Micro irrigation is popularly practiced in about 30 crops and is more popular in horticultural crops which allow relatively wide spacing. It is however critical that micro-irrigation is popularised and facilitated in field crops grown in rainfed cultivation systems. This will benefit the small and marginal farmers, who are predominant practitioners of field crops and rainfed farming systems. Studies have revealed that water savings ranging between 25 and 50 per cent are possible by drip irrigation compared with surface irrigation. Micro-irrigation also facilitates application of controlled quantity of water and nutrients in the vicinity of each plant, such that the crop, water and nutrient needs are almost matched with irrigation water supplies.

Table 3: Water requirements for mango and guava under HDP

Crop	1st Year (litre/plant/ day)	2nd Year (litre/plant/ day)	3rdYear (litre/plant/ day)	4th Year (litre/plant/ day)
Mango	0.93	3-4	8-10	14-16
Guava	2.0-3.0	4.0-5.0	6.0-8.0	10.0-12.0

The experimental results reveal that HDP and UHDP of mango and guava has been promising for enhancing the yield and quality of mango and guava to many folds under the climate change era. Manjunath *et al.* (2019) reported that the mulching with polythene enhanced soil moisture (up to 111%) and the impact was much visible for longer periods (160 days) after cessation of rainfall. Polythene mulching with raised soil around the root zone showed 39.8% higher fruit yield in guava over control on three years pooled mean basis. The treatment recorded 12.30 t/ha at sixth year of guava planting. Mulching with polythene although recorded slightly lower gross returns (Rs.6, 19, 870/ha), recorded higher benefit cost ratio (1: 5.25) and was followed by mulching with enriched coir pith (1: 4.83).

5.4. Rootstocks in Mango and Guava Production

Rootstocks become an essential component in commercial fruit crop production as rootstock can impart desirable traits to the fruit crop growth and development. Rootstocks are widely used throughout the world for several fruit trees. They are responsible for orchard performance, water uptake, mineral nutrition absorption and tree anchorage. Rootstocks play a vital role in intensive commercial fruit production, and the use of rootstocks in commercial orchards has increased manifold in recent past. They have wider applications such as improving fruit quality, precocity, adapting to different soil and climatic conditions, inducing dwarfness, etc., The priorities of rootstock selection in tropics and subtropics are mainly focused on regular bearing, high yield, and tree vigour. This is mainly because of the demand for higher fruit production with less land use in these densely inhabited regions where the evolutionary history has favoured the fruit trees to be vigorous in their natural habitat. The need in rootstock today is the creation of variability for rootstocks. In guava, the var.Pusa Srijan and *Psidium molle* are commonly used to induce dwarf and wilt tolerance. Mango rootstocks and cultivars were different in their response to salinity injury **(Nemat, 1991).** Association of salt tolerance features of Gomera-1 mongo rootstock is related to its capacity to restrict the uptake and transport of Cl- and Na+ ions from the rootstock to the above ground parts **(Duran et al., 2003).** Langra was the most sensitive mango cultivar to salt stress **(Jindal et al., 1976)** while rootstocks 13/1 and Gomera-1 demonstrated tolerance to saline water (**Kadman et al., 1976**; **Gazit and Kadman, 1983).** The main aim of rootstock breeding in mango is to develop the hybrids/varieties which are having resistant to adverse soil conditions, controlling the scion vigour, polyembryony for uniformity, tolerance to soil borne problems and physiological compatibility to commercial scion **cultivars (Iyer and Degani 1998**). Though, most of the Indian varieties are monoembryonic but there are some from polyembryonic varieties such as Kurukan, Chandrakaran, Olour, Bappakai, Muvandan, Mylepelian, Kitchner, Nekkare, Prior, Vellaikolumban, Peach, and Starch which give true to type seedling from nucelllar embryos. The Vellaikolumban was found to be controlling the scion vigour of Alphonso and recorded higher fruit yield, whereas, Olour gave the maximum yield and canopy height, at IIHR, Bengaluru. Salinity tolerance has also been the focus of several researchers. At IARI, New Delhi, **Dubey *et al.* (2007)** studied the effect of salinization on two polyembryonic mango rootstocks, i.e., Kurukan and Olour. They found that both the genotypes could survive 2.15 dS m-1 salinity level with mild necrosis and scorching on leaves. Screening of mango rootstocks to salinity has shown that the polyembryonic cultivars 'Olour' and 'Bappakkai' could withstand higher level of salinity **(Palaniappan, 2001**). Mango cultivar '13-1' was selected as a polyembryonic (3-6 embryos) rootstock for calcareous soils and/or for irrigation with saline water **(Gazit and kadman,1983).** Mango trees on '13-1' rootstocks showed excellent performance on soil containing 20% lime, three other cultivars on '13-1' rootstock showed good development on sandy soil with 10- 20% lime and irrigation water containing 250 ppm (**Gazit and Kadman 1980**). Pyramiding and stacking multiple genes controlling different aspects of salt tolerance and identifying QTLs for salt tolerance in M. indica L. cv. 13-1 and M. zeylanica may provide greater insights into salt tolerance mechanism in mango. Recent studies showed that salinity tolerance in plant was due to their resistance to oxidative stress **(Gueta et al., 1997).** The plant defense mechanism including antioxidant enzymes such as catalase, peroxidase, glutathione reductase, and polyphenol oxidase also, a non-enzymatic antioxidant and a cellular osmoregulation are involved **(Niknam et al., 2003**; **Agarwal and Pandey, 2004**; **Demir and Kocaliskan, 2001; Asada, 2006**). Leaves of salt-stressed plant exhibited a greater activity of peroxidase and polyphenyl oxidase while activity of catalase was reduced (**Abdallatif et al., 2015).** The increased activities of the antioxidant enzymes upon salt stress are often related to the enhanced tolerance to salt stress (**Gueta *et al*., 1997;Mittova *et al*., 2004).** Biochemical and physiological mechanisms in mango involved with the interaction between genotypes of scion and rootstock are still poorly understood **(Vishambhar *et al*., 2014).**

5.5. Canopy Management

Canopy management is the manipulation of tree canopies to optimize the production of quality fruits **(Singh,2010).** The canopy management, particularly its components like tree training and pruning, affects the quantity of sunlight intercepted by trees, as tree shape determines the presentation of leaf area to incoming radiation. An ideal training strategy centers around the arrangement of plant parts, especially, to develop a better plant architecture that optimizes the utilization of sunlight and promotes productivity.

Light is critical to growth and development of trees and their fruits. The green leaves harvest the sunlight to produce carbohydrates and sugars which are transported to the sites where they are needed – buds, flowers and fruits. Better light penetration into the tree canopy improves tree growth, productivity, yield and fruit quality. The density and orientation of planting also impact light penetration in an orchard. Generally, in close planting, quicker shading becomes a problem. An east-west row orientation results in more shading as compared to the western and southern orientation of trees. Strong bearing branches tend to produce larger fruits. The problem of a fruit grower is initially to build up a strong and balanced framework of the trees, then equip them with the appropriate fruiting. Obviously, pruning in the early years has to be of a training type to provide strong and stocky framework with well spaced limbs or any other desired shape.

5.6. Pollinators in mango and guava

Mango is a cross pollinated fruit crop. Mango trees produce both male and bisexual (hermaphrodite or perfect) flowers on branched terminal panicles. The number of panicles ranges from 200 to 3,000 per tree with 500 to 10,000 flowers per panicle. The proportion of bisexual flowers is very low compared to male and varies from 1 to 35 per cent depending on the variety. Bisexual flowers have a fleshy disk around the ovary which secrets nectar. The stamen (male part) is on the outer margin of this disk. When insects visit them to feed on either nectar or pollen, they are likely to transfer pollen from the anther to the stigma. In spite of having millions of flowers, the per cent fruit set in mango is very low (about 0.1%). Lack of adequate pollination is one of the factors responsible for poor fruit set. The extent of self-pollination is very limited and wind is not considered an important pollinating agent of mango. Hence insects play a significant role in transfer of pollen from anthers to stigma, whether within a bisexual flower or between male and bisexual flowers. The contribution of insect pollinators to fruit set in mango has been proved through experiments.

During blossom period, several kinds of insects visit mango flowers either for nectar or pollen or both. Majority of them are flies and bees. Other minor foragers include beetles, bugs, butterflies, and moths. Depending on the number and frequency of insects foraging on flowers, only a few speciesare considered key pollinators of mango. In Karnataka, Andhra Pradesh and parts of Tamil Nadu, little bee (*Apisflorea*), Blue bottle fly (*Chrysomya megacephala*), hover fly (*Eristalinusarvorum*)and a wasp mimicking fly, *Stomorhina discolor* and stingless bee or dammer bee (*Tetragonulairi dipennis*) were found to be important pollinators of mango. In the Konkan region of Maharashtra, stingless bee was found in considerably higher numbers than other species**(Reddy *et al*. 2019).**

Over the years the density of pollinators has been declining at a faster rate. It has become a rare event to hear the buzz of insect activity in commercial mango orchards. Several factors are responsible for this decline. They are large scale and indiscriminate spraying of insecticides, destruction of natural nests of pollinators, clean and monoculture leading to the non-availability of sufficient flora during off-season, pests and diseases and climate change.

Climate change affects pollinators at two levels. One is direct effect on biology and foraging efficiency of pollinating insects and another through the phenology of host plant. Being cold blooded animals, at higher temperatures, honey bees and other pollinators spend more energy in regulating their body temperature, which could in turn impact the foraging efficiency. Elevated temperatures brought about by climate change could also alter quantity and quality of floral rewards like nectar and pollen and either advance or delay the flowering periods Crops like mango are highly seasonal and have a flowering period lasting for relatively shorter periods. Hence it is very essential that adequate number of pollinators should be available during that period to meet pollination demand. Any disturbance to this highly evolved synchrony would lead to temporal mismatches between plant and pollinators. Our studies have clearly showed that the foraging behavior and efficiency of honey bees are affected with a rise in temperatures beyond certain point. In order to meet these eventualities, it is very essential to devise strategies to augment and conserve natural pollinator fauna in orchards.

6. Conclusion

Climate change impacts are going to be positive in general for fruit crops because of their resilient to withstand the harsh climates. In the light of possible global warming, more emphasis has to be given on the development of climate resilient varieties, identification of potential gene/genes for biotic and abiotic stress in the wild relatives and land races which can be introgressed on the commercial varieties background and development of rootstocks for biotic and abiotic stresses. The development of technologies on management of canopy architecture, efficient utilization of water and nutrients to adapt to warmer environmental conditions. There is need for regional level planning for resource allocation, including land, water, and horticultural developments by considering the climate change into account. The continuation of current and new initiatives to research potential minimizes the effects of climate change at farm, regional, national and international level and will help to provide a more detailed picture of how world horticulture and agriculture could change. Hence, a comprehensive plan covering R &D aspect for all horticultural crops is must and convergence of scientists, policy makers and public is the need of the hour for marching ahead and take the horticulture in to next level.

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Strategic Approaches for Climate Resilient and Sustainable Production of Less Known Fruits

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Introduction

The burgeoning global population together with the ongoing loss of arable lands and climate change led to an increasing demand for climate resilient crop production. To cope with these changing and challenging circumstances, horticulture production systems of the future need to be shaped sustainably. In developing countries like India, agriculture including horticulture is an important contributing factor to economic growth and poverty alleviation, particularly via providing food and employment opportunities besides ensuring nutritional securities. In India, major fruit crops such as mango, banana, citrus, guava and apple, account for more than 72% of the total area under fruit crops, while indigenous (native) or less known fruit crops contribute only 6.56% of the area ().437mha) with quite high productivity (11.47 tons/ha) [NHB, 2019] even though there is lot of scope for cultivation due to its diverse agro-climate. In general, those fruits which have less acreage and are available in low quantity in the market are generally called as minor or underutilized or less known fruits.

Climate change favors to rise in air temperatures, radiation levels and in the frequency of extreme events, such as drought or flood or very low temperature, which, especially in arid or semi-arid areas, can result in an intensification of the negative impact of salinity, mineral deficiency/toxicity and of diseases and insect-pest attacks on crops [Gora*et al*., 2019; Chatzistathis*et al*., 2021; Mumivand *et al*., 2022; Sanwal *et al*., 2022]. Consequently, climate change represents a great threat to obtaining the sustainable production of major commercial fruits [Gora*et al*., 2019]. Under such environmental conditions, the fulfillment of the consumers' choice and nutritional and food security at an affordable and sustainable level is a major concern for the researchers, policy makers as well as the growers. Under the given circumstances, specific growing areas may be utilized for exploiting the potential of less known fruit crops producing edible fruits that meet the food and nutritional demand of local population. The indigenous fruit crops are not only proven to be superior in terms of wider adaptability to environmental conditions but are also known for their nutritional value [Berwal *et al*., 2021]. However, a limited amount of research has been carried out for the development of production protocols and utilization of these less known fruit species. Moreover, the limited number of identified varieties, the low availability of quality planting materials and the inadequate availability of suitable cultural and post-harvest management practices are still major limitations challenging the systematic cultivation of these less known fruit crops. Moreover, these lesser known fruits are not very popular and are sold at very low prices in the local markets because of the lack of (a) people's awareness of their nutritive values (b) consumption habits (c) limited research and (d) developmental policies by the government agencies for their potential exploitation.

The scenario of climate change not only affects our environment but also affect the physiology of crop that we use for our consumptions. Most of the cereal and pulse crops that we consume for our food are annual crops which are not directly affected that much as compared to that of the fruit crops which are mostly perennial. Fruit crops are believed to have maximum adverse impact of climate change. For example, in mango, high temperature during floral bud differentiation led to poor sex ratio of flowers

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in the current season. Rising temperature prevents desirable fruit coloration in coloured guava and reduces quality grape productions that eventually decrease the area of cultivation and market demands also (Rajan, 2008). Similarly, temperature also determines the quantity and sex ratio of flowers. This directly impacts the fruiting potential for the crop for the season. Fruit crops like mandarin, coloured variety of guava and grapes require low night temperature to develop good-looking fruit peel color. Sweetness of warm climate fruits also increases with increase in diurnal temperature difference which surely affected by adverse climatic situations. These are some examples but the actual scenario is much larger and if proper measures are not taken situation may get worsen. The probable alternative to ensure nutritional security intact through fruits availability is by selection of climate smart fruit crops. These fruit crops are believed to be much more tolerant to heat stress and moisture stress. The fruit crops like dragon fruit, phalsa, pumello, bael, wood apple, aonla, karonda, Barbados cherry, pilu, kair, khejri and lasora are believed to be having a less moisture demand and have lesser transpiration rate. Besides, that these fruit crops are believed to withstand effects of climate change.

Scope for Less Known fruits Production

Utilization of fallow land

There is a vast scope for less known fruit cultivation in our country because total area under horticultural crop is very small and it is about 9% of total cropped area and fruit occupy 29% of total horticultural area. Area under fallow land is more. So, we can utilize this untapped fallow and degraded lands for cultivation of less known fruit crops. We can use all this available land to better contribute to rural income, in order to alleviate shortages of nutrition dense food (fruits), fuel wood, small-timber and fodder, especially for income-poor rural communities.

Hardy nature of plants

Less known fruit crops are found in numerous agricultural ecosystems and often survive mainly in marginal areas. These crops are hardy in nature and they are free from diseases and pests. They can grow without much care, they do not require irrigation, fertilization although they have great demand in national and international market and there is also a growing consumer interest in biological/organic agriculture, for which many underutilized species offer advantages.

Tolerance to adverse soil and climate

A large number of less-known fruit species which have immense potential for commercial exploitation under stress condition, are yet to be utilized to their full potential. Fruit crops like ber, phalsa, datepalm, bael, wood apple, etc. are capable of growing on waste land where other crops fail to grow. They are highly valued for nutritional and neutraceutical value of their fruits and also for their ability to grow successfully even under adverse agro-climatic condition. In view of increasing population pressure, decline in per capita land availability and escalating input cost, diversification of Indian Horticulture with hardy and high value indigenous fruit crops is necessary for boosting fruit production.

Nutritional value

The majority of the Indian population resides in village areas and they suffer from malnutrition. There is a great demand for fresh fruits because fruits are a rich source of vitamins and minerals. Fruit is considered as 'protective food' being a source of vitamins and minerals in readily available from. Due to this reason the scope of fruit cultivation becomes inevitable. In order to overcome malnutrition problems of arid, hilly and tribal people, it is necessary to enhance the production of minor fruits, which can be done by increasing production and area under fruit crops. Nutritional content of some minor fruits is shown in Table 1.

Table 1: Nutrient content of different minor crops (100 g $^{-1}$ fruit). Source: Das and Das (2006)

Different nutrient	Sources
Vit – A(retinol)	Persimmon (2710 IU), cape goose berry (1000-5000 IU), loquat (1528 IU), jackfruit (175-540 IU), tree tomato (150-500 IU), phalsa (419 IU), bael (55 mg)
Vit – B_{12} (riboflavin)	Bael (1.19 mg), Wood apple, ber
Niacin	Bael (1.1 mg), custard apple, wood apple
Vit – C(ascorbic acid)	Barbados cherry (1000-4000 mg), seabuckthorn (40-2500 mg), aonla (600 mg), Indian ber (50-150 mg), carambola, custard apple (37 mg), jamun (18 mg), phalsa (39 mg)
Calcium	Tamarind (0.74%). Karonda (0.16%). Wood apple (0.13%), bael (0.09%), aonla (50 mg), wood apple (130 mg), phalsa (129 mg), ber (30 mg), and date palm (0.3 g)
Phosphrous	Wood apple (110 mg), date palm (0.1 g), aonla (20 mg), karonda (600 mg), custard apple (23.5%) and tamarind
Iron	Karonda (39.1%), date palm (10.6%), ber (300 mg), sapota (2 mg), aonla (1.2 mg), phalsa (3.1 mg) and custard apple (1.9 g)
Organic acid	Aonla, jamun, tamarind
Protein	Wood apple (7.3 g), tamarind (3.1 g), custard apple (1.6 g), chironji and bael (1.8 g)
Carbohydrates	Dry karonda (67.1%), date palm (67.8%). Bael (31.8 g). Custard apple (23.5 g), jamun, phalsa (14.7 g), wood apple (15.5 g), ber (12.8 g) and tamarind (70.8 g)

Nutritional security

For a balanced diet we need minimum of 85g fruits per person per day. To meet this requirement in terms of vitamins and minerals for our increasing population above 125 crores, both area and production under fruit crops have to be increased. Less known fruit crops help in greater demands for increased dietary diversity for novel and nutritionally healthy foods.

High medicinal importance

Apart from nutritive value, less known fruits have also medicinal value. A diet predominated by seasonal fruits and taking controlling food is said to be a boon and to increase the longevity of life. Some examples are: aonla is the main ingredient of 'chyavanprash' which is famous for its therapeutic value in the Ayurvedic system of medicine; unripe bael fruit can cure diarrhea, constipation and dysentery with certainty; jamun fruits are helpful in curing diabetes. Thereby the expanding demand for herbal remedies, both internationally and in situations where modern pharmaceuticals are unavailable or too expensive for local populations.

Produce value-added products

With the advancement of postharvest technologies, installation of agro-industries, storage and transport facilities, there is great demand for less known fruits throughout the year as most of the fruits are used for preparation of value-added products. This will encourage the growers to go for minor fruit cultivation. Different processed products of different minor crops are shown in Table 2.

Table 2: Major processed products of different minor fruit. Source : Singh *et al.*(2008)

Processed product	Name of fruits
Jam	Jamun, Karonda, Aonla, mulberry, Soursop, tamarind, Wood apple
Jelly	Tamarind, Jamun, Karonda, tamarind
Preserved	Ber, aonla, Ker, sangria, karonda, bael, soursop
Candy	Aonla, karonda, tamarind
Glaized fruits	Tamarind, ananas, aonla
Confectionary	Amra, aonla, tamarind
Juice / Syrup	Aonla, ber, bael, jamun, karonda, Phalsa, mulberry
Beverage / squash	Pomegranate, soursop, wood apple, tamarind
Wine	Mahua, jujube, ber, Indian fig, karonda
Chutney	Karonda, wood apple, aonla
Sauce	Karonda, tamarind, wood apple, pomegranate
Pickle	Jujube, tamarind, ker, lasora, gonad
Dehydration	Aonla, karonda, ker, bael, ber, custard apple
Frozen puree	Bael, karonda, ker, phalsa, tamarind, custard apple
Canning	Ber, aonla, jamun, ker
Essential fatty acid	Chironji, Karonda and wood apple

New market opportunities

New tools are available to transform useful plant species into diverse products or to extend the shelf life of perishable crops and products. The movement of people across countries and regions provides opportunities for strengthening markets of less known fruit crops and breeds in which immigrants identify their own culture and traditions. Tourism represents an increasingly important source for supporting local commodity chains built around less known fruit species. The high standard of living in industrialized countries generates demands for more natural food and environmentally-friendly products, a demand which can also be met by underutilized species.

Improving socio-economic condition of tribal people

Most of the tribal population resides in remote, hilly, forest and degraded areas. Adaptation of suitable minor fruits cultivation region-wise helps to earn money, fuel and their engagement which create a socio-economic impact for their sustainability.

Minor fruit as ecological security

Most of the underutilized/minor fruits can tolerate adverse ecological conditions (drought, shallowness of profile, cold and wet soil). They can be grown in wasteland also.

Environmental changes and ecosystem stability

Climate changes, degradation of land and water resources have led to a greater appreciation of those crops to stress and difficult environments where they play a strategic role in maintaining a diversity rich and hence more stable environment.

Less Known Fruits for Different Climatic Zones of India

Broadly the country can be divided into tropical, subtropical and temperate regions. Within each broad category there are differences due to rainfall, humidity, altitude, etc. Considering these aspects six different horticultural zones have been identified so that appropriate choice of the crops can be made and development is planned. According to these zones less known fruit crops are classified below:

Temperate climate zone

Less known fruits like crabapple, chestnut, wild apricot, blackberry, seabuckthorn, etc., can be grown in this climatic condition.

Southern tropical climate zone

In this climate, less known fruits like ber, custard apple, aonla, bael, karonda, jamun, wood apple, Barbados cherry, bilimbi, hog plum, kokam butter tree, rose apple, star apple, star gooseberry, Surinam cherry, white sapota, kodampulli, etc. can be grown successfully.

North-eastern subtropical zone

The parts are Bihar, Assam, Meghalaya, Manipur, parts of West Bengal, Uttar Pradesh, etc. The crops are mahua, karonda, passion fruit.

North-western subtropical region

This includes parts of Jammu and Kashmir, Himachal Pradesh, hills of Utter Pradesh, South of Punjab and Haryana. The crops are phalsa, date palm, ber, custard apple, tamarind, loquat, amlok, behmi, kaliphal, wild apricot, pecan, lasoda, ker, etc.

Central tropical zone

South Madhya Pradesh, Chattisgarh, Gujarat, Maharashtra, Orissa and West Bengal. Under this zone crops are fig, mahua, phalsa, khirni.

Coastal tropical humid fruit zone

Kerala, Goa, Diu Daman, Tripura, coastal parts of Maharastra, Andhra Pradesh, West Bengal, Tamil Nadu, Orissa, Karnataka. Under this zone the minor fruit crops are bilimbi, breadfruit, hog plum, lanson, tamarind and kokum butter tree.

Importance of Less Known Fruit Crops

1. Provide variety of products that include food, fodder, fuel wood, gums, resins, fibre, medicine etc.
2. Easier to grow and hardy in nature, producing a crop even under adverse soil and climatic conditions.
3. Most of them are very rich sources of vitamins, minerals, and other nutrients such as carbohydrates, proteins, fats and nutraceuticals.
4. Cheap and readily available.
5. Vital source of genes against biotic and abiotic stresses.
6. Low input requiring crops.
7. Produce higher biomass than field crops per unit area resulting in efficient utilization of natural resources.
8. Can help achieving ecological security through

improvement of wastelands by preventing soil erosion, improving fertility of soil and promoting biodiversity

Constraints in Less Known Fruit Crops Cultivation

- Poor awareness about the nutritional and medicinal value of underutilized fruit crops.
- Less emphasis in researches for exploitation of potential underutilized fruits.
- Lack of standardized propagation techniques in many such fruits and non- availability of quality planting materials (seed and vegetative parts).
- Limited application of modern cultivation practices e.g. negligible use of innovative and novel technologies such as biotechnology, plasticulture for enhancement of productivity.
- Lack of proper transportation facilities for an efficient supply of production inputs and timely disposal of produced in the market.
- Lack of knowledge about suitable postharvest management practices. Under-developed marketing channels and infrastructure like storage facilities.
- Non-competitive prices of produce of underutilized fruits.
- Inadequate extension services for promotion of cultivation underutilized fruits.
- Negligible set up of agro-industrial units.

Strategies for the Promotion and Cultivation of Less Known Fruit Crops

- Creation of awareness about the nutritional importance of unexploited fruits through organization of special awareness camps/ campaigns, exhibition, etc., at micro and macro level, use of mass media like radio, TV, newspaper and distribution of other printed literature.
- Emphasis on sustainable collection and use of various fruits from forests and domestication of potential wild species for avoiding overexploitation from natural sources.
- More crop-specific systematic research and development efforts entailing conservation of genetics resources, improvement, production technology advancement, postharvest management, value addition etc., keeping in view the agro-climatic suitability of the region.
- Independent tailor-made research for crops important for subsistence farming and those exhibiting potential to become commodity crops. Development of trait-specific varieties from the available gene pool to cater the intended demand.
- Mass multiplication of planting materials and their distribution.
- Increased focus to document indigenous knowledge through ethno-botanical studies to tap multipurpose uses of such crops.
- Emphasis on development of processing units in rural areas.
- Expansion of infrastructure facilities with priority on market development, transport and communication.
- Promotion of export oriented production programmes of targeted crops. A number of underutilized fruits are available in arid parts of the country. The less known fruit crops should be popularized and improved cultural practices should be developed for different agro climatic regions. These plants are not only yields fruits but also provide firewood, leaf fodder and serve as wind breaks in arid regions. Owing to its multiple uses, it can be used in different farming systems to meet the basic needs of local inhabitants.

Thus, it can be concluded that more attention is needed on exploitation of genetic resources of less known fruits. There is a tremendous scope of less known fruits cultivation in water scarce areas of the country. Under drought conditions, using less known plants in horti-pasture and agro horticultural system are suitable to fulfill the local demand of food, fodder and fuel besides several products of economic uses. The genetic resources may be utilized for crop improvement as a source of resistance, hardiness and vigour. The post harvest management of underutilized fruits is essential for value addition.

Characteristics and Potential Uses of Less Known Fruit Crops

Arid and semi-arid regions are considered the hotspot for abiotic stresses, such as extreme temperatures, intense solar radiation, salinity, drought and nutrient deficiency, where the commercial fruit crops either fail to grow or struggle to express their potential performance. Under such climatic conditions, the integration of arid-zone less known fruit crops can be a better strategy to sustain the crop productivity under stress due to their typical morphological, physiological, anatomical and biochemical xerophytic characteristics that allow them to perform optimally under harsh climates. Therefore, adaptive traits such as those that increase the overall resilience and resistance to suboptimal environmental conditions do not necessarily result in a yield penalty. It is generally assumed that adaptive traits ensure yield stability in specific conditions, being fitness typically measured in terms of fertility, fruits and seeds. For instance, these traits include phenology shifts (flowering/ripening in a specific period of the year) and/or morphological characteristics (root/shoot ratio, leaf macro and/or micro-morphological traits, etc.) that allow specific genotypes to escape environmental stresses (not necessarily involving an active and metabolically costly response to stress). This can result in the capacity of these genotypes to have fruits reaching ripening compared to those that did not have any adaptive trait. In order to cope with abiotic stresses, the arid-zone underutilized fruit crops, such as ber (*Zizyphus* spp.), aonla (*Emblica officinalis*), bael (*Aegle marmelo*s), jamun (*Syzigium* spp.) and wood apple (*Feronia limonia*), have modified and/or developed their organs to assure vital morpho-physiological functions (i.e., strong deep root system, a high root-to-shoot ratio for reaching into deeper moist soil layers and uptake more water and nutrients). Similarly, crops such asber, bael, lasora (*Cordia mixa*) and pilu (*Salvadora persica*) have round, thick and barked stems for easier water storage and reduced cuticle transpiration. Some crops such as kair (*Capparis decidua*), lasora, aonla and pilu have synchronized flowering and fast fruit development during the season characterized by larger moisture availability. Crops such as ber, phalsa and bael exhibit leaf shedding/dormancy for reducing water loss in summer and for protecting the plants from frost in winter. Similarly, other underutilized crops possess numerous morphological characters, such as spines instead of leaves (ber), scanty foliage (kair), spiny cladodes (prickly pear), mucilaginous sap for reduced transpiration loss (kair, lasora, pilu, bael, etc.), small-sized and thick leaves, fur/hairiness and waxy coating on the leaf surface and sunken and deep stomata, for water saving through the reduction in transpiration rate and heat shocks (ber, phalsa, lasora, fig), and selective or reduced absorption of cation (Na+) and anions (Cl", SO4 2"). These characteristics are also associated with the accumulation of osmolytes, compatible organic and inorganic solutes (proline, phenolics, flavonoids, soluble sugars, glycine, betaine, etc.), and biosynthesis of enzymatic and non-enzymatic antioxidants, heat shock proteins and drought-responsive genes to maintain cell turgor, allowing better survival under the adverse conditions of arid and semi-arid environments. In addition, the genetic basis of the adaptive traits deserves to be studied because this information could be used in future breeding programs that may also involve novel tools, such as genome editing. These less known fruit crops may represent the next generation of futuristic crops, which could enhance the farmer's income through sustainable production systems even under a climate-change scenario.

Less Known / Climate Smart Fruit Crops

The fruit crop like dragon fruit, kair, phalsa, pumello, bael, wood apple, aonla, karonda, barbados cherry and pomegranate are believed to be having a less moisture demand and have lesser transpiration rate. Neither are their flowering and fruiting too much affected by fluctuating temperature. Hence, these crops can be the next generation climate smart fruit crop.

Dragon fruit/Pitaya (*Hylocereus undatus*)

This is a new emerging fruit of tropics and subtropics particularly in peri-urban and urban areas. The fruit belongs to the family cactaceae and have a high drought tolerance. In this succulent plant, leaves are modified to spine. Hence, the fruit crop has high drought tolerance. The fruit is borne in the junction of cladode when it reaches a certain height. In dragon fruit, the temperature and light intensity may affect the blooming. Dragon fruit can be grown at a high temperature up to 45^{O}C. Besides that, it can grow in rainfed conditions as well. It can be grown in rainfall up to 100-2000mm rainfall, with alternate dry and wet period (Swamy *et al*., 2004).

Phalsa (*Grewia subinaequalis*)

Phalsa is one of the hardiest fruit plant, drought resistant and thus requires little care with low inputs. It can be grown almost in all parts of north India except at higher elevations. It is mainly grown in the states of U.P., Bihar, Rajasthan, Haryana, Punjab, Gujarat, Maharashtra, Andhra Pradesh and Madhya Pradesh. Phalsa being very vigorous in growth can be an ideal plant for plugging gullies and ravines and for contours to protect bunds. The plants are deciduous and normally shed leaves on the onset of winter season and go on dormancy. But in warmer region plant does not shed leaves and there is no dormancy. It can grow at temperature ranging from 3^{o} C to 45^{o}C. Plant can tolerate light frost. However, it requires protection from the very low temperatures.

Being a bush, it can be grown as filler plant in aonla, bael, ber orchards. It is mainly propagated through seeds and stem cuttings. It is a small bush and bears many berries like fruits. Fruits ripen by the end of May and beginning of June. Fruits are perishable and keeping quality is very less. Recently, variety 'Thar Pragati' has been identified for cultivation by ICAR-CIAH, Bikaner. It is dwarf, early precocious bearer (bearing in 3rd year), drought tolerant and suitable for high density planting. It is suitable for table and processing purpose. The fruits are highly perishable and are used in preparation of squash and juice. Ripe fruits are acidic in taste and rich source of vitamins A and C. Its fruits have cooling effect. Fruits are good source of carbohydrate, proteins, minerals and vitamins. Processed products like jam, squash and pickle can also be prepared from phalsa fruits. Bark of plants is used during preparation of jaggary for improvement of the quality. Pruned phalsa canes/ shoots can be utilized for making baskets to transport fruit and vegetables to distant market.

Pummello (*C. grandis / C maxima*)

The pummelo is tropical or near-tropical and flourishes naturally at low altitudes close to the sea. Pummelo can be grown successfully in semi arid and hot sub-tropical regions as well. This can be attributed to the fact that among all other citrus species, it is having minimum water requirement. Beside that the flowering does not require critical or exact temperature requirement. It has a high heat requirement and can tolerate drought and heat waves. Pummelo is known to give sufficient fruiting even at 45^{O}C. The best thing with this citrus species is its extensive disease and pest resistance and it can be successfully grown in high temperature zones with scares rainfall.

Wood Apple [*Feronia limonia* (L.) Swingle]

Wood apple (*Feronia limonia* Linn. Swingle), syn. *Limoniaacidissima* L. *Feroniaelephantum* Correa, *Schinuslimonia* L. belongs to family Rutaceae. Wood apple is also called kainth, elephant apple, monkey fruit, curd fruit, kathabel and others name in India. The wood apple is native to India and common in the wild form in dry plains of India and Sri Lanka. It is also found growing throughout South East Asia, in Northern Malaysia and on Penang Island. In India, the fruit was traditionally a "Poor man's food" until processing techniques were developed in the mid-1950's. Systematic block plantation in the form of orchards of wood apple is uncommon, whereas it is mostly found in isolation as a stray plant in the plains of Southern Maharashtra, Uttar Pradesh, West Bengal, Madhya Pradesh and Chhattisgarh states of India. The wood apple is a small-to-moderate size, glabrous, deciduous tree with thorny branches, rough and spiny bark and it is able to grow on saline, poor and neglected lands normally unsuitable for fruit cultivation. It is the only species of the Citrus family that can tolerate both drought and salinity stress. Wood apple have the basic potential to withstand severe drought stress and can survive in dry soil as well. Wood apple is known to tolerate temperature as high as 45^{O}C. It can flower and fruit profusely even at water sparse condition. The fruit is processed as powder, preserve, squash, sherbet, beverage, jam, cream, leather, wine, toffee, candy, RTS, pickle and capsules.

Custard Apple (*Annona squamosa* L.)

Custard apple is one of the drought-hardy fruit plants belonging to the family Annonaceae, which is commercially cultivated in a limited area of the Indian

Deccan plateau region. The light, gravel and small pebbles soil is also suitable for its cultivation. Custard apple plants are small, semi-deciduous shrubs with simple leaves, cauliflorous flowering, bisexual and protogynous flowers, superior ovary, fruit etaerio of berries. Its flower is borne mostly in new flushes after the shedding of old leaves commencing from March to August with a peak in April–May. The fruit is climacteric, it may be symmetrically heart-shaped, lopsided or irregular, and the interspaces between the protuberances become yellow at full maturity. The demand of custard apple fruit is increasing in domestic and international markets thanks to their sensory, therapeutic and nutritional properties, as well as their pleasant flavor. Custard apple fruit contains vitamins A, B, C, E, and K1, essential minerals, antioxidants and polyunsaturated fatty acids. They are antimalarial, antifeedant, immunosuppressive, cytotoxic, diterpenes and are used to treat HIV. Moreover, a range of cosmetic products using custard apple is available in the market, such as perfumery, soaps, pimple creams, essential oils, hair lotions, ayur slim capsules, cold balms, anti-stress massage oil, pain massage oils, and foot care creams.

Ber/Indian Jujube (*Ziziphus mauritiana* Lamk; Rhamnaceae)

The Indian jujube (ber) is one of the most ancient cultivated fruit trees in north Indian plains. It grows even on marginal lands or inferior soils where most other fruit trees either fail to grow or give very poor performance. It is regarded as the king of arid zone fruits and also as poor man's apple. There are three main species found in the country. The *Z. mauritiana* is the main species of commercial importance with its several varieties. *Z. nummularia* is prized for its leaves (rich in protein) which provide fodder (Pala) for livestock. The third one, *Z. rotundifolia* also bears edible fruits but of smaller size. It is used as rootstock for commercial Indian jujube. The seeds contain saponins, jujubogenin and obelin lactone. Jujube fruits contain fairly high amount of vitamin C, besides vitamin A, B, protein, calcium and phosphorus. It is a perennial hardy fruit tree which gives income from multiple products such as fruits, fodder and fuel wood even in severe drought conditions to the resource deficient farmers. It is the only fruit crop which can give good returns even under rainfed conditions and can be grown in a variety of soils and climatic conditions ranging from sub-tropical to tropical. The branches are having the physiology to minimize moisture loss. The leaves are also hairy and are perfect to minimize water loss through stomata. Hence it can tolerate long dry spell and can withstand heavy drought condition.

The ber tree is extremely drought-hardy due to the deep taproot system and xerophytic characteristics, such as (a) dormancy (leaf shedding) during the peak period of hot summer preventing transpiration, (b) waxy and hairy leaves, (c) thick bark. It grows well even in marginal or poor soils where most other commercial fruit trees either fail to grow or have very poor performance. Ber fruit is mostly consumed as fresh within 4–5 days after harvest due to the short shelf life. Thus, it is necessary to develop a value-added product at a farmer-field or industry level, and there is the need to work on the diversification and popularization of jujube products. It is the only fruit crop that can give good returns even under rainfed conditions due to its wide adaptability under a large variety of soils, water availability conditions and climates (with the exception of heavy frosts) in arid and semi-arid regions. In addition to nutritional and economic health, some jujube cultivars, such as Dragon, Mushroom, So and Teapot, are known for their landscape values, such as unique fruit shape, fruit color and tree shape, and are planted in gardens and backyards due to their dwarf habit and compact canopy.

Aonla/Indian Gooseberry (*Emblica officinalis* Gaertn.; Euphorbiaceae)

The aonla is being cultivated in India since Vedic Era. As a result of intensive research and development, it has attained commercial status and also proved to be potential fruit crop for arid ecosystem. It is hardy, prolific bearer and highly remunerative even without much care and can be grown in variable agro-climatic and soil conditions. Due to pure deciduous nature and hard physiology, the tree can withstand long dry spell. The leaves are having minimum surface area because of which the moisture loss due to transpiration is also low. Aonla can successfully tolerate frost and can be grown successfully even at temperature nearing 50^0C (Chaubey, 2000). The medicinal and therapeutic properties of aonla are considered as 'amritphal' or a wonder fruit for health. The aonla fruit is 3 and 160-times richer in protein and vitamin C compared to apples, respectively. It is the richest source of

Vitamin C (500–1800 mg/100 g) among the fruits after Barbedos cherry, and the content in leucoanthocyanins, polyphenols, pectin, iron, calcium and phosphorus make its fruit largely used in Ayurvedic medicines for making "Triphala" and "Chyavanprash". Aonla fruit is generally used to prepare a number of delicious, processed food products such as preserve, candy, jelly, toffee, pickle, leather, squash, juice, RTS beverage, cider, shreds, dried powder and ayurvedic tonics such as Chayvanprash, Triphala, Amrit Kalash and Amol Ki Rasaya.

Pomegranate (*Punica granatum* L.; Lythraceae)

Pomegranate (anar) is an economically important commercial fruit crop of arid and semi-arid regions. Commercial plantations of pomegranate exist in Maharashtra, Gujarat, Rajasthan, Andhra Pradesh and Karnataka owing to its preference for arid climate. Its xerophytic characteristics and hardy nature makes it suitable crop for dry, rainfed, pasture and undulating land, where other fruit crops cannot grow successfully. Besides, being a favorite table fruit, it is also used for preparation of juice and squash. Dried seeds give an important condiment coined as "anardana". It also has medicinal value and rind is being used for dyeing cloths. Pomegranate can tolerate temperature upto 50^0C during normal season and 42-45^0C during peak fruiting season. Beside that it has low water requirement and can withstand long dry spells as well.

Kair [*Capparis decidua* (Forsk.)]

Capparis decidua Forsk belongs to the Capparidaceae family, and it is locally known as Kair, Ker, Karil Teent, Della, and Neptiin. It is an indigenous, multipurpose small woody perennial much-branched, leafless bushy shrub widely grown without much care on farm boundaries, orans, gochars and wastelands tracts of arid and semi-arid regions. Its xerophytic characteristics, such as deep root system, scanty foliage, mucilaginous sap and tough conical spine, make it an ideal plant for stabilizing sand dunes and controlling soil erosion by wind during the hot desiccating summer in the Thar desert of western Rajasthan. However, it easily survives in desert conditions characterized by temperatures ranging from "8 to +48^oC or more, drought, saline and poor nutrients soil ecological conditions. In general, kair is naturally propagated through seeds, root suckers, hardwood cuttings and tissue culture, but the plant survival rate is very low. Kair plants produce pink, red and white flowers in the axil of the spine three times a year, but the main flowering flush occurs in March–April, and fruit matures just before the monsoon. The kair fruit is used as a vegetable, pickles and condiments. Dried fruit is an important ingredient of a traditional vegetable of Rajasthan known as **'Panchkutta'**. Its fruit is rich in proteins, carbohydrates, fiber and minerals (Ca, P and Fe). It is used in medicine for sedation, anticonvulsant asthma, inflammation and cough, since it contains isocodonocarpine, á- and â-amyrin, taraxasterol, erythrodiol alkaloids in plant organs.

Besides fresh consumption, it has processed value and therefore, emphasis is required on its large-scale cultivation in arid and semi arid regions. Ker is multipurpose plant species, which every plant part is used by the local people. Fruits are highly nutritious and medicinally important. Ker tree is boon for Thar Desert. Stem wood of ker is very strong and durable. It is used to make the pivotals of stone mill. Thick wood of ker is used to make foundation around the well (Chandra *et al*., 1994) where as smooth thin wood of light yellow colour is used for making small agricultural implements (Singh, 1993). Ker wood resists the termite attack and therefore, thinner branches are used for fencing the field and mulching. It is also used as fuel wood in rural areas. The young twigs serve as a fodder for camels and goats. Immature flower buds and flowers of ker are used for vegetable and pickling purpose. The use of immature flowers buds and flowers of *Capparis decidua* is used as vegetable. There is a need to identify suitable types with the view of selecting plants that are heavy yielding, have large fruit size and high pulp content, are rich in protein; of the proper total soluble solids (TSS), tartness, less acrid, with small and soft seeds, etc. In general, two distinct plant types of ker occur: a tree form, which is relatively unusual, and a shrub form, in the majority of plants.

Karonda (*Carissa carandas* L.; Apocynaceae)

Karonda is an evergreen spiny shrub or a small tree up to 3 m height and suitable for arid tropics and sub-tropics. It grows successfully on marginal and wastelands and locally known as Christ's thorn. The plant is also useful for making attractive thorny dense hedge around any fruit orchard. It yields a heavy crop of attractive berry like fruits which are edible and rich in vitamin C and minerals especially iron, calcium, magnesium and phosphorus. Mature fruit contains high amount of pectin and, therefore, besides being suitable for making pickle, it can be exploited for making jelly, jam, squash, syrup and chutney, which are of great demand in the international market. Its main flowering season is March–April with fruits maturing during August–September which enables the plants to make best use of monsoon rain. However, some varieties/plant types also flower during October–November. Karonda can withstand temperature as high as 45^{O}C. The natural ability of the plant to withstand dry spell is remarkable. The tree can survive drought condition and hot loo without any loss in reproductive vigor in upcoming season.

Its drought-hardy nature is due to xerophytic features, and the plant offers 5–8 kg fruit yields without much care and management in arid and semi-arid regions. Karonda produces flowers in January–February and June–July and fruit ripen in 60–90 days after fruit set. Depending on the genotypes, white, green, purple and pinkish-red colored fruits are common, due to which it is also used as an ornamental plant in gardens. Immature fruit is usually used for producing pickles and chutney but occasionally is used as a vegetable, while fully ripe fruit is consumed fresh or processed to produce candies and colored extracts used as natural food colorant. Karonda fruit is considered the richest source of iron (39 mg per 100 g), contains a fair amount of vitamin C and is used to cure of anemia and scurvy. In addition, they are a good source of calcium, magnesium and phosphorus and have high antioxidant activity. The mature fruit is suitable for making pickles and jellies due to the high content of pectin. They can also be exploited for making jams, squashes, syrups and chutneys, which have high market demand.

Bael [*Aegle marmelos* L. (Correa)]

Bael is the only species of the genus Aegle, which belongs to the family Rutaceae; it is one of the oldest indigenous fruits known by various names in different parts of India, such as billi, Bengal quince, stone apple, golden apple and Japanese bitter orange. Bael has a wide distribution in various ranges of edaphic-climatic conditions due to its ability to withstand heat, drought and low-temperature poor-nutrient soil. Natural thorny nature of the tree enables it to survive even in the harshest of climate. It is found growing vigorously in temperature well above 40^{O}C in dry areas. It is deciduous, medium-sized, slender, gum bearing with a cauliflorous fruiting habit, deep taproot system, bold thorny branches and trifoliate leaves. Its trifoliate leaves resemble a trident, so people offer them to Lord Shiva Lingam to get rid of worry and suffering. Bael can be used as avenue and ornamental trees (golden color ripen fruit); shells of the dried fruit after removing pulp are used as fashioned cups, small containers, ornamental pills, snuff boxes, etc.. The bael fruit is a rich source of riboflavin used to cure beriberi, and unripe fruit is suggested to treat diarrhea and dysentery, whereas the marmelosin in fruit has therapeutic properties being a good remedy for stomach ailments. However, all plant parts of bael contain various compounds with medicinal values, e.g., coumarins, alkaloids, sterols and essential oils, that have analgesic, antipyretic, anti-inflammatory, anti-antifungal, microfilaria, hypoglycemic, anti dyslipidemic, antiproliferative, wound healing, insecticidal and anti-fertility abilities. Bael fruit is consumed only in processed products, such as powder, preserve, nectar, toffee. These products have had high market demand during the COVID-19 pandemic period due to its ayurvedic medicinal values. Their current price in the market is high and for this reason, bael is becoming a remunerative crop for farmers of arid and semi-arid areas.

Lasora (*Cordia myxa* L.)

Cordia, locally known as Gonda, Lasora, Lehsua, Indian cherry, Assyrian Plum or Bird's Nest Tree, belongs to the Boraginaceae family and is grown across India except for the high hills and the temperate climates. It is known as Indian cherry, lehsua or goonda. The other important species are *C. gharaf* (goondi), *C. rothii*, *C. macleodii*, *C. vestita* and *C. wallichii*. Out of these, goondi (*Cordia gharaf*) is a popularly grown species and medium size tree having dense foliage with crooked trunk. Lasora leaves have sunken stomata and other characters of drought tolerance. Plants are deciduous in nature. Cordia is a fast-growing tree with a beautiful inverted dome/umbrella crown, utilized as an avenue tree and ornamental furniture; ovate, alternate and stalked leaves used as fodder during hot summer when green grasses are not available and also used as rearing lac insect. Trees bear white color hermaphrodite flowers in March and drupaceous green unripe fruit ready for harvesting from April to June. It is mostly used as green fresh vegetables and pickles, especially in the lean period when the availability of conventional vegetables is limited. The fruit is considered as a naturally rich source of antioxidants, i.e., carotenoids, ascorbic acid, phenols, and minerals, crude fiber, protein, ascorbic acid, ash and vitamins, which represent essential nutrients for human health and for curing certain human ailments (improve digestion, birdlime, anti-tumor, anti-helmentic, diuretic, demulcent and expectorant; improve hair growth). Glue is also prepared from the mucilaginous pulp of lasora fruit. Plant gives light timber used for various domestic purposes. However, wood is light in weight and is used for making boat and agricultural implements. Stem barks contain 2% tannin.

Tamarind (*Tamarindus indica* L.)

Tamarindus indica is a dicotyledonous, monotypic, long-lived, semi-evergreen fruit plant belonging to the family Leguminosae. It has a wide range of adaptability, and it is an ideal tree for avenue plantation as a roadside, backyard and agro forestry systems. It bears terminal and lateral drooping bisexual flowers in May–June and forms fruit as pendulous pods ten months after fruit set. Tamarind fruit pulp and seeds contain tartaric acid, reducing sugar, tannin, pectin, cellulose, fiber, potassium, calcium phosphorous and other minerals, such as sodium, iron and zinc. The fruit pulp is the chief source for souring sauces, curries, chutneys, beverages, food colorants and it is considered a great delicacy. All its parts are valuable for food, fodder, timber, fuel, textile, nutritional and pharmaceutical industries, such as fluoride remover. Tamarind trees are planted as roadside avenue trees in the Banaras Hindu University, Varanasi, the largest university campus of India.

Jamun (*Syzygium cumunii* Skeels; Myrtaceae)

Jamun is an Indigenous evergreen hardy fruit tree that naturally grows in neglected and marshy areas. Deep loamy, well-drained soils and dry weather during the flowering and fruiting period are ideal conditions for its cultivation. Jamun flower panicles emerge at the leaf axil during March–April. Fruit is borne in clusters (10–40 fruit) and are round or oblong, single-seeded berries with a single sigmoid type development pattern, and are non-climacteric. Jamun is rich in biochemical compounds, e.g., anthocyanins, myrecetin, ellagic acid, isoquercetin, glucoside, kaemferol, and it is used for its anti-inflammatory, neuropsycho, anti-microbial, anti-HIV, nitric oxide or free radical scavenging, anti-fertility and antiulcerogenic activities. Glycosides in the seed, jambolin or antimellin, are considered to have anti-diabetic properties by halting the conversion of starch into sugar. Ripe jamun fruit is used to prepare many products, such as squashes, juices, jam, jelly, pickles and wines. In Goa and the Philippines, the fermented fruit of jambolans is used to produce Brandy and a distilled liquor called 'jambava'.

Jharber (*Ziziphus nummularia* Burm. f.)

Jharber is a 1–2 m tall, perennial, deciduous and thorny shrub with drooping branches that in nature occupies almost all the habitats of extremely arid environments (crop and grazing lands, sandy-saline, rocky, degraded pastures). Anatomical features, such as the presence of papilla, crypt stomata, epidermis with a thick outer wall and thick cuticle and deep taproot system provide the best tolerance to drought, salinity and high temperature stresses, making this species adaptable to extreme arid regions. It flowers in July–August, and fruit ripens in November–December; the fruit is small-sized drupes with a globose-ovoid shape, dark red color and little edible pulp of sub acidic taste. The jharber dried fruit contains triterpenoids, alkaloids and saponins and are used in medicine for their anticancer, stomachic, sedative, blood purifier, anti-obesity, antipyretic, anodyne, refrigerant, pectorial, anti-anemia, vomiting and styptic properties. Leaves of jharber, locally called 'Pala', are often used as fodder for camels, cattle, goats and sheep, being rich in crude fiber, crude protein, calcium and phosphorus. In addition, some plant organs have local medicinal uses. For instance, (a) the leaves are used to obtain poultices to heal wounds or they are used to cure asthma, fever, gum bleeding and liver problems; (b) the bark is used to treat diarrhea; (c) the roots are used as a decoction to cure fever, whereas its powder is adopted to treat ulcers and wounds; (d) the fruit is laxative and antiemetic; (e) the seeds are sedative.

Mahua [*Madhuca longifolia* (Koenig)]

Mahua is an indigenous deciduous tree belonging to the family Sapotaceae and is characterized by medium-to-large-sized canopy, grey-black cracked bark, milky and short trunk and many-branched. The flowers are grouped in dense clusters with long pedicels and have a coriaceous (leathery, stiff and tough) calyx and a tubular, cream colored, scented caduceus corolla. The fruit is a pinkish-yellow berry with 1–4 recalcitrant seeds. The trees are heterozygous and cross-pollinated. It is a multipurpose tree, which fulfills the three basic requirements of tribal people (food, fodder and fuel). Mahua flowers are edible and highly nutritive, being a good source of sugars, vitamins, proteins, minerals and fats, and they are used as a sweetener to prepare numerous traditional dishes, such as barfi, kheer, halwa and meethi puri, in the tribal belts of Madhya Pradesh, Rajasthan, Gujarat, Odissa, Jharkhand, Chhattisgarh and Andhra Pradesh. Mahua dry flowers are also fermented to produce wine, brandy, ethanol, acetone and lactic acids. Mahua is also used in medicine for its hepatoprotective, antiburn, anti-skin disease and wound healing, emollient, bone healing, swelling gum, anti-ulcer, anti-snake bite, milk production stimulation in lactating women, anti-bronchitis, anti-diabetic, diuretic, immune system stimulating, digestive, antioxidant, energetic and glucose booster activities. Mahua oil is used in manufacture of soap, lubricating grease, fatty alcohols and candles. Flowers of the plant are edible. The corolla commonly called as mahua flowers is a rich source of sugar containing appreciable amount of vitamins and minerals. The flowers are also used in preparation of distilled liquor, portable spirits, vinegar and feed for livestock (Ghosh, 2015).

Pilu (*Salvadora persica* L.)

Pilu is also known as kharijal, meetajal, mustard or salt bush, toothbrush tree, and belongs to the family Salvadoraeceae. It is a perennial, evergreen, large, much-branched shrub or tree widely found in Gujarat, Rajasthan, Haryana and Punjab and is suitable for the forestation of ravines, saline and alkaline lands as shelterbelts/windbreaks due to its hardy xerophytic nature. Pilu possesses a number of potentially therapeutic compounds, namely salvadoricine, salvadourea, â-sotisterol, trimethyl amine, thioglucoside, di-benzyl thiourea, rutin, potash, chlorine, sulfur, etc. Pilu's fibrous branches are a natural toothbrush (Miswak) and thus are used for oral hygiene. They are also used in a number of important medicines, e.g., antiseptics, abrasives, detergents, astringents, fluorides, enzyme inhibitors, dental diseases, anti-tumors, anti-leprosy, anti-ulcers, anti-gonorrhea, and antiscorbutic products. Moreover, the fruit is a source of sweeteners and are used for producing fermented drinks; the tender shoots are eaten as a salad, and the seeds are rich in C12 and C14 acids used in the soap and detergent industry.

Khejri [*Prosopis cineraria* (Druce.) L.]

Khejri or Jand/shami belongs to the Leguminosae family and is considered as the wonder tree, nature's gift, the king of desert and the golden tree. It is a desert dwelling tree that is the lifeline tree of the Indian Thar desert because each and every part of the tree is used to improve the socio-economic life of the local people. Khejri is an evergreen, slow-growing tree with exfoliated bark, rounded canopy, small and mucilaginous leaves and a strong deep taproot system that can reach extraordinary depths (up to 53 m or more). It was reported to be drought and salinity tolerant (10.0 to 25.0 EC dSm^{-1}). It is native to Arabia and the Indian Thar desert, and it is extensively distributed in the Thar Desert of the Indian states of Rajasthan Haryana, Gujarat, Punjab and Delhi. It is a multipurpose tree as it provides a vegetable pod, flour, cattle fodder, fuel, timber, gum, resin and medicine. It is also used as fencing/ windbreak, avenue tree, on farm boundaries in water deficit areas, topiary, bonsai and screening trees in home gardening, and forest restoration in arid landscapes. It is a high litter accumulating tree and improves soil fertility through fixing atmospheric nitrogen, and these effects result in the increase in the soil content of organic matter, soluble calcium and available phosphorus and in a reduction in soil pH. Moreover, the Khejri tree is considered a productivity booster in inter-cropping and companion cropping systems thus it is highly suitable for agroforestry systems in arid and semi-arid regions. Khejri green leaves have a very high nutritional value containing crude protein (11.9–18.0%), crude fiber (13–22%), nitrogen-free extract (43.5%), ash (6–

8%), ether extract (2.9%), calcium (2.1%) and phosphorus (0.4%). The unripe pods ('Sangri'), an important ingredient of the "Panchkutta" vegetable, is nutritionally rich in crude protein (18%), fat (2.0%), carbohydrate (56%), crude fiber (26%), phosphorus (0.4%), calcium (0.4%) and iron (0.2%), and is consumed as a green or dry vegetable, pickles and flour. All the organs of Khejri have therapeutic properties: flowers (Patuletin glycoside patulitrin, rutin sitosterol luteolin and prosogerin A and B) are used for their anti-diabetic activity and for treating Lewis lung carcinoma; leaves (spicigerine, campesterol and Tricosan-1-á) for mouth ulcers; pod and seed (Prosogerin, linoleic acid and prosophylline) for preventing protein malnutrition and calcium iron deficiency in blood, asthma, piles and leprosy, etc.

Mulberry (*Morus* spp.)

Mulberry grows throughout India but more extensive in Karnataka particularly Mysore especially for sericulture. In India, there are many species, of which *Morus alba* and *M. indica* are fully domesticated while other important species are *M. laevigata*, *M. rubra, M. nigra* and *M. serrata*. Mulberry is a fast growing deciduous woody perennial plant, wide-spreading, round-topped, trunk attaining 60 cm in diameter. It has a deep root system. All three mulberry species (*M. alba*, *M. rubra* and *M. nigra*) are deciduous trees of varying sizes. White mulberries can grow to 24 m and are the most variable in form, including drooping and pyramidal shapes. In the South on rich soils the red mulberry can reach 20 m in height. The black mulberry is the smallest of the three, sometimes growing to 10 m in height, but it tends to be a bush if not trained when it is young. The species vary greatly in longevity. Red mulberry trees rarely live more than 75 years, while black mulberries have been known to bear fruit for hundreds of years. The mulberry makes an attractive tree which bears fruit while still small and young (Krishna *et al*., 2018). The ripe fruit of mulberry is highly appreciated for its delicious taste which is consumed fresh or after extraction of juice. Immature fruits are used for chutney preparation. Mulberry fruit is used to treat weakness, dizziness, tinnitus, fatigue, anemia, and incontinence (Krishna and Chauhan, 2015). They are used as a functional food in the forms of masala, herbal tea, marmalades, juices, yogurt, biscuits, smoothies, capsules or as natural dyes, cosmetics oil and dietary food products, such as pekmez, kome and pestil. The various suggested pharmacological uses are for obesity, cardiac diseases, diabetes, hypercholesterolemia, tumors, oxidative stress, brain damage and for their anti-fungal, anti-aging, anxiolytic and hepato-protective activities.

Chironji (*Buchana nialanzan;* Anacardiaceae)

Chironji has originated from the Indian subcontinent and has no specific requirements in terms of soil and climate. It is naturally found in the arid and semi-arid forests of Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan, Gujarat and Uttar Pradesh. Chironji is a medium-sized, sub deciduous/ evergreen plant with a straight trunk and coriaceous leaves. It is a highly heterozygous, cross-pollinated plant with a strong tendency to alternate bearing. The fruit can be eaten both raw and roasted. Its kernel contains fats (59.0%), proteins (19.0–21.6%), carbohydrates (12.1%), fiber (3.8%), phosphorus (528.0 mg), calcium (279.0 mg), iron (8.5 mg) and vitamins [139]. It has the potential capacity to cure various diseases, such as snakebite, dysentery, diarrhea, asthma, burning sensation of body, fever, ulcers, cold and Alzheimer's, and it has anti-diabetic and anti hyperlipidemic activity.

It is a deciduous tree which produces edible seeds. These almond-flavoured seeds are used as a cooking spice primarily in India. After the hard shell is cracked, the stubby seed within is as soft as a pine nut. The chironji seed is lentil-sized, is slightly flattened and has an almond-like flavour. Though they can be eaten and used raw they are often toasted or roasted before use, as this intensifies the flavour. TSS 23.90^{o} Brix, 1.24% acidity, 13.06% total sugars, 6.67% reducing sugar, 48.70mg/100g vitamin C and 31.36% kernel protein. The fruit yield is 11.90 kg/ tree. The chironji seeds are commonly used in sweets in India. However, they are also ground into powders for thickening savory sauces and flavoring batters, and stewed into rich, meaty kormas. Seeds are also used in the Ayurveda and Unani systems of medicine.

Manila Tamarind [*Pithecellobium dulce* (Roxb.) Benth.]

Manila tamarind is commonly known as Madras thorn Monkey pod and Jungle jalebi and belongs to the Fabaceae family. It is a multipurpose, fast-growing, medium-sized thorny tree used as live fencing, animal fodder, hardwood timber, windbreak and a potential source of lac culture. Its fruit has a sweet acidic taste and high content of dietary fiber, proteins, Ca, Fe, P, unsaturated fatty acids and antioxidants. Manila fruit is used to treat toothaches, mouth ulcers, sore gums, dysentery, chronic diarrhea, stress, aging symptoms and dark skin spots.

Timroo (*Diospyros melanoxylon* Roxb.)

Timroo or tendu belongs to the family Ebenaceae and is native to India and Sri Lanka. It is found in endemic conditions within limited areas of Gujarat, Madhya Pradesh, Rajasthan, Jharkhand, Bihar, Chhattisgarh and Tamil Nadu. It is a long-lived, deciduous, dioecious, seedless parthenocarpic berry fruit. Its leaves are commercially used for bidis making (indigenous, traditional cigarette), agricultural implements and furniture. Most importantly, it is used as an indicator for high sulfur dioxide concentration. Timroo fresh fruit has high total phenolic content, flavonoids, scavenging activity, antioxidants and â-carotene content as equal or more to guava, plum, star fruit, mango, kiwi and apple fruit. Its bark extracts are used to treat dyspepsia, diarrhea, and smallpox (burnt bark) by ethno medicine practitioners.

Khirni (*Manilkara hexendra* L.)

Khirni/rayan belongs to the Sapotaceae family, and it is a native to India, evergreen, medium-sized, slow-growing fruit plant with a spreading canopy. It is a wild plant found in the arid and semi-arid to tropical climate as an avenue tree and can be used as bonsai due to the evergreen, dense foliage and dwarf habit. It bears flowers in February–March, whereas fruit ripen in May–June, and it is commercially used as rootstock for sapota to exploit its tolerance to salinity and drought. Its bark, seeds and fruit are rich sources of tannins, oil and vitamin A, respectively. Khirni fruit and bark are used for numerous medicinal purposes, such as curing fever, flatulence, stomach disorder, leprosy, ulcers, opacity of the cornea, dyspepsia, urethrorrhea and bronchitis.

Kumat (*Acacia senegal*)

It is a much-branched thorny tree with pale smooth bark. It founds on hillsides and stabilized sand dunes. It is hardy species surviving under harsh edapho-climatic conditions. It is an ideal species for agro forestry systems. It is used in "Pachkutta", a traditional vegetable delicacy of arid regions. It yields the true gum Arabic, an important commercial product and used in pharmaceuticals. Apart from gum production, its seeds are used as food; leaves and pods as fodder, and wood for fuel wood and charcoal preparation.

Gangana (*Grewia tenax*)

This winter deciduous shrub naturally occurs in buried pediments, hills and pediplains in arid region. Deep sandy loam is best soil for species; however it can grow in very shallow, skeletal, gravelly or clay soils. It is extremely drought hardy and tolerates frost. Fruits (drupe) are smooth, shinning, yellow orange to red when mature. Fruit production in natural stands varies very much. Ripe fruits are eaten as fresh. It also provides excellent leaf fodder.

Conclusion

Global climate changes are likely to exert pressure on the fruit production system and may constrain in the attainment of future fruit production targets. These changes are natural but its control in our hand through several mitigation measures which reduce the concentrated gases in the atmosphere that are responsible for climate change and fruit crops have a great role in the mitigation of these gases through carbon sequestration by photosynthesis. At present, available adaptation, strategies can help to reduce negative impact in the short term but to a limited extent. Though minor fruits are popularly known as 'less known fruits' these fruits have great values both in nutritional and medicinal properties. However, in spite of rich germplasm existing in India, development of standard varieties is limited. Having a wide degree of adaptability with high degree of tolerance, they can thrive well under adverse climatic and edaphic conditions. These fruits also serve a potentiality in sustainable agriculture. Hence, research and development work, farmers awareness and feasibility for cultivation of these less known fruits are to be given due consideration.

Future Thrust

Evaluation of less known fruits should be carried out to locate useful genotypes. Development of stable genotypes, which can perform across different environments within the region, is needed. There is a need to develop and test the performance of different genotypes across several environments so that their suitability can be judged. Development or location of rootstocks that can tolerate abiotic and biotic stresses induced by temperature regimes is needed. Adoption of improved agro-techniques like mulching and cover crops in orchards will help in bringing down the orchard temperature. It is feasible to grow cover crops of economic importance, which will also add to the income from the orchard. Use of precision farming methods like high- density planting and drip irrigation would help in providing microclimate with proved to be suitable against climate change.

Besides

(i) Quantification of sensitive stages and sensitivity in fruit crops to weather aberrations.

(ii) Quantifying the impact of elevated CO_2, changing temperature and rainfall on growth, development, yield and quality.

(iii) Quantification of carbon sequestration potential of the fruit cropping system.

(iv) Monitoring the phenology of fruit crops under changing climate situation and location-specific weather forecast based on eco-friendly horti advisory and real-time for fruit crop monitoring is to be done in adhoc mode to address the issues related to climate change.

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Impact & Improvement Strategies for Climate Resilience and Sustainability in Onion & Garlic

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Onion is an important vegetable crop cultivated across the world belongs to the genus Allium of the family Alliaceae playing a significant role in daily human diet (Suleria et al., 2015). World-wide, India ranks first in area, second in production next to China but in terms of productivity it is very low *i.e.* 14.21 Tons/ha (Tirlapur et al., 2017). From the last few years, its demand is increasing continuously in the national and international market, India itself supply onion to 38 different countries throughout the world in varying quantity (Mishra et al., 2013). Thus, onion is not only important from food, nutritional and medicinal point of view but also provide an economic security to country. Weather plays a predominant role in growth, development and productivity of onion crop. Recently the extreme environmental events namely, drought, floods, elevated temperature, cold waves and soil salinity are the major constraints limiting its production and quality globally. Aberrant weather conditions have always been unpredictable and often impairing realizable yield in various economically important crop plants. Global warming mainly due to increased emission of greenhouse gases (GHG) from industrial and other technological advances of modern world is responsible for climate change. Further, it is well acknowledged worldwide that the concentration of GHG *viz*., carbon dioxide, methane and nitrous oxide is increasing at alarming rate thereby contributing the changing climatic scenario at a faster rate (Vetter et al., 2017). Climate change is predicted to cause by an elevation in atmospheric temperature by 1 to 4^{0}C, increases in atmospheric CO_2 concentration and significant changes in rainfall distribution pattern. Nowadays, temperature variations more than critical levels are experienced. Although total rainfall might not have changed but the distribution pattern has changed largely. For overcoming the challenges ahead and achieving sustainable onion production in the challenged environment it requires systematic analysis, advance planning and climate smart crop management interventions. Thus, climate change and global warming are most likely to influence the severity of environmental stress in onion crop.

Response of onion crop to temperature and carbon-dioxide extremes

Onion is mainly a cool season crop and performs very well during winter followed by early part of summer season. In short day onion cultivars, bulb initiation takes place between 10-15^{0}C night and 20-25^{0}C day temperature. Bulb development is at its best at 18-20^{0}C night and 25-30^{0}C day temperature. For maturity, day temperature between 35-38^{0}C is required. Temperature is an important abiotic stress factor that severely limits onion yield and productivity mostly in *rabi* season due to sharp increase in atmospheric temperature mostly in the month of March-April which is highly detrimental for bulb development. In brief, high night temperature at bulb initiation stage leads to poor bulb development whereas, temperature more than 42^{0}C at the time of bulb maturity during April-May leads to reduction in bulb size along with poor keeping quality. Sudden increase in temperature increases evapo-transpiration rate, leads to drought stress and causes tremendous reduction in bulb yield. High temperature forces the crop to complete its life cycle within short period resulting into early maturity without proper bulb development with low productivity. Increasing temperature has also negative impact on fertilizer use efficiency which declines under elevated temperature regime. On the other hand very low temperature (<10^{0}C) during bulb development

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initiates bolting in onion that possesses considerable impact on its production ultimately affecting its value in domestic and international market. A case study of Pune for last 10 years indicated that rainfall vary greatly than normal range. High rainfall in Aug-Sept spoiled onion in respective years, while high temperatures during March and April reduced yield and storage quality of onion. Very low temperatures (<10^0C) in sensitive onion varieties for more than one week in Jan-Feb caused high percentage of bolting. In late *kharif* low temperature during Nov-Dec resulted in bolting which is the major problem in Maharashtra in sensitive varieties. Similarly, it is well known fact that there exist a positive interaction between carbon dioxide concentration and atmospheric temperature. It was evident that response to elevated carbon dioxide concentrations is greater at high temperature up-to certain extent leading to an increase in photosynthesis rate. This finding thus implies that an increase in temperature should be even more effective in stimulating the benefits of increased carbon dioxide levels at the low end of the temperature range than at the higher end. However, the negative effect of temperature on crop duration appears to be prominent, so that the overall effect of climate change is likely to reduce yield. In onion seed crop, dry weather with high temperature above 35^0C causes secreted nectar to become highly concentrated, making it less desirable to bees, and can decrease stigma receptivity and pollen viability ultimately affecting seed setting and yield.

Besides, temperature, atmospheric humidity, clear sunshine and moderate rainfall play significant role in onion productivity. Sunshine hours of 12-13 during bulb development and maturity, humidity between 65-75% and 500-600 mm well distributed rainfall ensures good crop growth. Excessive rainfall, cloudy weather in *kharif* and late *kharif* season lead to crop failures even up to 60-70%. Thus, the photo and thermo sensitivity of onion crop are affected extensively by the climatic aberrations particularly the temperature, CO_2, water stress and humidity. Even though very little information exists in literature pertaining to the studies of the interaction of carbon dioxide and high temperature on onion growth, development and yield particularly in short day onion. In *kharif* season due to heavy rainfall followed by high temperature, production of onion crop gets severely hampered resulting into its shortage in domestic market. Excessive rainfall experienced in the year 1998, 2005 and 2010 caused heavy crop losses due to bulb rotting and sprouting that leads to drastic reduction in quality of the produce.

Response of elevated temperature and humidity on onion pest and disease

A shift in atmospheric temperature, humidity and rainfall distribution pattern predominately influences the pest and disease outbreak in onion crop. Heavy rainfall during *kharif* season built up the incidence of many soil-borne and fungal diseases. In onion crop thrips are the major pest causing extensive damage to the crop and also act as a vector for many viral diseases too. The onion thrips have greater adaptability for atmospheric temperature ranging from 8-38^0C with an optimum at 27^0C and relative humidity of 70%. Study on seasonal incidence and population dynamics reported that onion thrips population reached to maximum (48/plant) in August during *kharif* season and lowest (1/plant) in October. Whereas, it started multiplying from December and reached highest (112/plant) in February and drastically comes down to 14/plant during March. During the entire onion growing period, two peaks of thrips population were recorded one in August and the second in February as low humidity during this period favors the thrips incidence (Srinivas and Lawande, 2004). Relative humidity and rainfall have negative effect on thrips population. Heavy rains wash out thrips off the plants causing a sudden decline in their population but, it causes resurgence of diseases like anthracnose and purple blotch in poor drained soil resulting into heavy yield reduction (Mishra et al., 2014). Thrips multiply faster under hot and dry weather, whereas incidence of diseases is more pronounced under elevated temperature with high humidity.

Response of onion to soil salinity

Salinity is one of the serious environmental threats, affecting about 7% of world's area and is growing progressively in arid and semi-arid part of world (Munns, 2002). In future it has a devastating impact on arable land with 30% land loss in next 25 year and 50% by the middle of twenty-first century (Wang et al., 2003). Every day world losses about 2000 to 4000 ha land area due to soil salinization making it unfit for crop cultivation (Qadir et al., 2014). It decreases crop production of more than

20% of irrigated land worldwide. In India nearly 9.38 million ha area is occupied by salt-affected soils out of which 5.5 million ha are saline soils (including coastal) and 3.88 million ha alkali soils (Mishra and Dave, 2013). These occur from Jammu & Kashmir (Ladakh region) in north to Kanyakumari in south and Andaman & Nicobar Islands in the east to Gujarat in the west. Generally, onion crop is considered to be salt sensitive (Shahbaz et al., 2012). Little genetic variation has been detected even though many cultivars have been tested. Tolerance is high at germination, very low during seedling growth and increases again at about the three- to five-leaf stage. Leaves change from rich green to dull blue-green with salt stress and leaf tips express burn symptoms typically associated with salinity stress (Grieve and Shannon, 1999). The previous studies conducted in India on the influence of salinity on seed germination, growth, flavor, and yield attributes in onion showed an adverse effect on these traits (Joshi and Sawant, 2012). Limited information is reported about the losses in onion yield as well as quality due to soil salinization and various tolerance mechanism in response to soil salinity in onion.

Response of climate change on onion seed production

Onion is a cool-season herbaceous biennial crop where; bulbs are produced in first season and that are planted subsequently in next season for seed production. The bulbs are stored at low temperature (4.5 to 14°C) either in the field or in store before planting that helps in flower stalks initiation. Onion seed production is manly carried out in *rabi* season with proper irrigation schedule. During the growing period low temperature favours the initiation of flower stalk. The optimum atmospheric temperature for onion flowering should be between 15 to 25^{0}C. The higher temperature (>35°C) affects the growth of pollen tube and receptivity of stigma, which results in poor seed set. The high temperature is required at the time of seed maturity and ripening. The high atmospheric humidity, fog and frost are not desirable conditions for onion seed production. Hence, the area prone to high fog and frost during November to March are not suitable for onion seed production. The unseasonal rain and hailstorm during seed maturity and harvesting further negatively influences the seed yield and quality. Taken together, low temperature at the time of bulb planting (November-December), moderate temperature during stalk development, flowering and seed setting (January-February) and warm temperature at seed maturity and drying (March-April) with bright sunshine free of cloudy weather is the best situation for seed production. Peninsular and central part of India is more suitable in this regard. Likewise, in onion seed crop the reproductive stage is highly sensitive to drought stress limiting the seed production and quality. Any changes in irrigation frequency drastically hamper the onion seed formation and quality. Proper irrigation scheduled depending upon the soil type, season and temperature during December 13-14 days recommended for black soil and 7-8 days during February month resulted into increased seed yield with good quality. In onion seed crop, drought stress affects the seed yield and quality by decreasing the number of pollinator visits. This occurred mainly due to decrease in amount of sugary nectar produced by onion floret which is disliked among the pollinators particularly the honey bee. Secondly, decrease in amount of viable pollen grains per flowers and floret abortion per umbel due to increase in temperature above 35^{0}C and drought stress significantly contributes to the lower seed yield. Previous findings showed that among the different growth stages in onion seed crop, bolting stage is found to be the most sensitive for drought stress as significant reduction in seed yield and quality is being recorded as compared to drought stress coinciding with other growth stages (Balla et al., 2013). Besides these factors, well-drained medium to heavy soils with pH ranging from 6.5 to 7.0 are good for onion seed production as it has capacity to retain the moisture for longer period. However, the light soil can be used for seed production after application of sufficient quantity of well rotten organic manures. Whereas, sandy, calcareous, rocky unfertile soil and soil with pH more than 8 are not suitable for onion seed production. This information thus revealed that proper irrigation management during onion seed production is necessary for getting good quality seeds with higher yield.

Response of onion crop to hailstorm

In addition to the various climatic factors, severe storms with high winds, hail, rain, and blowing soil particles collectively called as hailstorms are the most damaging event in onion crop. This sudden and unpredictable event of hail storm generally occurred during late *Kharif* and *Rabi* season in India. This damaging event occurred frequently during the pre-monsoon season of March, April and May; Maharashtra has witnessed this unseasonal weather pattern in 2014 during last week of February and first week of March affecting the standing late *Kharif* as well as *Rabi* crop in Nasik, Ahmednagar, Pune, and Sholapur districts. The quality of the bulb was severely affected by the hail storm event severely limiting its keeping quality and ultimately the export. In onion crop, bulb initiation is the most sensitive growth stage for hail storm that completely damaged the foliage and bulbs. Defoliation and damage to standing crop can certainly increases the plant wounding, which enable pathogens to enter and infect plant tissues ultimately killing the plant completely. The incidence of *Stemphylium* blight and bacterial soft rot was higher due to unseasonal rainfall received during February and March. The unseasonal rain and hail storm keeps the underground bulbs intact which when harvested and exposed to the sun and heat, becomes rotten, turned black and emanate a foul smell which reduces its marketing value. Following management strategies will help to overcome the damage caused by hailstorm:

- If bulb crop growth is at 45 to 60 days after transplanting and foliage present, foliar spray of Tricyclazole @1g/l or Hexaconazole @1 ml/l or Propiconazol @ 1g/l immediately after the incidence will reduce the appearance of stemphyllium blight. Foliar application of water soluble NPK fertilizer (19:19:19) will be effective for quick recovery.
- If the crop is at 45 to 60 days after transplanting and foliage completely damaged, soil application of NPKS @ 25:20:20:10 kg/ha through water soluble fertilizer may boost vegetative growth. Foliar application of water soluble NPK fertilizer (19:19:19) at 10-15 days interval up to 90 days on newly emerging leaves will supply nutrients readily to the plants and improve the bulb development and enlargement. Soil application of plant nutrients after 60 days was seldom effective in improving crop yield because the nutrient uptake after 60 days to till harvest accounted for 5-10% only. Foliar spray of Tricyclazole @1g/l or Hexaconazole @1 ml/l or Propiconazol @ 1g/l will reduce the spread of stemphillium and purple blotch disease.
- If crop is at stage of 60 to 90 days after transplanting and foliage is present or slightly damaged, prophylactic spray of Tricyclazole @1g/l or Hexaconazole @1 ml/l or Prpiconazol @ 1g/l will prevent the spread of disease and foliar application of water soluble NPK fertilizer (19:19:19) @ 10 g/l will improve crop stand and prevent the loss of bulb yield.
- If the wounds or injury is caused by storms with heavy rain and high winds, it should be protected within hours with sprays containing copper-based material or streptocycline (1 mg/l) to check or reduce the bacterial infection. Delay in spray after the appearance of symptoms will not control bacterial soft rot (Delahaut and Stevenson, 2004).
- Stickers should be added in all the foliar sprays @ 0.5 to 1 ml/l depending upon crop growth
- If the crop is at maturity stage or harvested and bulbs are exposed by hail storm, it should be harvested, cured and immediately marketed, otherwise its keeping quality may be affected.
- Crop should be given light irrigation immediately after appearance of hailstorm to avoid chilling injury. Smoking during evening in the fields by burning wet straw or stubbles or grass will increase the temperature during cold or foggy weather.
- Application of irrigation water through sprinkler irrigation system in standing crop during initial stage or bulb development stages will reduce the damage of hail storm.
- Water logging due to rains or mild hail storm at harvesting in the field will affect the storage quality of onion bulbs. Hence proper drainage on excess water is important to improve the quality of bulbs.

Climatic conditions and effect of climate change in Onion

Kharif crop is grown during hot and humid months and ready for harvest when temperatures are low. The bulbs do not become mature as growth continues due to shorter days and cooler temperature. The bulbs of Kharif season do not have good storability. Although, the day length during this period is slightly more than rabi, the critical value of day length available is around 11-11.5 hrs due to cloudy weather. Through centuries of selection the types, which can respond to warm and humid days with 11-11.5 hrs, have been identified and maintained and superior genotypes like N-53, Agrifound Dark Red, Basawant 780, Bhima Super, Bhima Red, Bhima Dark Red, Bhima Raj, Bhima Shubra and Arka Kalyan have been developed.

In case of winter (rabi) crop seedlings are transplanted in November-December, low temperatures (20-25^0 C) during December-January favour bulb initiation under again short-day conditions i.e. 11-11.5 hrs. Bulb growth and maturity is in February and March where nights are cool and days are warm (35-40^{0}C). High temperatures during April-May hasten maturity. There is better curing of neck and such bulbs store well up to 5-6 months. In hills of Uttar Pradesh, Himachal Pradesh, winter crop is transplanted in October-November and harvested in June-July, while summer crop is planted in February-March and harvested in August-October. In hills, days are longer (>13 hrs) and temperatures are cool. Duration is long (>7 months). Due to congenial climate, growth and development is very good, bulb size big and therefore yields are high. Granex types with yellow colour varieties are grown in hills.

Recently due to late monsoon or irregularities of rain in Kharif season there has been shift in planting from Kharif to late Kharif. Availability of irrigation water from September to February, failure of Kharif crop due to high rainfall coupled with high incidence of diseases and pest and poor storage of Kharif produce, farmers in Western Maharashtra are inclining towards late Kharif crop commonly called as Rangda onion. Seedlings are transplanted in September-October and bulbs are ready for harvest in January-February. Low temperature during November-December favours bulb initiation and good development. Warm days during January-February facilitate maturity, as the day length available is again 11-11.5 hrs. The yields are high with good bulb size but percentage of bolting and twins is very high and therefore reduce marketable yield. Further, storability of bulbs is also low as compared to rabi produce. Some of the varieties like Bhima Shakti and Bhima Shubra developed by ICAR-DOGR and Phule Samarth developed by MPKV, Rahuri are recommended for late kharif season. Still there is need to intensify research work in India for different location for late kharif season for early arrivals in market.

Climate change due to global warming and pollution has become major concern to the crop scientists and how to address this and prepare for is an important issue. Effect on total ecology and subsequently on certain important commodities is really not being studied. Hence, ther is need to take up systematic studies in this regard. The visible effect on distribution of rainfall has been noticed, which had exercised effect on increasing disease and pest in *Kharif* onion. *Kharif* onion is a very sensitive and crucial crop in meeting domestic supply from October to January. Failure of *Kharif* crop leads to hike in prices. Sudden rise in temperature in *rabi* season during December-January result in poor bulb initiation and bulb development of *rabi* onion and garlic. Dry weather with high temperature favours incidence of thrips and mites on the crop. Very high temperatures in March-April-May lead to reducing keeping quality of onion and garlic bulbs. Detailed studies under simulated conditions of weather parameters need to be initiated for understanding critical impact of climate change on different crops. Work on development of photo and thermo insensitive varieties is undertaken at Directorate of Onion and Garlic Research, Rajgurunagar to tackle the changing climatic situations. Some of the germplasms were found promising and can be grown in all the three seasons *viz*., *Kharif*, late *Kharif* and Rabi seasons is being exploited for such situations. Varieties like Bhima Super, Bhima Red, Bhima Raj and Bhima Shweta gives photo and thermo neutral response have wider adaptability and can be cultivated in all the three seasons under short day plains as well as under long day hills conditions.

Onion Varieties

Varieties are notified by either the central varietal release committee (CVRC) or state varietal release committee (SVRC) for commercial utilization. Hence, these are extensively evaluated for their performance in multi-location trials conducted under the AICVIP/ AINRPOG, which play a key role in testing, identification and release of new varieties. Onion is biennial crop and takes almost 12 to 14 years to purify or develop a new variety which is cumbersome. Varieties in onion were developed by different SAUs and ICAR institutes and tested under coordinated/ network project for release at national level for different agro-climatic conditions. Till now about 65 onion varieties including 2 F_1 hybrids and 6 multiplier type have been developed and released from public sectors for different colours (Light red, dark red, white and yellow), types (Common, rose and multiplier type), locations (short and long day) and seasons (Kharif, late Kharif and rabi) at state or national level. Out of which 33 onion varieties have been released through AICVIP/ AINRPOG including 10 onion varieties from ICAR-DOGR.

A number of cultivars have been developed and released in India and occupies a large area under cultivation, however still a substantial area is under the cultivation of local cultivar or land races. There is urgent need to develop onion cultivars for processing, salad purposes and for resistant to biotic and abiotic stresses. Some of the varieties before 1986 and after 1986 are given below.

Extant onion varieties before 1986: N-2-4-1, N-53, N-257-9-1, Pusa Red, Pusa White Flat, Pusa White Round, Pusa Ratnar, S-131, Early Grano, Punjab Selection, Punjab Red Round, Punjab-48, Punjab Red Round, CO-1(Multiplier), CO-2, CO-3, CO-4, MDU-1, Hissar 2, Kalyanpur Red Round, *Udaipur 101*, *Brown Spanish (Long day) and VL-1 (Long day)* etc.

Improved onion varieties after 1986: Bhima Red, Bhima Raj, Bhima Super, Bhima Kiran, Bhima Shakti, Bhima Dark Red, Bhima Light Red, Bhima Shubra, Bhima Shweta, Bhima Safed, Baswant-780, Pusa Madhavi, Arka Niketan, Arka Kalyan, Arka Bindu, Arka Pragati, Arka Pitambar, Arka Lalima (F_1 hybrid), Arka Kirtiman (F_1 hybrid), Phule Safed, Phule Suwarna, Phule Samarth, HOS-1, Agrifound Dark Red, Agrifound Light Red, Agrifound White, L-28, *Agrifound Rose, Agrifound Red (Multiplier)*, Line-355, Udaipur 102, Udaipur 103, Punjab Naroya, Punjab White, Punjab White ,VL-3 (Long day), Akola Safed, Rajasthan Onion-1 and Aprita (RO-59) etc.

Local/ farmers varieties: Fursungi Local (Pune), Sukhsagar (West Bengal), Bellary Red (Karnataka), K. P. Onion (Andhra Pradesh), Nasik Red (Nasik), Pillipatti Junagarh (Gujrat), Telgi Local (Vijapur) and Nimar Local (Madhya Pradesh)

Onion Processing

Dehydrated products such as flakes, rings, granules, powder etc. and processed onion as onion in vinegar and brine are the important by products being prepared and marketed worldwide. Processing industries in any commodity play an important role in stabilizing prices in domestic markets. Dehydration industries demand for white onion varieties with globose shape pf bulb and high TSS (>18%). All Indian white onion genotypes are having TSS range between 11-13%. The world trade of processed onion is more than two lakh tons. USA, China, India, and Egypt are the leaders in onion processing. India though started late in processing, is gaining momentum. About70 to 80 big to medium processing plants were established and still more are coming up in Maharashtra, Gujarat, Madhya Pradesh and Rajasthan which are competing in world market. Some of the Women Self Help groups also started processing of onion at small scale. Indian export of processed onion has increased from about 4000 to 55000 tons over last ten years. India has got special advantage being located in tropics as onion produced in tropical countries has got high pungency and flavor, which adds to processed products also. Present day processing industry is suffering from non availability of high TSS white onion varieties, irregular year round supply, poor seed supply, high post harvest losses, greening of bulbs etc. Coordinated efforts of scientific research, Processing and Agriculture Ministry, processing units, progressive entrepreneurs and farmers have taken up a momentum in India. There are some problems to run the processing plants are shortage of desired quality raw material, high cost of raw material, less availability of processing varieties. Some of the long day varieties which mature within 150-180 days offer high T.S.S. range from 15 to 24%, but do-not produce bulbs under Indian short-day conditions. Some of the short-day white onion varieties were developed by various research organizations in the country but they do not offer TSS range more than 12 per cent. Earlier there was no white onion *kharif* variety available in India. But, with the development of white onion variety Bhima Shubhra and Bhima Shweta by ICAR-DOGR, the bulbs can be made available in kharif and late Kharif also which can be used for processing and will help for continuous supply for the processing plants. ICAR-DOGR has taken up research programme since last sixteen years for the development of short day high TSS white onion variety and got success in development of high

TSS lines which is being purified and can flower in Indian plains where high temperature facilitates high sulphur built up and more pungency suitable for processing.

Onion Storage

Storage of onion is very important for regular supply to consumers, value addition and exercising control over price fluctuations. India produces about 210 lakh tons of onion. Among the total production about 71% is used for domestic consumption, 20% goes as waster during storage and handling, 5% is used for export, 3% for processing and 1% bulbs are used for seed production. The country needs on an average about 11 lakh tons of onion every month. The total production of onion is available in three different seasons. About 20% production is from *kharif* crop in the month of Oct-Nov., 30% onion is available as late *kharif* crop during Jan-Feb., and 50% produce is available as *rabi* crop or main crop countrywide during April-June. *Kharif* and late *kharif* produce is consumed during one or two months as there is heavy demand for domestic market as well as export and therefore does not require storage. Further, the produce of *kharif has* no storage capacity and late *kharif* has medium storage, hence marketed immediately. *Rabi* harvest is available countrywide in April-June in high quantity thus the rates are low from April to July. As there is no crop to harvest till November; rabi bulbs are required to be stored for regular supply till November. Sometimes due to poor weather and failure of Kharif crop, the stored bulbs of rabi needs to be supplied till late Kharif crop comes to harvest in February.

If *kharif crop* fails prices start shooting up right from September onwards and further increases till March beyond imagination if late *kharif also* fails. Contrary to this if there is bumper harvest during late *kharif*, the prices crash down from Feb to July. If the area planted during *rabi* is lessdue to unavailability of sufficient irrigation water or the crop is damaged by pre-monsoon rains, hailstorms and thus storage is less, the prices start rising right from August till next harvest is available. In augmenting regular supply vis-à-vis price stabilization, and storage of *rabi* onion is highly essential. Productivity of *kharif* onion in Maharashtra, Karnataka, Tamil Nadu, Rajasthan and Madhya Pradesh need to be ensured as per recommendations of ICAR-DOGR, Rajgurunagar, selection of correct varieties, planting on raised beds and drip irrigation ensures higher productivity in *kharif* onion. To ensure a steady supply of onion in the nation with control over price and better remuneration to farmers, there is need to ensure higher productivity during rabi by adopting good storage varieties developed by ICAR-DOGR and other organizations along with onion production in all the three seasons with advance production technology through raised bed planting, fertigation technique, IPM & IDM and further it becomes more essential to increase the storage for about 60 lakh tons.

Onion is among the living commodities but respires slowly, hence looses energy in the form of water besides some metabolic changes during post harvest storage. The weight loss in *rabi* onion under ambient conditions is to the tune of 20-25% depending on variety and storage environment, whereas, rotting looses are 10-12% due to storage diseases and sprouting looses 10-12%. Rotting and sprouting looses are to the tune of 50-60% in *kharif* onion and therefore need to be marketed immediately. The storability of onion is influenced by various factors viz. genotype, pre and post harvest management practices, growing season and storage environment. The genetically controlled factors influencing storage may be dry matter content, pungency, skin colour, number of adhering scales and period of natural dormancy in the variety. Among the pre harvest factors affecting storage quality of onion includes nutrient management specially application nitrogenous fertilisers besides potassium and sulphur, amount and quality of irrigation, pest and disease management and foliar application of growth retardants etc. The growing season, time of withholding irrigation, method of harvesting, field and shade curing, type of storage structures, storage environment also influence considerably on storage life of the onion. If proper care with integrated approach is taken for the above factors, it will helps in reducing storage losses from 50 to 20%. Kharif onion do-not store well but, *rabi* season onion can be stored for 4-6 months, while late *kharif* produce can also be stored very well till rabi produce arrives in the market.

Among the environmental factors, temperature and relative humidity are most important in onion storage. The ideal storage environment should have 25-30^{o}C temperature with relative humidity of 65-75%. The onions are stored in heaps/stakes under ambient conditions in India in various types of traditional structures. Several modified onion storage structures have been designed with the available resources considering the desired storage conditions in lowest possible cost help in reducing storage losses. The staking height and width during storage of bulbs has greater impact and filling height should not be more than 5 feet and width not more than 4 feet, else increases the temperature and humidity at the center of heap which results in increase in storage losses.

Advanced plant production and protection technologies are available for different locations and seasons besides the development of varieties for quality production in the country. Various storage structures are tested and recommended for storage of onion. Hence, there is need and have wide scope to promote kharif cultivation and storage structures in different parts of the country for regular supply through the year with production and supply of quality seed of recommended varieties to the farmers which will benefit the producer as well as consumers, besides constant and steady export of onion from India.

Performance of contrasting onion genotypes under drought stress in Rain-out Shelter

A field experiment was conducted to evaluate the effect of drought stress in 8 onion genotypes (W-009, W-355, W-448, W-344, W-396, Acc. 1656, Acc. 1627, and RGP-2) during *Rabi*, 2019-20 at ICAR-DOGR. These contrasting genotypes were selected on the basis of their tolerance ability in response to drought stress. Drought stress was imposed 50 days after transplanting by withholding irrigation for continuous 25 days (Bulb enlargement stage) after that routine irrigation schedule was followed throughout the crop growth period. Genotypes namely, Acc 1656, W-009, W-355, W-448, and RGP-2 performed superiorly over the other genotypes viz. W-344, W-396, and Acc. 1627 under drought stress hence characterized as tolerant genotypes. These tolerant genotypes were recorded with maximum survival percentage (>95%), plant water status (70-75%), maintained chlorophyll level, cellular membrane stability as reflected by higher MSI (>50%), better root architecture as compared to the other genotypes. The biochemical parameters evaluated from these genotypes further confined its tolerance characteristic with higher antioxidant enzyme activity under stress and after recovery phase. The characteristic bulb quality trait i.e. pyruvic acid was found to be comparatively higher in tolerant genotypes. Whereas, W-344, W-396, and Acc. 1627 recorded with poor plant stand, high leaf senescence rate, lower plant water status (40-50%), more membrane damage as reflected poor MSI (25-35%), low antioxidant enzyme activity hence classified as susceptible genotypes. The tolerant genotype Acc. 1656 produces bulbs of good size (A and B Grade bulbs) and weight followed by W-009, W-355, W-448, and RGP-2 under stress condition with less than 20-25% change in bulb weight as compared to control (Figure 4.17). Sensitive genotypes (Acc. 1627) failed to produce marketable sizes bulbs. Taken together, the evaluation of contrasting genotypes proved that the Acc. 1656, recorded with superior drought tolerance traits that can directly used in breeding program for developing drought tolerant onion variety (Annual report ICAR.DOGR 2020).

Garlic improvement

Germplasm resources

In India, ICAR-NBPGR nominated ICAR-Directorate of Onion and Garlic Research (DOGR), Rajgurunagar as a National Active Germplasm Site (NAGS) for collection and conservation of garlic germplasm. Presently, ICAR-DOGR holds almost 700 garlic ecotypes in field gene bank. All these genotypes are characterized by 25 agro-morphological traits and information has been published as a technical bulletin. This entire germplasm collection is collected through exploration and collection trips throughout India. Besides ICAR-DOGR, National Horticultural Research and Development Foundation, Nasik; MPKV, Rahuri; ICAR-VPKAS, Almora; and Junagadh Agricultural University, Junagadh; also involve in garlic germplasm maintenance. However, CITH, Srinagar act as active germplasm site for long day garlic genotypes.

Based on temperature and day-length response, garlic has been classified as having long-day and short- day varieties. It has also been classified as having hard neck and soft neck varieties. Hard-neck varieties bolt and flower but these flowers are usually sterile, while soft-neck varieties do not flower at all. Hard neck varieties cannot be braided for storage whereas soft neck varieties can be braided and stored. Hard neck (long- day varieties) is characterized by big bulbs, less number of cloves (10-15), ease of peeling and, generally, have low storage life. Typical examples are Agrifound Parvati and Chinese garlic. Because of big size, their productivity is higher and these fetch a good price in local and international markets. Soft-neck (short-day) varieties are characterized by small bulbs, more number of cloves (20-45), more aroma and are, generally, good storer e.g., Indian garlic varieties G41, G1, G50, G282, etc.

The short-day garlic grown in plains of North India, western India and hills of Nilgiris suffer from degeneration effects, small size of clove and susceptibility to diseases, pests and finally low yield. Therefore, improvement is needed to solve these problems.

At ICAR-DOGR, core set of entire garlic has been developed which comprises 46 garlic accessions. This accession represents variability of total 625 entire collection of ICAR-DOGR garlic accessions. This set containing accessions with high-low yield, bigger-small clove, high-less allicin, high-low TSS, three type of plant architecture, thin and wide leaf width, three range of leaf colour etc. Besides maintaining garlic germplasm in field, ICAR-DOGR also developed a protocol for *in vitro* slow growth conservation at ambient temperature where established plantlets can be slow growth conserved up to four months. This will be alternate conservation strategy for field gene bank, as in the field, crop can be devastated due to natural calamities. Work on enhancing conservation period (*in vitro* at normal temperature) up to six months is in progress.

a. Improvement in garlic through selection: Breeding methods for development of garlic are limited to clonal selection and mutagenesis among conventional methods, and somaclonal variation among biotechnological approaches. In India, most varieties have been developed through clonal selection and one or two through introduction. National Horticultural Research and Development Foundation (NHRDF) has been at the forefront of garlic research (with maximum number of varieties developed under their research programmes), followed by agricultural universities, viz., Gujarat Agricultural University (GAU), Punjab Agricultural University (PAU), MPKV, Rahuri, etc.

Later on, ICAR-Directorate of Onion and Garlic Research, NHRDF and State Agricultural University started working and few more varieties have been developed under All India Network Research Project on Onion and Garlic. Yield potential of all these varieties is in typical range and percent increase over check varieties is not crossing due to clonal selection. Clonal propagation method in garlic limits use in application of conventional breeding method through crossing. Except few accessions from place of origin of garlic all are exclusively clonally propagated. In India, two long day type accessions are showing flowering where pollens are sterile in nature. Hence, there is urgent need to study on restoration of fertility in flowering garlic and induce flowering in other types of garlic for varietal improvement. The environmental conditions might be allowed for fertility restoration and seed production in bolting type of garlic. 32 garlic genotypes were assessed for bolting behavior using molecular marker and find 10 bolting accessions which further can be used for imposing environmental manipulation artificially for flowering study. On diverting the nutrients from developing bulbils including their manual removal at early bolting and at initiation of flower-bulbils differentiation and sexual seed development in garlic. Garlic under long day photoperiod (14-16 hrs.) bolts and produces aerial true to type bulbils. Further reports are available that a long photoperiodic requirement of these genotypes was evident from the non-flowering of same garlic varieties under northern parts of India during April-July with 13 hours photoperiod. The scientists of different institutes including ICAR-DOGR have now started induce the genetic variability through irradiation treatment, mutagens and *in vitro* somaclone development. Some promising lines were studied for variability and stability also assessed the chemical mutagens for plant growth and yield characteristics in garlic variety.

The germplasm collections at the NHRDF were considerably augmented by introducing 475 accessions from exotic and indigenous sources in garlic. The significant progress has taken place during the past three and half decades in development of ten high yielding varieties. During the course of evaluation/investigation/study of germplasm several genotypes selected for further recommendation for varieties development and also several technologies developed and demonstrated in farmers fields.

List of garlic varieties developed by different organization in India:

MPKV, Rahuri: Godawari (P), Sweta (W), Phule Baswant (P);

IARI, New Delhi: Pusa Sel – 10;

HAU, Hissar: HG 1 (W), HG 2 (W);

NHRDF, Nasik: Short day - G-1 (W), G-41 (W), G-50 (W), G-189 (W), G-282 (W), G-323 (W), G-384 (W), G-386; Long day- G-313 (P), G-404 (W), W-408 (W);

VPKAS, Almora: Long day- VLG 1 (W), VGP-5 (W), VL-6 (W), VL-7 (W); ARU, Almora: ARU 52 (W);

PAU, Ludhiana: Punjab Garlic –1, Garlic 56-4 (W);

GAU, Gujarat: GG-1 (W), GG-2 (W), GG-10 (W);

ICAR-DOGR, Rajgurunagar: Bhima Omkar (W), Bhima Purple (P);

TNAU, Coimbatore: Ooty 1 (W); DARL: Long day- DARL 52 (W);

BAU, Sabour: RAUG-5 (W);

ICAR-CITH, Srinagar: CITH-G-1 (P), CITH-G-2 (P), CITH-G-3 (W),

(W= White coloured bulb, P= Pink coloured bulbs)

Although much varieties were released in India developed by different organizations, price of garlic goes up in market from Oct to Feb. Here in overall India garlic has been grown in *rabi* season, hence there is need to start offseason planting of garlic. Since last four years an attempt of evaluation of garlic genotypes during *kharif* season has been started at ICAR-DOGR and few adaptable accessions recorded potential yield during *kharif* season.

b. Biotechnological approach for garlic improvement: For species like garlic which do not undergo normal cross fertilization, *in vitro* tissue culture techniques open up the possibility of genetic modification and perhaps genetic interchange. It can be exploited for production of virus free garlic production as well as for creating variability. ICAR-DOGR has developed and standardized a protocol for regeneration of plantlet through callus using root tip as an explant. Further this regenerating callus has been imposed to mutagenic treatments viz. colchicine, oryzaline and sodium azide etc. for creating variability. This standardized protocol will be used for developing transgenic in garlic. Molecular diversity in garlic was studied for cross transferability of onion microsatellite markers and detected variation in garlic ecotypes. Other researcher also assessed variation in garlic genotypes using molecular markers like RAPD marker etc.

Processing in garlic

Garlic is mainly processed in the form of dehydrated products for use in curries and soup powders. Dehydrated garlic is also used in the pharmaceutical preparation like garlic capsules and tablets. Pickles and garlic paste are other processed forms of garlic which are gaining popularity. Garlic oil, garlic juice, garlic paste are other processed forms of garlic which are widely used by the food industry. Garlic is also processed in the form of garlic in brine, garlic juice, garlic paste, crush and garlic salt. Garlic oleoresin is also extracted which is a dark viscous liquid, having 12 times the flavor of dehydrated garlic and 50 times that of fresh garlic cloves. Garlic paste is formulated from garlic suitable for flavors and viscous edible base. Garlic salt is also prepared which comprised of a free flowing, uniformly blended dry mixture of non-iodized salt. Garlic salt has recorded much wider culinary potential than powder. The studies on the nutritional composition of garlic are taken up by NHRDF so as to use the variety for specific requirement including processing. The technologies for odorless garlic powder, garlic paste, garlic crush, garlic oil and garlic oleoresin as well as several other processed products have been developed by CFTRI.

Garlic oil is recovered by steam distillation of freshly ground cloves. It is a reddish brown over powdering liquid. One gram of oil is equivalent in flavoring terms to 900 g fresh garlic or 200 g dehydrated garlic powder. The high pungency of garlic oil makes it difficult to use directly. The oil is commonly diluted in vegetable oil. It is being used in ice-cream, ices, confectionary, baked goods, chewing gum and condiments. The rates of 6 ppm in baked products, 0.01–0.3 ppm in beverages, 16 ppm in condiments, 12 ppm in chewing gums, 12.9 ppm in confectionery and 40 ppm in ice cream are being used. The studies are taken by NHRDF for screening of varieties and collection of garlic for dehydration qualities. The garlic variety Yamuna Safed-5 and Yamuna Safed-4 having bigger cloves, bulb size, higher yield potential have been found suitable for dehydration.

Post-Harvest management and storage in Garlic:

The storage losses are mostly depending upon the pre- and post-harvest practices followed during the production of garlic. The important recommendations on post-harvest studies conducted by different institutes are as Ghawade*et al*. during 2011 reported that total storage loss in garlic was significantly lower in the bulbs stored by hanging method than the bulbs kept in polythene, netted and hessian bags. Nair *et al*., during 2013 reported that irradiation with 2-6 krad of cobalt 60 gamma rays have been recommended for controlling sprouting in storage. He further reported that pre-harvest spraying with 0.1% Carbendazim in standing garlic crop and disinfection of premises for handling and storage of garlic also reduced the post-harvest losses particularly decay. Lowest storage loss was recorded in garlic variety Agrifound White if stored without tops in nylon netted bags at Karnal and Nasik. The harvesting of garlic variety Yamuna Safed if done after 100% neck fall and field curing is done by windrow method significantly reduced the total loss in storage. (NHRDF Research, 1978-2010). The application of last irrigation before 10 days of harvesting and curing of garlic in field with foliage for 3 days along with 3 cm neck cutting reduced the losses at Karnal. (NHRDF Research, 1978-2010). Foliar application of Borax @ 500 ppm at 105 days after planting recorded lower losses in garlic variety Yamuna Safed-4 at Karnal (NHRDF Research, 1978-2015). In storage facility creation NHRDF has developed a naturally ventilated three tire garlic storage of 25 MT capacity wherein losses after six months were significantly reduced.

Approaches to Face the Challenges

For resolving major constraints in production of onion and garlic in major growing areas, a systematic approach will definitely help to achieve the goals. Considering the aspects of natural resource degradation, climate change and associated stresses, world trade and markets, IP regimes and human resource needs, though various technologies and varieties are available but still following aspects needs to be focused in systematic way to achieve challenges pertaining to onion & garlic in future as per details given below:

1. Genetic Resource Management and Crop Improvement

- Germplasm collection, evaluation, characterization and maintenance
- Development of high yielding varieties/hybrids in red and light red onion suitable for different seasons and export coupled with resistance to biotic and abiotic stresses
- Development of white onion varieties/hybrids for processing and desirable horticultural traits suitable for different seasons coupled with resistance to biotic and abiotic stresses
- Development of varieties/hybrids in yellow onion for export to European markets
- Development of varieties in Bangalore Rose onion and multiplier onion
- Development of big clove garlic varieties for short day conditions
- DNA fingerprinting of onion and garlic varieties
- *In vitro* screening for biotic and abiotic stresses
- Development of haploids and doubled haploids in onion for variety/inbred development programme
- Development of resistant varieties for diseases through biotechnological approaches
- Production of disease-free garlic through meristem tip culture
- Population structure and genetic differentiation in onion and garlic using molecular markers and next generation sequencing
- Development of linkage maps in onion for important horticultural and resistant traits
- Identification of genotypes to withstand climatic aberrations and genome probing for climate resilience
- Development of heat, drought and flood tolerant varieties

- Multiple diseases and pest tolerant onion and garlic cultivars
- Identification of non-heavy metal accumulating genotypes
- Allele mining for desirable traits
- Novel *Alliums* with enhanced functional values
- Metabolic profiling for mitigation of human diseases using *Alliums*
- Transgenics for herbicide andstress resistance

2. Crop Production and Physiology

- Basic physiological studies on adaptation of short day onion
- Studies on seed physiology for storage enhancement
- Productivity enhancement through integrated nutrient and water management
- Improvement of fertilizer nutrient use efficiency
- Organic production of onion and garlic
- Mechanization in onion and garlic production
- Year-round production technology for onion and garlic under changing global climate
- Sensor based input management practices in onion and garlic
- Quality seed production in view of climate change
- Good Agricultural Practices (GAP) for onion and garlic export
- Standardization of technology for garlic through true seed production
- Site specific nutrient management and yield targeting modules
- Geo-satellite/sensor based/intervention of drone for precision farming

3. Crop Protection

- Seasonal incidence studies on diseases and pest and development of forecasting models
- Integrated pest and disease management
- Collection and characterization of isolates of different onion and garlic diseases
- Antagonism studies in controlling diseases of onion and garlic
- Development of high throughput and robust diagnostics for detection of onion and garlic pathogens
- Host pathogen interaction studies in onion particularly in case of *Alterneria, Stemphylium* and Iris Yellow Spot Virus (IYSV)
- Utilization of Pathogen Derived Resistance (PDR) for the development of major fungal and viral disease resistance in onion
- Impact assessment of minor and emerging diseases, viz., White tip, Powdery Mildew, Downy Mildew and Botrytis Blight
- Exploration of nano molecules for pathogen probing and management
- Micro array based multiple pathogen detection system
- Exploitation of virus Induced gene silencing for management of virus diseases
- Identification of virus promoters for transgene expression
- Development of ultra virulent strains of insect pathogens through genetic manipulation for efficient management
- Development of sensor based personal digital assistance (PDA) system for assessment of damage due to insect pest and diseases
- Use of drones for monitoring and pest and disease management

4. Postharvest Management

- Standardization of pre and post-harvest practices for enhancement of storage life of onion and garlic
- Improvement in storage structures
- Standardization of techniques for grading and packing for domestic as well as export market
- Standardization of pre-cooling technology and establishment of cool chain for export
- Solid waste management technology to use onion and garlic waste

- Standardization of preliminary processing techniques in onion and garlic for cottage industries
- Controlled Atmosphere Storage (CAS) technology
- **Processed products with functional food and nutraceutical values**

5. Transfer of Technology

- Collection, documentation and validation of ITKs in production and post-harvest management of onion and garlic
- Impact analysis of DOGR developed technologies on socio-economic status of onion and garlic growers
- Identification of socio-economic, operational and institutional constraints in transfer of technology
- Frontline demonstrations
- 'On farm' research and village adoption
- Farmers participatory research for technology generation

6. Seed Technology

- Enhancement of seed yield through physiological and agronomic intervention
- Seed quality enhancement through seed treatments
- Development of nano-molecule based trait specific technology for acquisition of desirable traits
- Aeroponics for production of pathogen free planting material

7. Information Technology

- Collection and documentation of information from primary and secondary sources on all aspects of research, development, market and trade
- Development of appropriate information retrieval system
- Development of linkages with other national and international agencies for sharing information
- Human Resource Development
- Development of research skills through training/advance studies inside country and overseas
- Visiting scientists exchange programme
- Trainer's training programme

Conclusion

Climate change is global, but its impact and extent vary in different region and crops. There is an urgent need to take up suitable possible measures to cope with the challenges due to climate change in future. One of the strategies is to screen the onion germplasm under hot spot areas or simulate within climate change condition and to identify photo and thermo neutral genotypes which can sustain climate change for year-round supply. Production technology also plays major role in sustaining onion production, but now focus on research shall be to standardize the technology to face the climate change by manipulating irrigation, fertigation, crop geometry, identification of suitable anti-transparents during drought or high temperature. Critical stages affected by changing climate and various factors are required to be studied systematically. Focus shall be towards development of technology for precision farming in onion bulb as well as seed crop. Systematic studies are required on impact of climate change on insurgence for development of new pest and disease including the effect on existing one along with development of management practices. There is a need to develop area specific intelligent forecasting modular with farmer friendly management strategies. In view of the potential impact of climate change on onion production, a critical analysis, planning, management and precise knowledge of most erratic abiotic climatic factor in a given ecosystem is highly essential. There should be area specific intelligent forecasting modular in advance with farmer friendly management strategies. Innovative methods are needed to be developed for making simulation models for onion crop and must be validated in different agro-climatic zones. Thus, various improved adaptation strategies and mitigation technologies could be worked out and farmers awareness will successfully help in overcoming this environmental disaster and thereby saving crop.

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Diversification of Alliums in View of Present Climatic Conditions in India

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Alliums are among the cultivated plant species under family Alliaceae cultivated for food, medicines and religious purpose since early times. Onion (*Allium cepa* L.) is one of the oldest cultivated species, and it has been in use as a food source for over 5000 years (Jones 1983). These crops are mostly strong flavoured due to presence of sulphur containing compounds responsible for distinctive smell and pungency (Robinowitch and Currah, 2002).

Adoption of onion in India is carried through from very early times before Christian era. Originally, native of Central Asia of temperate region with perennial/ biennial habit and long day bulbing characters, it has established well in India under tropical and short day (11-11.5 hrs.) photoperiodic conditions. During acclimatization of different kinds of vegetable crops and their varieties, farmers applied selection pressure involuntarily to meet the market preferences. In case of onion, ability to produce seeds indigenously has played an important role in the adaptation. In course of adaptation and diversification, out breeding mechanisms present in onion has promoted selections suited to diverse environments. In the centre of origin and area between35 to 40^{0}N latitude, onion is biennial in seed production and requires more than 14 hrs day lengths for bulb production. In subtropical and tropical parts of India between 12 to 25^{0}N latitude, it is biennial but able to produce bulbs under comparatively shorter photoperiod (11-11.5 hrs.) during winter season. Winter season crop accounts for about 50-60 per cent of total production in the country. The concentration of onion growing in Western Maharashtra and Gujarat is very significant, where two crops – one in rainy season (*kharif*) and other in winter season (*rabi*) – are regularly grown. The tropicalization progresses further southwards towards Bellary region in Northern Karnataka and finally a vegetatively propagated multiplier onion (aggregatum) type got established in Tamil Nadu (6 – 8 ^{0}N latitude). The adoption to hardy conditions of high rainfall, high temperature and short-day photoperiod typical of rainy (*kharif*) season of Western India has not been chronologically documented (Sheshadri & Chaterjee, 1996).

Export trade from Mumbai and Kandla port mainly to Gulf countries predominantly during November to April coincides with harvest of rainy seasons (*kharif*) and late rainy seasons (*Rangda*) crops. This market forces have influenced domestication and diversification to great extend. Demand for highly pungent and pink skinned bulbs from Gulf countries made farmers of Western India to select such type of plants, which can produce seeds under Indian conditions. This kind of adaptations made the crop plant to become annual. This phenomenon resulted in loss of short dormancy of bulbs. This fascinating aspect of onion domestication in Western India had gone unnoticed and unrecorded (Sheshadri and Chaterjee, 1996). Among the cultivated species of *Allium*, onion (*A. cepa* L.), leek (*A. porrum* L.), shallot (*A. ascalonicum* L.) and chives (*A. schoenoprasum* L.) are well known vegetable crops grown in different part of India (Wealth of India 1985; Pandey *et al.,*2005a).

Need for develeopment of varieties in India for diversification

So many varieties were developed in India but restricted to rabi season and only yield only. New areas like North Easter Hills are untouched. There is

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need to diversify onion cultivation in kharif season to different states. Techenologies were standardized by ICAR-DOGR for kharif production and being adopted by the farmers of Maharashtra and to some extent in MP, Karnataka and Gujarat. Now varieties for kharif and late kharif cultivation is also developed after evaluation in different parts of the country. Red onion variety Bhima Super, Bhima Red, Bhima Dark Red, Bhima Raj and white onion variety Bhima Shubhra, Bhima Shweta and Bhima Safed are recently developed by ICAR-DOGR and notified by central varietal committee have wider adoptability. Other varieties developed earlier are Basvant-780, Agrifound Dark Red, Arka Kalyan. Hence, there is need to diversify cultivation of kharif onion in large scale in states like UttarPradesh, Orrisa, Bihar, North Easter Hill region, Chhattisgarh, Andhra Pradesh where there is great potential. It will help for year-round availability of onion in the market and will regulate onion prices. Looking to its diverfication there is need to concentrate on breeding programme for various objectives.

Breeding for seasonal adaptability

Onion in India is planted between 12 to 25^0 N latitude during following seasons Mahajan & Lawande (2008a). But in some of the states it is restricted mainly to rabi season.

Kharif crop is grown during hot and humid months and ready for harvest when temperatures are low. The bulbs do not become mature as growth continues due to shorter days and cooler temperature. The bulbs of Kharif season do not have good storability. Recently due to late monsoon or irregularities of rain in Kharif season there has been shift in planting from Kharif to late Kharif. Availability of irrigation water from September to February, failure of Kharif crop due to high rainfall coupled with high incidence of diseases and pest and poor storage of kharif produce, farmers in Western Maharashtra are inclining towards late Kharif crop commonly called as Rangda onion. Seedlings are transplanted in September-October and bulbs are ready for harvest in January-February. Low temperature during November -December favours bulb initiation and good development. Warm days during January-February facilitate maturity, as the day length available is again 11-11.5 hrs. The yields are high with good bulb size but percentage of bolting and twins is very high and therefore reduce marketable yield. Still there is need to intensify research work in India for different location for late kharif season for early arrivals in market (Mahajan & Lawande, 2008a).

Staggered planting in different seasons warrantee for steady supply of onion in the country. Unfortunately, there is limited Varietal wealth for Kharif and late Kharif season. Early maturity, dark red colour and resistance to colletotrichum and purple blotch is the need of Kharif season. High percentages of bolting and poor storage are the limited factors particularly during late kharif and work on development on bolting tolerant lines is in progress at ICAR-DOGR..

Seasons in different state for diversifying onion cultivation

Sr.No.	Season	Time of Sowing	Time ofTransplanting	Time of Harvesting
A.	Maharashtra and some parts of Gujarat			
	1. Kharif	May-June	July-August	October-December
	2. Early rabi or late Kharif	August-Sept.	Sept.-October	January-March
	3. Rabi	Nov.-Dec.	Dec.- first week of January	April-June
B.	Tamil Nadu, Karnataka and Andhra Pradesh			
	1. Early Kharif	April-May	May-June	August
	2. Kharif	May-June	July-August	October-Nov.
	3. Rabi	Sept.-Oct.	Nov.-Dec.	March-April
C.	Rajasthan, U.P., Haryana, Bihar, Punjab, West Bengal and Orissa			
	1.Kharif	May-June	July-August	Nov.-December
	2.Rabi	Oct.-Nov.	Dec.-January	May-June
D.	Hills			
	1. Rabi	Sept.-Oct.	Oct.-Nov.	June-July
	2. Summer (long day type)	Nov.-Dec.	Feb.-March	August-October

Breeding for Processing Qualities:

Dehydrated products such as flakes, rings, granules, powder etc. and processed onion as onion in vinegar and brine are the important byproducts being prepared and marketed world wide and have great scope to diversify the crop. Processing industries in any commodity play an important role in stabilizing prices in domestic markets. Dehydration industries demand for white onion varieties with globose shape pf bulb and high TSS (>18%). All Indian white onion genotypes are having TSS range between 11-13%. Model variety for dehydration should be pure white, with globose shape, thin neck, free from greening and moulds, high pungency and high T.S.S. The variety should be high yielding with field tolerance/resistance to diseases and pests. Wider seasonal adaptability is also an important character from continuous supply point of view. T.S.S. and pungency is a function of genotype, cultural practices and environment. Indian varieties are short day type mature within 90-120 days. They are basically low T.S.S. varieties. The T.S.S. varies from 10 to 14% in Indian material. Some of the long day varieties which mature within 150-180 days offer high T.S.S. range from 15 to 24%. But long day varieties do-not produce bulbs under Indian short-day conditions. However, intermediate short day varieties produce good bulbs but seed production is not possible under plains. In plains of India varieties mature in high temperature, which facilitates high sulphur built up and therefore Indian varieties are more pungent. In India attempts were made for development of white onion varieties by different research institutes (Mahajan & Lawande, 2011). After assessing Indian varieties and land races which do-not offer T.S.S. range more than 12 per cent. Jain Food Park Industries, Jalgaon introduced White Creole, which further subjected to selection pressure, for high T.S.S. character and developed V-12 variety with T.S.S. range from 15-18%. This variety is under contract production for processing but seed production is not possible under Indian plains.

Since, establishment of NRC for Onion and Garlic in 1998 at Rajgurunagar (now ICAR-DOGR), a special programme for development of high T.S.S. white onion variety was launched through selfing and massing from available germplasm. In the year 2000 about 7199 bulbs were examined for T.S.S. range. Only 2.72% bulbs recorded T.S.S. more than 14 per cent. 109 bulbs offering T.S.S. range from 15 to 23% were selfed and populations were developed. After rejecting poor performing populations, 30 populations having 16 to 19% T.S.S. are advanced. In 6th generation of selection cycle we are able to achieve more than 85% bulbs having average TSS about 18% or even more in about 15 populations in short day onion. It would be possible to develop high T.S.S. open pollinated varieties suitable for *rabi* and late *kharif* seasons (Mahajan & Lawande, 2011).

Diversification of Onion through export of quality onion:

India is number one in export of onion followed by Netherlands. India's export is mostly to South East Asian and Gulf countries. Dark red and light red onions with globe shape are mostly preferred with various diameter sizes. The present practice of export is grading and packing from the total bulk arriving in various onion markets. Uniformity is shape size and colour is seldom attained, as there no systematic control over planting of required varieties. Further, there is lack in varieties, which can suit to exclusive markets. European markets require yellow or brown onion with big size. There are hardly any indigenous varieties, which can meet to these standards. NRCOG has initiated work in this direction and recommended Mercedes, Linda Vista, Cougre and Collina from exotic material for growing in late Kharif season. There is need for development of varieties in dark red and light red colour exclusively for export markets. Breeding work using long day and intermediate day exotic varieties with aim to transfer desirable characters in short day onion varieties is undertaken by this Directorate in collaboration with CITH Srinagar. Crosses were made and further selections for desirable characters were done which is further followed by mass selection (Mahajan & Lawande, 2011).

Diversification through breeding and cultivation of for yellow onion:

Indians do not prefer yellow onion but these find international market in European. Minimum requirements for export are: bigger sized (>60 mm diameter), less pungent and single-centered types. As is evident, most work has been done in European countries and USA whereas, in India, research on onion has not been of any great significance. Very little work has been done in India for development of yellow onion varieties, particularly for export. Only two varieties were developed, viz., Phule Swarna from MPKV, Rahuri and Arka Pitambar from IIHR, Bangalore and were released at the state / institute level. Yield of these varieties was comparatively less than in commercial red onion varieties and bulb size is also not upto the mark. Hence, with systematic breeding programme varieties for cultivation under short day plains as well as special focus for hills of north India can be good option for diversifying onion cultivation and its export to European countries where ther is graet demand. ICAR-DOGR conducted trials with intermediate type yellow exotic onion and recommended Mercedes, Linda Vista, Couger and Collina yellow onion for cultivation during late kharif and rabi where yield potentioal of these onions are upto 80 tons/ha. Farmers of Alephata, near Pune cultivated on lagre scale and exported to Germany. This shows great scope of diversification of yellow onion.

Varietal development with special reference to climate change for diverdificatio:

Climate change due to global warming and pollution has become major concern to the crop scientists and how to address this and prepare for is an important issue. Effect on total ecology and subsequently on certain important commodities is really not being studied. Onion and garlic are no bar to this shortcoming. No systematic studies are done in this regard. However, visible effect on distribution of rainfall has been noticed, which had exercised effect on increasing disease and pest in *Kharif* onion. *Kharif* onion is a very sensitive and crucial crop in meeting domestic supply from October to January. Failure of *Kharif* crop leads to hike in prices. Sudden rise in temperature in *rabi* season during December-January result in poor bulb initiation and bulb development of *rabi* onion and garlic. Dry weather with high temperature favours incidence of thrips and mites on this crop. Very high temperatures in March-April-May lead to reducing keeping quality of onion and garlic bulbs. Detailed studies under simulated conditions of weather parameters need to be initiated for understanding critical impact of climate change on different crops. Work on development of photo and thermo insensitive varieties is undertaken at Directorate of Onion and Garlic Research, Rajgurunagar to tackle the changing climatic situations. Some of the germplasms were found promising and can be grown in all the three seasons *viz*., *Kharif*, late *Kharif* and Rabi seasons is being exploited for such situations.

Though onion is biannual in nature, extremely cross-pollinated crop, shows inbreeding depression, have less storage life of seed etc. But looking to the methods exploited in onion improvement in the world, there is lot of scope for population improvement in India also in following areas but one has to work with patience. There is need for identification of areas where off season seed can be produced or to standardize techniques of seed production during kharif season to reduce the time of breeding from biannual to annual particularly for late kharif and rabi season varieties. Some of the reports are available where efforts were made to produce seed during kharif season which was successful (Mahajan et al., 2002) and can be exploited for population improvement for rabi and late kharif onion varieties. There is need to develop 1. Varieties for different seasons, 2. Varieties for biotic and abiotic stress, 3. Varieties for processing, 4. Varieties for green foliage, 5. Varieties for export quality, 6. Varieties for mechanized farming for large as well as small farmers 7. Varieties for better keeping quality, 8. Varieties according to consumers demand, 9. Varieties for organic cultivation, 10. Varieties for set planting and 10. Varieties to face Climate Change.

Diversification as food through *Allium* species

Field surveys and exploratory studies have confirmed to utilization of wild *Allium* species in the Garhwal and Kumaon regions of Himalaya for edible purposes (Negi and Gaur 1991). Generally, all plant parts have edible value and consumed raw or as cooked vegetables. Young leaves of many wild species are preferred over the mature ones in the form of vegetable, in soups or for raw consumption given in following table. Freshly harvested leaves or bulbs are occasionally sold in village markets. The leaves and tuberous/fibrous roots are rich in carbohydrates, vitamins and minerals. Bulb/pseudostem of *A. clarkei*, *A. griffithianum*, *A. pratii* and *A. victorialis* are consumed raw, cooked or pickled. Cloves or bulbs of *A. ampeloprasum* and *A. chinense* are pickled. In Pithoragarh region of

Uttarakhand Himalaya, India, young leaves of *A. stracheyi* are used as potherb or cooked mixed with potato. Fleshy fibrous roots of *A. hookeri* are consumed as vegetable in the north-eastern hill region or in soups and pickles in same way as *A. stracheyi* in the north-western Himalaya. In Bhutan, *A. fasciculatum* is generally used as vegetable (leaves and scape), salad and in soups (young inflorescence).

Several lesser-known wild species of *Allium* as given in following table were reported from the north-western Himalayan region of India (Gohil 1992; Negi and Pant 1992; Sharma *et al*. 1996).

Distribution of wild *Allium* species in Indian gene centre, status of occurrence

Species	Distribution; status of occurrence	Wild (W); occasionally cultivated (OC)
Allium ampeloprasum L. var. *ampeloprasum* L.	Western Himalaya; C	W; OC (vegetable, pickle, condiment)
Allium atropurpureum Waldst. et Kit.	Western Himalaya; C	W
Allium atrosanguineum Schrenk	Western Himalaya (Kashmir); C	W
Allium auriculatum Kunth*	Western Himalaya (Kumaon); LC	W; OC (condiment)
Allium caesium Schrenk	Lahaul, Himachal Pradesh; LC	W
Allium carolinianum DC.* (*A. thomsonii* Baker)	Western Himalaya; C	W; OC (condiment)
Allium chinense G. Don*	North-eastern Himalayan region (Khasi hills); C	W; OC (vegetable, pickle, condiment) (high seed sterility)
Allium clarkei Hk. f.*	Uttarakhand (Kashmir) Himalaya; rare species	W
Allium consanguineum Kunth*	Western (Kashmir) and central Himalaya; C	W; OC (minor cultivated species grown for vegetables and condiment in eastern Himalaya)
Allium fasciculatum Rendle	Indian Himalaya, Tibet, Nepal; LC	W
Allium fedschenkoanum Regel	Western Himalaya (Kashmir); rare species	W
Allium griffithianum Boiss.*	Western Himalaya; C	W; OC (condiment)
Allium hookeri Thw.*	North-eastern Himalaya (Khasi hills); sporadic in upper gengetic plains; C	W
Allium humile Kunth*	Western Himalaya; C; endemic species	W; OC (condiment)
Allium longistylum Baker	Western Himalaya; LC	W
Allium loratum Baker	Western Himalaya, Tibet; rare species	W
Allium macranthum Baker	Bhutan and adjoining region; LC	W
Allium odorum L.	Western Nepal, West Tibet; LC	W
Allium oreoprasum Schrenk	Ladak Himalaya; LC	W
Allium platyspathum Schrenk	Western Tibet; LC	W
Allium prattii Wight	West Nepal and adjoining Himalaya; rare species/ sporadic in distribution	W
Allium przewalskianum Regel*	Western Himalaya; C	W; OC (vegetable, condiment)
Allium roylei Stearn* (*A. lilacinum* Royle)	Western Himalaya; rare species	W; OC (condiment)
Allium schoenoprasum L.	Western Himalaya (Kashmir, Drass); C	W; OC (vegetable, salad, condiment)
Allium schrenkii Regel	Himalayan mountains to Siberia; LC	W
Allium semenovii Regel	Western Himalaya, Kashmir to Uttarakhand, Himachal Pradesh, Zanskar; C	W
Allium sikkimense Baker	Ladak, Sikkim Himalaya, Tibet; C	W
Allium stracheyi Baker*	Western Himalaya (Kashmir-Kumaon); narrow endemic species, rare/threatened species	W; OC (vegetable, condiment; recorded in the Red Data Book of Indian Plants)
Allium tuberosum Rottl. ex Spreng.	Widely distributed in Himalaya; C	W; OC (vegetable, condiment)
Allium victorialis L.	Temperate Himalaya; C	W
Allium wallichii Kunth	Eastern part of Western Himalaya; C; endemic species	W; OC (vegetable, condiment)

* Commercially important species; C, common; LC, less common; SGB, seed genebank; FGB, field genebank; IV, in vitro repository

There is lot of scope to evaluate systematically for yield and nutritional value and other desirable traits which can be directly used for commercial cultivation and also can be used in breeding programme for widening the genetic basse of the cultivated onion. These above-mentioned Allium species are restricted to kitchen garder in Northern Hill region with the tribal population, have great potential for its meditional use and direct consumption (Mahajan et al. 2016a). These can be substitute to common onion and diversified for year-round availability and will help in regulating the market price. Some of the under utilized and wild *Allium* species viz. *A. ampeloprasum, A. tuberosum, A. chinense, A. ascalonicum, A. hookeri* and *A. cepa. var. aggregatum* collected from different parts of Himalayan ranges are being multiplied and evaluated for utilization as foliage consumption at ICAR-DOGR Rajgurunagar, Pune. Among nile lines evaluated foliage yield of 22.89 t/ha was recorded in *A. tuberosum* All-1587 followed by 20.21 t/ha in *A. tuberosum* CGN-16373 during rainy season at 30 days interval. During summer maximum yield was 19.25 t/ha in *A. tuberosum* All-1587 followed by 19.12 t/ha in *A. tuberosum* line CGN-20779 and 18.75 t/ha in *A. tuberosum* line CGN-16373 at 30 days interval. During winter, maximum yield of 18.16 t/ha was in *A. tuberosum* line CGN-16373 followed by 17.13 t/ha in *A. tuberosum* line CGN-16418 and 15.77 t/ha in *A. tuberosum* line All-1587 at 30 days interval. The added advantage of these species is that only once it has to be planted, gives number of tillers and can take foliate cuttings at every 15 to 30 days interval under plains of India (Mahajan et al. 2016b).

Diversification of Allium species as Condiment/flavor:

Although all *Allium* species have different aroma (strongly pungent to mildly aromatic) and flavour (onion or garlic like odour) but selective use of the species/plant part is based on utilization and preference by local communities. Young leaves and bulbs of *A. humile*, *A. carolinianum* and *A. loratum* have garlic flavour and are used to garnish different food preparations. Similarly, *A. stracheyi*, *A. roylei* and *A. tuberosum* have mild onion flavour and widely used as flavouring agent and for garnishing purpose. For routine domestic use fresh leaves and bulbs are commonly used whereas for off-season requirement, leaves are generally dried and processed for long-term. In Kumaon region of Uttarakhand (Western Himalaya), dried leaves of *A. stracheyi* (jumbo) are primarily used for garnishing or seasoning vegetable/curries (Negi and Gaur 1991). In areas of abundant availability of these species, Bhotia tribals collect and process (dry) and bring marketable produce for sale at the lower elevations (Chaurasia and Singh 1996–2001; Sanyal *et al.*, 2000). Bulbs of *A. consanguineum* and leaves and flowers of *A. chinense* are commonly used as flavours in various food preparations such as soups, curries, etc.

Diversification for Medicinal use:

Medicinal use varied from domestic/local usage to commercialization. Some wild *Allium* as *A. humile*, *A. carolinianum* and *A. przewalskianum* are collected on large scale and traded to drug and trade industries in Himachal Pradesh (Chauhan 1999). Dried scales of *A. wallichii* are locally used for pectoral complaints; cloves of *A. ampeloprasum* are utilized after dipping in mustard oil for paralytic limb, ear pain and arthritis; bulbs of *A. wallichii* are used for anti-flatulence and digestive disorders and leaves of *A. griffithianum* and *A. tuberosum* as carminative agents. Information was collected about current medical applications of sixteen wild species, nine of which belong to different sections of *Allium* subgenus *Melanocrommyum* from Tajikistan and Uzbekistan region by Keusgen *et al., 2006.* These plants are used against headache, cold, and stomach problems, and are mostly applied fresh or after boiling. Three wild *Allium* species growing in Tajikistan and Uzbekistan (*A. oschaninii*, *A. pskemense*, *A. praemixtum*) are closely related to common onion are traditionally collected and used as spice like common onion, but only *A. oschaninii* and *A. pskemense* are also used for medicinal purpose. Special dishes, which are much esteemed for strong tonic properties, are prepared from the leaves of three species of the subgenus *Melanocrommyum: A. motor*, *A. rosenbachianum*, and *A. rosenorum*.

Diversification as Potential ornamentals

Use of *Allium* species for ornamental purposes is not very common in India. *Allium* species have gained much popularity as ornamental in rock gardens, herbaceous beds, perennial borders, pot plant, as decorative items and in dry arrangements (Davies 1992; Kamenetsky and Fritsch 2002).

Ornamental value of *Allium* is due to wide range of attractive coloured flowers and persistence of floral or long vegetative cycle. Flower colour in wild *Allium* ranges from white, rose, lilac, purple, violet, blue and yellow. Some wild species of *Allium* have been identified for their potential ornamental values are as follows.

Wild ornamental *Allium* species in India

Species	Ornamental use
Allium ampeloprasum	Herbaceous bed, cut flower
Allium atropurpureum	Herbaceous bed, border, cut flower
Allium caesium	Borders of gardens, rock garden
Allium macranthum	Border and cool spots
Allium oreoprasum	Rock garden, herbaceous bed
Allium przewalskianum	Rock gardens, flower beds
Allium roylei	Border, flower bed
Allium schoenoprasum	Pot plant, rock garden, herbaceous bed, border, cut flower
Allium semenovii	Herbaceous bed, damp soil, cut flowers
Allium sikkimense	Border, herb bed, cut flowers
Allium tuberosum	Herbaceous bed, border, pot plant
Allium victorialis	Herbaceous bed, damp soil

Commercial wild species

Many wild species of *Allium* (11 species) have their commercial value for food, flavour and medicine from natural population or grown on the small scale in homegardens. In recent years processed products in the form of dried bulbs, leaves, buds and flowers of some wild species of *Allium* (*A. auriculatum*, *A. carolinianum*, *A. griffithianum*, *A. humile*, *A. roylei* and *A. wallichii*) are in great demand and thus these species are occasionally grown in the homegardens. Sun dried/furnaces dried leaf powder has good shelf-life for off-season consumption (Negi 2006a, b) and for sale in the market. Market products are also available in refined forms as processed bricks/cakes or balls, sold in border areas of Himachal Pradesh, Uttarakhand and adjoining regions. Crushed foliage of *A. przewalskianum* prepared as balls and put in string were reportedly sold in market in cold desert region of India (Baker 1874). The dried leaves of different species are sold at the rate of Rs. 150–250 per kg (approximately 3.5–4.0 US Dollars) (Negi 2006a). Ornamental value of wild species in India is yet to be explored for Indian market. Pandey *et al*. (2008), suggested that the genetic resources of *Allium* species representing wild useful/commercial taxa offer great scope for utilization in crop improvement programmes. The genepool needs to be assembled from areas of occurrence and evaluated for biotic and abiotic traits so as to realize their value in National and International programmes. Research and development efforts need to be focus towards management of wild *Allium* species. Evaluation of the decorative characters of wild/potential species is desirable for their commercial ornamental use. Suitable strategies for conservation, assessment of domestication potential for commercialization and value addition would widen the scope of utilization of wild *Allium* species in India. In India onion Allium cepa & garlic Allium sativum is widely cultivated but there are other Allium species like Japanese bunching onion (*A. fistulosum* L.), leek (*A. ampeloprasum porrum* L.), A. tuberousum, A. macaranthum, A. hookeri are restricted to Himalayan hill in small kitchen garden mostly used as condiments, and also have medicinal value have great scope to diversify its cultivation in different parts of the country.

Diversification through processing & processed products of onion and garlic

Onion is a perishable crop it cannot be stored for long period. Under all storage conditions, onion bulbs continually loose water and dry matter. Therefore, in order to overcome the above difficulties, the dehydration of onions came into existence. Onion is a unique vegetable that is used throughout the year in the form of salad or condiment or for the cooking with other vegetables. It is also used for making pickles in vinegar or brine. Its uses in soups and sauces are common. Onion powder is obtained from dehydrated onion bulbs. Dried onion flakes are also prepared. The main advantages of preparation of value-added products from alliums (Onion and garlic) are to increase the storage life of onion and also reduces the transportation cost and earn more foreign exchange. It is among one of the important factors for stabilizing prices in internal markets and thereby bringing sustainability in production of certain commodities. Onion and garlic offer very good scope for value addition in the form of dehydrated flakes, rings, powder, granules, paste, oils, juice and onion and garlic salts. Onion pickles in brine or acetic acid solution is a novel product popular in European markets. Among all these products, dehydrated flakes and powder of onion and garlic are important from export point of view. Major export is made to Spain, Germany, U.K., Netherlands, France, Poland, Australia, Israel, Japan, Nepal, Hongkong, Iran, Gulf countries etc. There is increasing demand for onion flakes and powder and steadily is being met with from India (Mahajan & Lawande, 2008b).

Dehydrated onion and garlic: Onions and garlic are widely used in dehydrated form. Being perishable crops huge losses occur in transport and also in storage. The transportation of onion is very expensive due to large space requirement and losses in storage are noticed up to 50%. To regulate the production and prices it is necessary to develop the dehydration industry in our country. Dehydrated onions are becoming a product of considerable importance in world food trade. The dehydrated onions are more uniform in flavour than fresh onions and also reduced the transportation costs during transit and avoidance of losses of bulbs in storage. Dehydrated onions are highly competitive commodity in the international market; a proper selection of suitable variety/hybrids of onion is very essential. Dehydrated products such as flakes, rings, granules, powder etc and processed onion in vinegar and brine are the important byproducts being prepared and marketed worldwide. Processing industries in any commodity play an important role in stabilizing prices in domestic markets. More and more dehydration units are coming up in Maharasthra and Gujarat. The onion dehydration units are facing problems of continuous year-round supply of white onions with high T.S.S. at reasonable prices. The present-day white onion varieties available in India offer T.S.S. range between 11-13 per cent. However, varieties with high T.S.S. (>18%) increase profit margin and reduce overheads of processing units. High T.S.S. genotypes available in long day types fail to bulb and flower under plains of India. Research support for development of high T.S.S. lines among Indian material is the need of the day. NRCOG has initiated programmes in this direction. A concrete production plan with contract farming approach needs to be developed by the processing units and farmers. The varieties of white onion at present such as Agrifound white –1, Phule Safed, Pusa White Flat, Pusa white Round, V-12 are being used for dehydration. To maintain the quality, the product is packed in cans, pouches or foil-laminated drums. The product may be used as such, converted in to powder, granules or flakes or used in the formulation of other products like coarse, ground, minced, chopped, chopped special, large and small chopped, kibbled, standard powder granulated, ground random chopped, sliced and dices, each of which may be produced in roasted and unroasted form. Dehydrated onion is used widely in sauces, soups, mayonnaise, salad dressing, sweet pickles and dog food etc.

Processing of garlic in the form of dehydrated cloves and powder is common. The erratic domestic production and supply has effect on processing and export of the same. Recently, onion+garlic+giner paste prepared cottage industries is becoming popular and has widened base of garlic and onion value addition. Further, processed garlic and onion are also being used by pharmaceutical companies for preparation of Aurvedic medicines. The Indian garlic varieties though low yielder, are more valued from processing point of view. The processing and pharmaceutical companies, research organizations and farmers need to consult at common forum for contract production of garlic for fresh export and value addition. Processed onion and garlic are in great demand for export. The current export is to the tune of 55000 tons. However, standing demand is three times more and there is need to fulfill world demand and capture world market. Besides other products are made but not commercialized in India except onion & garlic paste are onion and garlic oil, onion and garlic juices, onion - garlic pickles, solid flavouring, canned and bottled onions etc.

Diversifying through value addition and Marketing of Graded onions: The onion is graded in three grades i.e. A (60-80mm), B (50-60mm), C (35-50mm) grades according to their size if the bulbs. Only A and B bulbs should be kept in store. In India grading of onion is usually performed manually either before storage or before marketing. It is a cumbersome process and requires lot of labours. The grading with machine reduces the cost on labour charges and also increases precision. NRC onion & Garlic has developed manually and motorized graders for grading of onions. The manual grader also grades onions in five sizes and its efficiency is five times higher than manual grading. The accuracy of grading is 90 % as compared to 70% in manual grading. The cost of grading with machine is around Rs.26/ tones as compared to Rs.80/tones in manual grading. The motorized grader also grades onions in five sizes but the capacity of grading is 1.5 to 2.0 tons per hour, which is 20 times higher than manual grading. The accuracy of grading of onion by the grader is around 90% as compared to 60 % with manual grading. The grading charges would be around Rs. 15/ tone as compared to Rs. 80/ tone in manual grading.

Diversification through onion seed production: Quality seed is a basic requirement for successful cultivation. Presently, about 10000 tons of onion seed is required. Onion seed production is adversely affected due to hail storm and heavy rains at the time of flowering and seed setting stage. Seeing the availability position of seed of onion in organized sector and private seed companies, it is clear that around 60% seed is produced by the farmers without following any standards for isolation or varietal purity etc. The public sector regularly producing the seed in each and every year about 8 to 10% of total requirement. The exact quantity of onion seed shortage could not be assessed as the seed production is not being taken in organized manner in the country. In this way, inspite of the farmers and public sector seed production, there is 30% dependency on private seed sectors also. Onion seed production are being taken by some of the farmers to meet their requirement in all onion producing states, but the major commercial onion seed production states are Maharashtra, Karnataka, Gujarat, Rajasthan and Madhya Pradesh where 70 to 80% of the total quantity of the onion seeds are being produced. The onion seed production has also got affected due to less honey bee's activities at the time of flowering stage, which is essentially required for pollination. Moreover, sudden rise in the temperature at the time of seed setting also affected seed production. This can be diversified to developed as organized seed industry for availability of seed in India as well as export to other countries.

Diversification through intercropping: Sugarcane is an important cash cum industrial crop in India. It is being a long duration and widely spaced crop does not cover the vacant space between the rows up to 3-4 months. There is ample scope to grow one or two additional short duration intercrops. Now a days intercropping in sugarcane with vegetables are gaining importance among the farmers to get additional income during initial growing period and for effective use of all available resources. Onion and garlic are closely spaced crop with short stature, non-branching habit, sparse foliage, shallow root systems which do not compete with deep rooted long duration crops like sugarcane for nutrients and space. Hence, both the crops are best suited for intercrop with paired row planting of sugar cane (Nov.-Dec. Planting) under drip irrigation system. The field experiment was conducted at ICAR-DOGR to study the benefits of intercropping of onion in sugarcane. Sugarcane sets with the single bud were planted at 30 cm apart in the bottom of the ridges. After every two rows of sugar cane, flat bed of 180 cm was prepared for planting onion crop. Onion seedlings were planted at time of sugarcane planting. Additional fertilizer nutrients required for onion crop were calculated and applied as per requirement. Irrigation water was applied through drip irrigation system. Onion crop were harvested after 120 DAT (Days after transplanting). The results showed that inter crops did not affect sugarcane yield. In addition to 239 t/ha sugarcane yield, 42.95 t/ha onion yield were obtained (Tripathi and Lawande 2005).

Future thrust for diversification:

- Development of varieties suitable for long storage life in different seasons.
- Development of high TSS white onion varieties for dehydration along with year round availability for processing.
- Standardization of pre and post harvest practices for enhancement of storage life of onion and garlic.
- Improvement in storage structures.
- Standardization of techniques for grading and packing for domestic as well as export market.
- Standardization of processing techniques in onion and garlic for cottage industries.
- Popularization and expansion of Irradiation followed by cold storage technology for storage of onion & garlic.
- Development of new products in onion & garlic.
- Exploitation of underutilized or wild allium species as a subsitude of onion & garlic for year round supply.
- Populaization of onion cultivation in non traditional areas and off-season cultivation.

- Popularization through intercropping in widely spaced fruit orchards & other crops

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Strategic Approaches for Climate Resilient Production of Mushrooms

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The health challenges raised during the COVID-19 pandemic have sparked the quest for new super foods and revived the idea of nutritional immunology. Mushrooms being rich in vital nutrients, minerals and abundant bio-active compounds have attracted the immunity conscious consumers to build up the foundation of wellness by including mushrooms in their dietary plan (Annepu and Gupta *et al.,* 2021). In developing countries like India, where there is heavy dependence on cereal diets, mushrooms are one of the vegan friendly protein sources. They are also rich source of nutrients such as iron, vitamin B_{12} and vitamin D which are typically found in animal based food products. Among the possible direct medicinal value of mushrooms, the most important ones are anti-cancer, hypolipidemic, hypocholesterolemic and anti-hypertensive (Sharma and Annepu, 2018). The significant feature of mushroom cultivation is that it utilizes a wide range of agricultural waste material as growing substrate and converts the waste into a nutritious food. Mushroom farming created a revived opportunity in indoor agriculture and attracted the unemployed youth and new generation farmers to venture into its production across the country (Shirur and Sharma, 2016). Undoubtedly, mushrooms are the high value agriculture crop with the potential of augmenting income of small and marginal farmers. Mushroom cultivation is a strong means to diversify and strengthen the resilience of farmers.

Importance of mushrooms under climate change scenario

i. Recycling of agro-waste: India, the second largest agro-based economy with year-round crop cultivation, generates a large amount of agricultural waste, including crop residues. According to the Indian Ministry of New and Renewable Energy (MNRE), India generates on an average 500 Million tons (Mt here after) of crop residue per year. The same report shows that a majority of this crop residue is in fact used as fodder, fuel for other domestic and industrial purposes. However, there is still a surplus of 140 Mt out of which 92 Mt is burned each year. Specifically, India is the second largest producer of rice and wheat in the world, two crops that usually produce large volume of residue. Mushroom cultivation being an extended agricultural activity have the potential to utilize these agro residues in a sustainable way to produce the protein rich functional foods.

ii. **Mushroom as a component in vertical farming:** The demand for land by other sectors has led to reduction in the share of arable land to 52.80 % (2013) from 55.00 % in 1985. Coupled with increasing pressure of population, the per capita land availability in India has reduced from 0.34 ha in 1961 to 0.20 in 1985 and further down to 0.12 ha in 2013. The similar trend for few more years will put increasing pressure on land availability which can jeopardize the farmer's income levels. In this context, mushroom cultivation assumes special significance as it is least dependent on land area and produce maximum quality protein per unit area utilizing the vertical space.

iii. **Zero waste farming:** There are more and more agro-wastes are generated in the present agriculture scenario, but only negligible amount of those are recycled. Mounting of agricultural residues and black carbon emission from the

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burning of these residues are threatening the public health. An effective approach to manage these mounting agro-wastes is growing mushrooms on waste residues. This is regarded as an environmental friendly solution with potential economic benefit. Mushroom growing is a significant tool for the restoration, replenishment and remediation of Earth's overburdened ecosphere.

iv. **Contributions to livelihoods:** Mushroom being an indoor crop, its farming is less affected by the vagaries of the climatic conditions. Mushroom can also be fitted either as an agribusiness with environment-controlled production unit by the resource rich farmers or as a livelihood activity for small farmers (Shirur and Sharma, 2016). Since mushroom cultivation does not require a lot of land and the business scale depends on modest to low capital investment and labour use, it can become a viable and attractive activity for side income and a part time enterprise for rural youth and women.

v. **A source of high quality protein:** The crude protein content in mushrooms is found to be in the range of 19 to 35%, on dry weight basis which is far higher than major cereals such as rice (7.3%), wheat (12.7%) and corn (7.4%). Even the production of protein per unit area is higher in mushrooms than the animal source of protein. Mushroom protein is distinctly superior to that of vegetable protein on account of its essential amino acids content i.e., alanine, proline, tryptophan, glutamic acid, aspartic acid, etc. Edible mushrooms contain proteins that are composed of theronine and valine but deficient in sulphur containing amino acids (methionine and cysteine). Supplementation of the cereals diet with the mushrooms would significantly helps to overcome the lysine deficiency.

vi. **To meet the nutritional security of ever growing population:** Edible mushrooms are going to be important vegetables of future because of their nutritional and medicinal properties and their ability to produce high protein per unit area. Vegetarianism is assumed to the norm of India and its diet is primarily based on cereals (wheat, rice and maize) which are deficient in protein. Incorporation of mushrooms in Indian diet will bridge this protein gap and reduces the problem of malnutrition to the great extent. The pharmacological properties of mushrooms include immunity enhancement, maintenance of homeostasis, regulation of biorhythm, and most importantly cure and prevention of various life-threatening diseases such as cancer, stroke, and heart diseases. Mushrooms are nutritionally important as they are rich in protein, fibers, and minerals, while poor in fats. The mushroom protein contains all the nine essential amino acids required by humans. Mushrooms are considered as a potential substitute of muscle protein on account of their high digestibility. Besides this, mushrooms are also rich source of vitamin B1, B2, B12, C, D, and E and a relatively good source of nutrients like phosphorus, iron, and vitamins, including thiamine, riboflavin, ascorbic acid, ergosterol, and niacin. Mushrooms are also an excellent source of vitamin D which is otherwise not available in other food supplements of plant origin. Mushrooms are low in calories, fat-free, cholesterol-free, gluten-free, and very low in sodium. Minerals such as potassium, iron, copper, zinc, and manganese are high in fruit bodies. They also have ash, glycosides, volatile oils, tocopherols, phenolic compounds, flavonoids, carotenoids, folates, organic acids, etc. Mushrooms are also important from nutraceutical point of view, as they contain several compounds like unsaturated fatty acids, phenolic compounds, tocopherols, ascorbic acid, and carotenoids. The nutritional attributes of edible mushrooms and the health-benefiting effects of the bioactive compounds they contain make mushrooms a health food (Gupta *et al.,* 2019).

vii. **Therapeutic and nutraceutial properties of mushrooms:** In the past three decades, there has been an upsurge in research on the medicinal value of traditionally used fungi and their products, particularly in China, Korea and Japan. Consequently, the traditional uses of many fungi have been confirmed and new wider usages discovered. Several classes of bio-molecules such as lipopolysaccharides, glycoproteins and polysaccharides were identified as mushroomceuticals with the potent effects on the human immune system.

The beneficial role of these compounds extracted from medicinal mushrooms has drawn the attention of various research and pharmaceutical industries to understand their bioactivity. Some of these compounds are noted as biological response modifiers (BRMs) and became an integral part in the cancer treatments together with the chemotherapy, radiotherapy and surgical treatments. Several mushroom products developed with clinical and commercial applications are D-fraction from *Grifola frondosa*, schizophyllan/soniûlan from *Schizophyllum commune*, lentinan from *Lentinula edodes*, polysaccharides from *Ganoderma lucidum*, polysaccharide-K (PSK) and polysaccharopeptide (PSP) from *Trametes versicolor*, etc. Many other secondary metabolites such as terpenoids, lactones, lectins, antibiotics, alkaloids and metal chelating agents were extracted from medicinal mushrooms which are showing the positive responses in improving the human immune system (Sharma and Annepu, 2018). Mushrooms secrete extracellular ligninolytic enzymes such as laccase, glucose oxidase, superoxide dismutase and peroxidase to degrade the lignocellulosic substrates. Many reports are showing that these enzymes are playing a great role in preventing the oxidative stress and inhibiting the tumour growth in various cancer treatments.

Along with the stimulatory effects on the human immune system, it has also been documented the role of mushroom bioactive compounds in modulating the specific cellular responses by interfering in transduction pathways. For example, caffeic acid phenethyl ester (CAPE) isolated from *Agaricus bisporus* and *L. edodes* has shown positive results in curing breast cancer. The CAPE specifically alters the cellular responses in MCF-7 cells by inhibiting the DNA-binding activity of NF-êB proteins. Panepoxydone is a novel compound extracted from *Panus conchatus*, and *Lentinus crinitus* was also found very effective in inhibiting the expression of several NF-êB- dependent pro-inûammatory genes by preventing the phosphorylation of IêB protein and thereby interrupts the signaling pathway. These reports are indicating that such novel mushroom metabolites can be effectively used in malignant cells to combat the cancer and other tumour growths. Unlike the synthetic compounds, the mushroom metabolites can penetrate into the target cell membrane easily and increase its bio-efûcacy due to the low molecular size. There have been new discoveries and developments in the ûeld of medicinal fungi which proved the beneficial role of mushroom compounds

Table 1: Bioactive compounds and associated therapeutic effects of different edible and medicinal mushrooms

S.No	Mushroom	Common name	Bioactive compounds	Therapeutic effects
1	*Agaricus bisporus*	White button mushroom	Agariciten	Antitumour property
2	*Lentinula edodes*	Shiitake mushroom	Lentinan	Antitumour and antiageingproperty
3	*Pleurotus spp.*	Oyster mushroom	Lovastatin	Antiobesity property
4	*Hericium erinaceus*	Monkey head mushroom	Hericenone	Found to induce synthesis of nerve growth factor, which is associated with anameliorative effect in Alzheimer's dementias
5	*Ganoderma lucidum*	Reishi mushroom	β-Glucans,ganoderic acid, polysaccharidesand triterpenes	Hepatopathy, chronic hepatitis, nephritis, hypertension, arthritis, neurasthenia, insomnia, bronchitis, asthma and gastric ulcers
6	*Schizophyllum commune*	Split gill mushroom	Schizophyllan orsonifilan	Antitumour properties
7	*Grifola frondosa*	Maitake	β-Glucan(β-1,6-glucanbranched with aβ-1,3-linkage)	Antioxidant, antiinflammatory, Free radical scavenging activities and the antiageing process
8	*Trametes versicolor*	Turkey tail mushroom	Proteoglycanfractions, PSPand PSK	Antitumour properties
9	*Cordyceps militaris*	Cordyceps mushroom	Cordycepin	Biological response modifier
10	*Auricularia polytricha*	Wood ear mushroom	Polysaccharides	Anti-inflammatory effect

Source: Shirur *et al.* (2021)

not only as crude drugs but also as functional foods and dietary supplements that can improve the overall human immune system.

Principles of climate resilient mushroom farming

The commercial production of edible mushrooms represents the unique exploitation of a microbial technology for the bioconversion of agricultural, industrial, forestry and household wastes into nutritious food. Mushrooms have the capacity to breakdown the lignin and utilize it as a food source, thus exposing the underlying cellulose and hemicellulose for food use by other organisms. Thus, mushroom cultivation represents a very basic natural process of fungal decay. Though, different from the conventional farming, basic steps involved in cultivation of any mushrooms follows the similar pattern with little modifications specific to the species chosen for cultivation. The steps involved in mushroom cultivation are as below.

Step -1	Selection of the mushroom species for cultivation
Step-2	Preparation of good quality spawn (mushroom seed)
Step-3	Choosing a suitable growing substrate
Step-4	Substrate preparation either by composting, pasteurization or by sterilization
Step-5	Seeding the substrate with the spawn
Step-6	Maintaining optimal growing conditions such as temperature, moisture, light and CO_2
Step-7	Harvesting, processing and marketing

a. Selection of mushroom species

Mushrooms which are commonly growing for food and/or medicinal purposes across the India are, white button mushroom (*Agaricus bisporus*), shiitake (*Lentinula edodes*), oyster (*Pleurotus* spp.), paddy straw (*Volvariella volvacea*), milky (*Calocybe indica*) wood ear (*Auricularia polytricha*), winter (*Flammulina velutipes*) and reishi (*Ganoderma*) mushrooms. Although there has been a considerable research efforts done on cultivation of mushrooms in temperate regions, very few varieties are available that can grow naturally in subtropical and tropical regions of the country. Hence, for choosing a species for commercial cultivation, the grower must consider the following key factors.

i. Availability of waste materials to use as a growth medium – not all the mushrooms can be grown on similar type of substrate. The mushroom species that is able to fruit on the abundantly available agro residues can be chosen.

ii. Environmental conditions - choose a species that fruits at temperatures near your outdoor temperatures. This limits investments in climate control and reduces costs incurred in energy.

iii. Available expertise - some mushrooms are more difficult to grow than others. For beginners it is recommended to select the mushrooms such as oyster or milky which are relatively easy to grow.

iv. Available resources – it is necessary to identify the machinery or growing conditions required for forcing into fruiting stage.

v. Market demand – the product that consumers are willing to buy is the primary driving force for selecting a mushroom species for cultivation

b. Choosing a suitable growing substrate

Substrate is the base material on which mushroom grows and gives the fruiting bodies by utilizing the substrate components. Although some of the mushrooms can be grown on a wide range of materials, for commercial scale production every mushroom species prefers a specific growing medium or substrate. Following is the list of major edible and mushrooms and their substrate suitability.

Mushroom species	Suitable substrates
White button mushroom	Wheat straw, mustard straw, paddy straw, sugar cane bagasse, soya straw
Oyster mushroom	Wheat straw, mustard straw, paddy straw, sugar cane bagasse, soya straw, coffee pulp, oilpalm waste, cotton straw
Milky mushroom	Paddy straw, wheat straw
Paddy straw mushroom	Paddy straw, cotton waste
Shiitake mushroom	Sawdust, corncobs, wheat straw, cotton seed hulls
Winter mushroom	Sawdust, corn cobs
Black ear mushroom	Paddy straw, wheat straw
Reishi mushroom	Sawdust, corn cobs
Macrocybe mushroom	Paddy straw, wheat straw

c. Substrate preparation and spawning

The substrate selected for growing the specific mushroom species is then composted or pasteurized or sterilized to exclude the other fungi that would compete with the mushroom. The substrate preparation steps helps in avoiding the competition. The method of substrate preparation largely depends on the growth patterns and the enzymatic system of the mushrooms. The detailed procedure of substrate preparation discussed in the upcoming sections. Technically spawn is considered as the mushroom seed. It is prepared from the pure tissue culture obtained from the healthy fruit bodies of mushrooms. This tissue/mycelium is then transferred on a sterilized cereal based substrate such as wheat, jowar, sorgum, paddy, rye etc. to make the mother spawn. Once the grain has been completely colonized by the mushroom mycelium, it can be used to re inoculate the substrate for large scale multiplication which is known as commercial spawn. This grain and mycelium mixture in the form of commercial spawn is used to seed the pasteurized substrate or compost for growing the mushrooms. Spawning is a process of addition of freshly prepared grain spawn to the substrate under hygienic conditions. The amount of spawn to be added to the substrate and the methodology to add the spawn (such as through mixing, layer spawning, surface spawning) depends on the mushroom species selected for cultivation. While mixing the spawn it must be ensured that the mycelium grows evenly throughout the substrate.

d. Maintaining optimal growing conditions

Growing systems should be selected that are best suited to local conditions based on the resources available. The species such as oyster, milky and paddy straw mushrooms can be successfully cultivated on a small-scale, by farmers and other growers who have limited access to resources and vulnerable to risk. It is quite possible for growers to gradually shift from a low-cost system to a higher cost production process, with greater output, when they have gained sufficient skills and income. For cultivation of button mushroom under large-scale commercial methods, it requires significant capital investment to construct the permanent civil structures and to purchase chilling machinery and steam sterilizers.

Mushrooms require maintenance of proper air, temperature and humidity levels asper the stage of the crop. All varieties of mushrooms have specific temperature andhumidity requirement for their vegetative and reproductive phases (Table 2). Hence, the mushroom growing structures, whether the temporary hutsor the permanent rooms, must be designed/planned to achieve these growingambiences. The task is easy for environmentally controlled growing rooms wherethe temperature and humidity are controlled through chilling plant and humidifiers.In the seasonal type of

Table 2: Temperature requirement (°C) of different mushroom species at vegetative and reproductive stages

Nature of the mushrooms	Mushroom species	Spawn run state	Fruiting stage
Tropical mushrooms	*Pleurotus sapidus*	25-30	22-26
	P. flabellatus	25-30	20-26
	P. sajor-caju	25-30	18-26
	P. membranaceus	25-30	22-30
	P. djamor	26-32	28-30
	Calocybe indica	30-35	30-32
	Volvariella volvacea	30-35	30-32
	Ganoderma lucidum	23-25	30-32
	Auricularia polytricha	23-25	30-32
Sub tropical mushrooms	*P. ostreatus*	22-26	14-20
	P. ostreatus var. florida	22-28	14-22
	P. citrinopileatus	24-28	18-22
	Cordyceps militaris	18-22	18-22
	Hericium erinaceus	23-25	18-20
Temperate mushrooms	*Agaricus bisporus*	23-25	16-18
	Agaricus bitorquis	23-25	18-20
	Lentinual edodes	23-25	18-20
	P. eryngii	20-24	10-15
	Flammulina velutipes	18-24	5-10

huts, the farmers depend on day and night temperatures to maintain the temperature and humidity inside the huts by opening and closing thedoors during day or night to allow the movement of cool/hot and dry/humid air. Inaddition, they resort to frequent spraying of water on the floor to moderate thehumidity and temperature to some extent.

This economic activity uses all the agriculture residues. It is in line with theclimate-friendly practices of agriculture. However, in environment-controlled units,the growers must be judicious in saving the resources and adopt the seasonalcultivation of mushrooms based on the prevailing temperature in the season. Forthis, the consumers must also be educated to eat the mushrooms as per the season. InIndia, the skewed demand for white button mushroom has caused less demand forother tropical mushrooms, and also efforts on their popularisation are lacking.

In Himachal Pradesh and Jammu and Kashmir, the growing houses vary fromtemporary to semi permanent to permanent structures. Some farmers use concreterooms with cemented floor and roof. Most commonly observed mushroom growingrooms are simple unplastered brick walls raised to 12–16' height and covered witheither tin or asbestos sheets. They are covering such sheets with locally available(Sarkhanda) grass as an insulating material to avoid excessive heating of thegrowing rooms. This helps in moderating the temperature of growing rooms,especially during the beginning of season when outside temperature is very high.Some poor farmers erect small huts using locally available wooden poles and straw.Even the very resource-poor farmers in the region were seen making the mushroomsheds using the decrepit materials available with them.In contrast, the oyster and milky mushrooms are grown in different and diversestructures. The structures range from huts to mud houses to polysheds and concretebuildings. The oyster mushroom bags with compost and spawn are either hangedfrom the ceiling in three to five tiers or placed over the shelves. The roomtemperature during the spawn run is maintained to suit the type of mushroom varietyselected.

Production technology of different mushroom species

The detailed cultivation technology for the most commonly grown mushrooms such as white button mushroom, oyster, shiitake, milky and paddy straw mushrooms are discussed here.

i. Button mushroom

In spite of predominantly tropical and subtropical climates in India, it is the temperate button mushroom that has ruled and is still dominating the Indian mushroom industry with more than 75% share. But its method of cultivation is not as simple as oyster and straw mushrooms. Its growing requirements are also more exacting than other mushroom species. In the north western regions like Haryana and Punjab, farmers are growing the button mushroom under natural conditions starting from October to February months. But in other regions of the country, its commercial cultivation has already attained a hi-tech farming status. Irrespective of the choice of mushroom species, techniques for growing all mushrooms follow the similar pattern, which directly reflects life cycle of the mushrooms. As discussed earlier, the life cycle begins with the initiation of vegetative growth in the homogenised substrate or compost. At large scale this can be achieved by inoculating the substrate with the spawn.

a. Compost preparation

A partially decomposed organic matter prepared under aerobic conditions is using as a substrate for growing button mushroom. This substrate is generally termed as compost. The purpose of composting is to prepare a physically and chemically homogeneous medium forthe growth of mushroom mycelium. The composting can be done either by long method of composting (LMC) or by short method of composting (SMC). The farmers who are growing the button mushroom under seasonal conditions adopted the LMC.In this method the entire composting operation is carried out in open fields and pasteurizationrequired for conditioning of compost is achievedby natural means.SMC is followed by the commercial button mushroom units with environmental control facilities for composting and cropping. In SMC, the compost is prepared in two phases. During the first phase, outdoor composting for 10-12 days followed by indoor pasteurization and conditioning for seven days in the second phase. The most successful formula for SMC standardized at ICAR-Directorate of Mushroom Research, Solan is Wheat straw – 1000 kg; Chicken manure – 400 kg; Wheat bran-70 kg; Urea – 14.5 kg; Gypsum–30 kg.

During the phase -1, the cereal straw is thoroughly wetted on the cemented floor. This pre wetted straw is then mixed with the chicken manure and wheat bran and kept as such for 2 days in a pile. After that, the pile is broken and water to be added to the dry portions and again the stack is made. Four days later, the compost is turned and the entire quantity of urea is to be added and high aerobic pile is made. The stack is again turned and watered after every two days and the gypsum is added in the third turning. During this stage the temperature of pile will raise to 70-80ÚC. The final turning will be given on the 12^{th} day when the colour of the compost changes into dark brown and it starts emitting a strong smell of ammonia. The compost prepared as a result of microbial fermentation process needs to be pasteurized in order to kill undesirable microbes and competitors. The compost from phase -1 should be filled in the pasteurization tunnels to the maximum height of 2-2.3 mts. At this stage temperature inside the tunnel should be in the uniform range of 45-48ÚC. Later, the temperature of compost should raise to 48-52ÚC by the help of fresh air and maintain the same for 48 hrs. After 48 hrs, the compost temperature should raise to 58-62ÚC by inducting the steam and maintain the same for 4-6 hrs. Then the temperature should brought down to 48-52ÚC and allow the compost to retain at this temperature for 3 days. The ammonia levels in the compost should be monitored regularly with the help of ammonia meters. If no ammonia persists in the compost, then bring down the compost temperature to room temperature. At this stage the final compost should be granular in structure with 65-70% moisture and pH range of 7.2-7.5. The final compost should be in dark brown colour with sweet smell and completely free from ammonia.

b. Spawning and spawn run

After phase –II of SMC, the compost should be thoroughly mixed with the spawn. The spawning activity can be done on the clean and disinfected area. 500 g to 750 g (0.5-0.75 %) of grain spawn can be used to spawn 100 kg of prepared compost.Fill the 10 kg of spawned compost in polythene bags of 20 x 24" size. Maintain moisture content of the substrate at 65-70 % and temperature at 23±1ÚC. It will take, 12-14 days for the complete colonization of mycelium.

c. Casing and case run

Once mycelium completely colonizes the compost, it can be switched over to fruiting stage by covering the surface of the substrate with a thin layer of moist material. This process is called as casing. The casing layer must maintain mycelial growth, stimulate fruiting and also should support the continual flushes of mushrooms. Mixture of 2 years old FYM and garden soil in 1:1 ratio is most preferable casing material. If coir pith is available, it can be used along with the FYM and garden soil in 1:1:1 ratio. The prepared casing soil is treated either by steam at 65-70ÚC for 6-8 hours or by drenching with commercial grade formaldehyde solution @ 3 litres in 40 litres of water per cubic meter of casing soil. The pH of casing soil must be adjusted to 7-7.5 with an addition of calcium carbonate. Uniform depth and evenness are the two important factors while casing the substrate. Substrate depths of six to eight inches are cased 1.25 to 1.5 inches deep. Substrates deeper than 8 inches are cased 1.5 to 2 inches deep. Spray the water immediately after casing application and thereafter daily.

d. Crop management

Environmental conditions after casing should be the same as during spawn running. Substrate temperatures are maintained within the optimum range for mycelial growth; relative humidity is 90-100%; and fresh air is kept to a minimum. Within three days of application, the mycelium should be growing into the casing layer. Once mycelial growth is firmly established, the casing is gradually watered up to its optimum moisture holding capacity. This is accomplished by a series of light watering with a misting nozzle over a two to four day period. At this stage the micro climate in the cropping room should be adjusted as mentioned below to promote the fruiting.

- Substrate and air temperatures are lowered to the fruiting range of 16-18ÚC
- The humidity is lowered to85%
- The carbon dioxide content of the room is reduced to < 1000 ppm by the induction of fresh air
- The room is lighted on a 12 hour on/off cycle

This change in environmental parameters helps to the initiation of pinning and subsequent development of pin heads into solid fruit bodies within 3-4 days. During fruiting, the fresh air should be inducted 4-5 times in a day to maintain the CO_2 levels at optimum range. The mushroom crop grows in cycles called as “flushes or breaks”. The uniform fruit bodies of 4-5 cm in dia should be handpicked in a twisting motion. Trim the stem base with sharp knife, removing only flesh to which the casing is attached. Damage to resting pinheads and disturbance of the casing soil must be minimized during picking otherwise it affects the future flushes. Daily watering is required after harvesting the first flush. 18-20 kg of fresh mushrooms can be harvested from 100 kg of prepared compost in a total of three breaks. The expenditure required for establishing the button mushroom unit with year round production facility is directly linked with the expected production output. On an average an entrepreneur/ grower has to invest capital expenditure of one lakh rupees for every one ton production of mushroom per annum. With the best crop management practices, the production unit will reach breakeven point in the fourth year and thereby the benefit cost ratio will ranges from 1.6 to 2.0.

ii. Oyster mushroom

Pleurotus species popularly known as oyster mushroom or “dhingri” mushroom is emerging as an important mushroom variety because of its wider adaptability to different temperature regimes and substrates, easy cultivation technique and high productivity. Oyster mushrooms are a good choice for inexperienced and start-up cultivators because they are easier to grow than many other specieswith low to moderate initial investment.

a. Substrate preparation

The oyster mushroom has less specificity towards the substrate. Hence, it can be cultivated on a large number of agro-wastes such as cereal straw, sugarcane bagasse, saw dust, jute and cotton waste, dehulled corncobs, pea nut shells, dried grasses, discarded waste paper etc.When growing mushrooms, primary goal is to facilitate quick colonisation of mushroom mycelium in a given substrate. Pasteurisation of agricultural residue helps in achieving this objective by killing of harmful competitor moulds and other fungi.Pasteurization occurs between 58-62ÚCtemperature. Any higher temperature than this may kill several beneficial microorganisms thus adversely affecting the productivity of mushrooms.The pasteurisation of the substrate can be achieved either by steam pasteurisation or hot water treatment.Chemical pasteurisation also results in elimination of competitor fungi, but its use is discouraged due to the residual levels in the mushroom fruit bodies.In the steam pasteurisation, the straw is initially wetted to hold about 50-60 per cent moisture and then packed in wooden trays or boxes. These trays or boxes are then kept in a pasteurization room where temperature is maintained between 58-62ÚC for four hours with the help of steam provided through boiler. Whereas, in the hot water treatment, the substrate is soaked in hot water at a temperature of 65 to 70°C for 60 to 120 minutes. This process makes the substrate soft to promote the quick growth of mycelia. The substrate is thenallowed to drain excess water and cool at room temperature.

b. Spawning and incubation

Freshly prepared grain spawn is mixed thoroughly @ 2-3% of the substrate on wet weight basis under hygiene conditions.The spawned substrate will be filled in the polythene bags and tightly pressed and tied with a nylon rope. 10 to 15 small holes should be made on all sides of the bag to facilitate the aeration and for drainage of excess water. Empty fruit packing cartons or wooden boxes also can be used for filling the substrate. Polythene sheets are spread in rectangular wooden or metal box, spawned substrate is filled and the polythene sheet is folded from all the four sides to make a compact rectangular box. Then the bags will be shifted to the incubation room and kept on a raised platform or shelves for mycelial colonization of the substrate. During the spawn run stage, the bags are not to be opened and it doesn’t require much ventilation or water sprays.

c. Crop management

Although mycelium can grow between 10-30°C, the optimum temperature ranges between 22-26°C. Higher temperatures more than 30°C in the cropping room will inhibit the growth of the mycelium. Once the mycelium fully colonizes the substrate, it forms a thick mycelial mat which indicates the readiness for fruiting. During the fruiting period a relative humidity of 80-85% should be maintained by spraying the water 2-3 times and sufficient ventilation should be provided for air circulation.The colour of the oyster is also influenced by the light intensity and its duration. Fruit bodies raised in bright light appears in dark brown or grey in colour and the fruit bodies raised in less intensity of light appears in pale yellowish colour.With suitable crop management practices, mushroom fruit bodies are ready for harvesting in 6-8 days after pinheads formation. Pick the mushrooms while the edges of the caps are still curled down. It is advisable to harvest all the mushrooms at one time from a bag so that the next crop of mushrooms starts early. The best quality of mushrooms can be harvested from the first and second flushes due to the availability of sufficient nutrients. Under normal room temperature conditions fresh mushrooms can be stored for 2-3 days without any deterioration.The fruit bodies can be dried under sunlight to the moisture level of 8-10 %. The dried oyster mushroom can be successfully stored for 4 to 6 months withoutlosing its original properties.The cultivation technology of oyster mushroom is very simple which does not require costly infrastructure facilities. For the production of 40-50 kg fresh mushrooms per day, minimum four low cost growing rooms of 20 feet length and 15 feet breadth are required. Depending on the type of materials used for constructionthe required investment for oyster mushroom unit may cost Rs. 3.0-4.0 lakh.

iii. Shiitake mushroom

Shiitake mushroom is one of the world's most popular edible mushroom species known for its nutrition, flavour and medicinal properties. Shiitake contains a bioactive compound–lentinan, which is having anti-carcinogenic andtumor suppressing properties. Traditionally shiitake mushroom was cultivated on fallen wood logs stacked in evergreen forests in China since centuries. But its commercial cultivation gained the momentum after developing the synthetic log cultivation technology.

Saw dust obtained from the broad leaved trees such as tuni, poplar, mango, safeda, oak, maple etc. is the main basal ingredient for the preparation of synthetic logs. Saw dust is supplemented with the wheat bran or rice bran in the ratio of 80:20 and calcium carbonate is mixed @ 1% on dry weight basis to maintain the pH levels below 7.0. Ingredients are thoroughly mixed and moistened to a level of 60-65%. 1.5 kg of the prepared substrate is filled in the heat resistant polypropylene bags and then sterilized for 2 h at 121ÚC and 22 p.s.i of pressure. The sawdust logs will be allowed for cooling at room temperature for a day after sterilization.

After cooling the bags should be seeded with fresh grain spawn @ 45-50 g per bag. As the substrate contains high amounts of nitrogen, doing the spawning activity in the outside environment may lead to contamination. Hence spawning should be done under aseptic conditions using laminar air flow chamber. The bags after heat sealing are shaken to distribute the spawn evenly. After inoculation, the bags will be shifted to incubation roomwhere the temperature should be maintained at 22-26ÚC. Although mycelia can grow in darkness, exposure to light of four hours in a day for the first three weeks of spawn run is critical for the browning of the mycelia blocks. Spawn-run will be completedwithin30-35 days. A thick mycelia coat will develop on the surface of the substrate after 6-8 weeks of spawning. This mycelia coat will eventually turn into brown colour with some exudates. Clumps of mycelium will form on the surface of the mycelial coat 10-12 days after mycelial coat formation. These clumps will turn into mushroom fruit bodies at the later stage.

When one third of synthetic logs have turned brown,peel off the polycoverto allow the hardening of the substrate surface. The mushroom crop cycle requires a sudden change in the environmental factors to induce the vegetative mycelium to turn to reproductive phase. This physiological change is achieved by soaking the synthetic blocks in ice cold water (4-6ÚC) for 10-15 minutes. Later, the synthetic logs will be shifted to growing rooms. The temperature of about 18-20ºC and relative humidity of more than 85% are required to be maintained till the maturity of the fruit bodies.The primordia will be initiated and matured into fruit bodies within 7-9 days after cold shock treatment. Mushrooms are harvested by hand by gently twisting the stipe of the fruiting body and then the stipe is cut with sharp knife. The mushrooms keep coming for 15-20 days in a flush after each shock treatment. Cold water treatment should be repeated for the subsequent 3-4 flushes also till the exhaustion of nutrients in the substrate.ICAR-DMR, Solan has developed a technology in which the first crop of shiitake is harvested in 45-47 days by using specific strains.

a. Button mushroom

b. Oyster mushroom

c. Shiitake mushroom

d. Paddy straw mushroom

e. Milky mushroom

Fig. 1: Edible mushrooms growing at commercial scale in India

The harvested fresh fruiting bodies of shiitake mushroom can be stored for 3-4 days at 18-20ÚC and keeping them at 4-6ÚC will extend their shelf life up to 14 days.The shiitake mushroom can also be stored up to one year by drying.

iv. Paddy straw mushroom

Volvariella volvacea commonly known as paddy straw mushroom is a warm temperature loving, tropical edible mushroom with a temperature requirement as high as 35ÚC.This mushroom is known for its textural characteristics and unique aroma. Cultivation of paddy straw mushroom is very popular in regions like Odisha, coastal Andhra Pradesh, West Bengal and parts of Chhattisgarh. The paddy straw mushroom is the only mushroom, which can be cultivated both outdoor as well as indoor.

The traditional outdoor cultivation is done seasonally under the shades of trees by making mushroom beds on the raised platform made from bricks and bamboo poles. Straw bundles of 45 cm length and 10 cm width are prepared by cutting the top leafy portion and part of thick stalk near the roots by hand or motorized cutter. The bundles are soaked in water or in 2% $CaCO_3$ solution for 12-14 hours. Then these bundles are placed side-by-side followed by placing the mushroom spawn at 6 to 8 spots and covering of spawn with red gram dal powder.12-15 beds are prepared in the similar manner and the whole lot of beds prepared in a line are compressed a little and covered with clean plastic sheet.The beds are checked for moisture content in between by removing the plastic sheets and if needed water has to be sprayed with rose can to maintain 60% moisture.The spawn run requires a temperature of above 39ÚC and spawn run will be completed in 6 to 7 days.After the completion of spawn run, the plastic sheet is kept loosely covered over the beds. The mushrooms will start coming from all sides of the bed after 12-13 days of spawning. They can be harvested at egg stage by holding between forefinger and thumb followed by twisting clockwise or anticlockwise direction.The harvested mushrooms can be cleaned and packed in polythene bags or in paper bags but the bags should not to be sealed. These packed mushrooms must be sold for consumption preferably on the same day.

Indoor cultivation can be done on a substrate/ compost prepared by mixing cotton ginning mill waste and paddy straw in 1:1 ratio on weight basis.The substrate after mixing can be wetted for two days and later the poultry manure will be added @5%. The substrate will be mixed thoroughly and made a pile. First 2 turnings are given at an interval of one day each and calcium carbonate @ 1.50% is added at third turning and the substrate is left for fermentation for next 2 days. After 4 days of outdoor composting, the compost is spread on the shelves to a thickness of 10 cm to 15cm depending upon the season. The steam is introduced inside the cropping room for heat conditioning of the compost. Temperature is maintained at 62°C for 4-5 hours. After a day, the compost is spawned @ 1.5%on wet weight basis and the beds will be covered with the plastic sheet.The room temperature is maintained at 32 to 34°C during spawn run period. The compost will be colonized within next 4-5 days and then the beds will be sprinkled with water by removing the plastic sheet. The pinhead will start appearing on 5th – 6th day of spawning.After another 4 to 5 days, the first flush of mushroom will be ready for harvesting.The paddy straw mushroom is not suitable for storing in refrigerator and must be consumed fresh immediately after harvesting or may be stored at room temperature for few hours.

v. Milky mushroom

Milky mushroom (*Calocybeindica*) is another warm temperature loving tropical mushroom with the temperature requirement of 30-35ÚC for fruiting. Cultivation of milky mushroom is gaining popularity in the southern parts of India specially, in the states of Tamil Nadu, Kerala and Andhra Pradesh. The cultivation technology is similar to oyster mushroom production with an additional requirement of casing layer application. Milky mushrooms can be grown on wide range of lignocellulosic residues, but commercial cultivation is done on paddy straw or wheat straw.

The substrate can be prepared by wetting the straw in water for 10-12 hours. After draining out the excess water the wetted straw will be arranged in a pile. The pile will be broken with turning after two days and the calcium carbonate should be added @ 1%. Then substrate will be pasteurized at 60ÚC for 4 hours either by steam or hot water. Five kg of this pasterurized substrate is filled in the polythene bags and spawn will be added @ 4-5% on wet weight basis. The spawned bags will be shifted to incubation room at 28-32ÚC under dark conditions. It takes 20-25 days for completion of spawn run. The sterilized casing material prepared by mixing garden soil and sand in 3:1 ratio will be added on the surface of colonized substrate as casing layer. Maintain temperature of 30-35ÚC, R.H. 80-90%and light intensity at 600-1000 lux for cropping. Primordia will be formed and matured within 8-10 days after casing. Harvest the mushrooms when the stipe length reaches of 7-8cm by twisting with hand. Harvested fruit bodies can be consumed fresh or store the clean mushrooms by wrapping in film for 7-10 days at room temperature.

Crop management to achieve sustainability and resiliency

Farmers practicing seasonal button mushroom cultivation mostly depend on purchasedspawn as it is seasonal agriculture activity for them. Generally, 0.5% seedrate (5 g of spawn/kg of compost) on a wet compost weight basis is adopted amongthe growers. In Haryana and Punjab, prepared compost is mixed with mushroomspawn and spread over the racks for about 4–600 height and allowed for the fungalmycelia to spread (spawn run) for about 7–12 days. After the spawn run, a layer ofcasing soil of about 100 is spread over compost uniformly. Mushroom pinheads startappearing 8–12 days after spreading the casing soil. Such pinheads develop into fullgrownmushroom fruiting bodies after 3–4 days. In case of oyster mushroom, theseed rate is around 2.5–3.0%, while for milky mushroom, it is 5.0% on a wet weightbasis. The spawn is mixed alternatively with the layers of straw and placed in a roomwith suitable temperature and humidity for spawn run. After the incubation period,the spawn run completes and the temperature and humidity are altered to facilitatethe fruiting.

Since mushroom cultivation is a very sensitive enterprise for several competitormicroorganisms, hygiene is most critical factor in all three facilities. Any chance ofinfection and contamination either in spawn laboratory, production rooms orcomposting facility is sure to affect the mushroom quality and production. Usually,the spawn production facility is an integral part of the mushroom production unitswith 250 ton per annum (TPA) of fresh mushrooms. For successful commercialwhite button mushroom production, the minimum ideal production capacity is250 ton per annum. Though many entrepreneurs are trying to set up 100 TPAunits with indigenous cooling systems, their B:C (benefit-cost) ratio may be lowdue to higher operational expenses per unit mushroom production. It is alwaysadvisable to consult the experts to decide about the size and scale of mushroomunits and accordingly design the type of growing rooms, compost yard andcomposting bunkers if required.

The reason for failure of mushroom enterprises to achieve the profitability is tostart with uneconomical production and not following the cropping cycle to keep theproduction constant. This is essential to be a credible supplier of fresh mushrooms inthe market and use the farm resources appropriately. Since the mushroom crop givesno yield in the initial spawn running period and gives a higher quantity of mushroomin the initial period of cropping, one- or two-room production facility and even fourtofive-room structures create problem to achieve uniform supply of mushroomscontinuously. Minimum of eight rooms can mitigate such a constraint, and havingmore cropping rooms will help to offset the uneven distribution of mushroomproduction in a single room. Unlike the white button mushrooms, the milky mushroom and oyster mushroomcan be grown in four to five separate rooms with one room exclusively meant forspawn run to maintain the constant supply of mushrooms for the market. Thispractice is very important as it helps to maintain the rooms with a defined set oftemperatures and humidity as per the crop stages. Since the spawn-run room does notrequire exclusive aeration facility, spawn run may ideally take 12–15 days, and themore number of bags can be put compared to the growing rooms. Hence, this kind ofarrangement will be able to give sufficient bags to be placed for three to five growingrooms. However, this will require labour during the shifting of the spawn-run bags togrowing rooms for fruiting.

Sustainable cultivation of mushrooms for doubling the farmers' income

Mushroom can also be fitted either as an agribusiness with environment controlled production unit by the resource rich farmers or as a livelihood activity for small farmers. Many farmers in North Indian states have adopted mushroom cultivation as a regular farming activity during winter. The use of low cost mushroom houses made from bamboo, paddy straw and other cheap raw materials has made huge difference to their income levels. In recent times, the practice of adopting tropical mushrooms like *Pleurotus* sp. and *Calocybe indica* adjusting to the prevailing climate and using the same facilities has helped the farmers in getting round the year returns compared to just three to four months returns earlier (Barh *et al.,* 2019). Extending the mushroom cultivation beyond winter has turned the mushroom growing as a year activity than as four months activity of growing white button mushroom alone in the past. Due to the varied agro climatic conditions prevailing in the country, all mushrooms can't be grown in every region. For this purpose, the country has been broadly classified into five major agro climatic regions and five different types of mushrooms are proposed for each region.

Marketing opportunities

India has a good combination of both the technical and non-technical manpower needed to operate the mushroom growing activities. The supply

Region	States covered	*Average temperatures of the region	Suitable mushroom species	Temperature requirement for fruiting	No. of crops to be grown in a year	Total net income (Per annum) in Lakhs
North Western India	Punjab, Haryana, Himachal Pradesh, Uttarakhand, J&K	15-25 ºC	White button mushroom, Oyster	16-20 ºC	One crop of button mushroom (Nov-Jan) Three crop of oyster mushroom (Feb-April & July-Oct)	Rs. 3.98 L
Northeast India	Assam, Manipur, Sikkim, Meghalaya, Nagaland, Tripura, Mizoram	16-26 ºC	Shiitake, oyster	18-20 ºC	One crop of shiitake Two crops of oyster (Feb-April & July-Sep) (Sep-Feb)	Rs. 3.09 L
Central India	Madhya Pradesh, Maharashtra, Uttar Pradesh	25-35 ºC	Oyster, Milky	32-35 ºC	Two crop of oyster (Sep-Feb)Two crops of milky (Mar-August)	Rs. 3.17 L
South India	Kerala, Tamilnadu, Karnataka, Andhra Pradesh, Telangana	25-35 ºC	Oyster, Milky, Paddy straw mushroom	32-35 ºC	One crop of oyster (Sep-Nov)Two crops of milky (Jan-April) One crop Paddy straw mushroom (July-August)	Rs. 2.95 L
East coastal area	Odisha, West Bengal, Chattishgarh	30-35 ºC	Paddy straw mushroom, Milky, Oyster	30-35ºC	Thee crop of paddy straw mushroom (March-August) One crop of oyster (Jan-Feb) One crop of milky (Sept-Oct)	Rs. 3.48 L

(*average temperatures are excluding the hottest summer months)

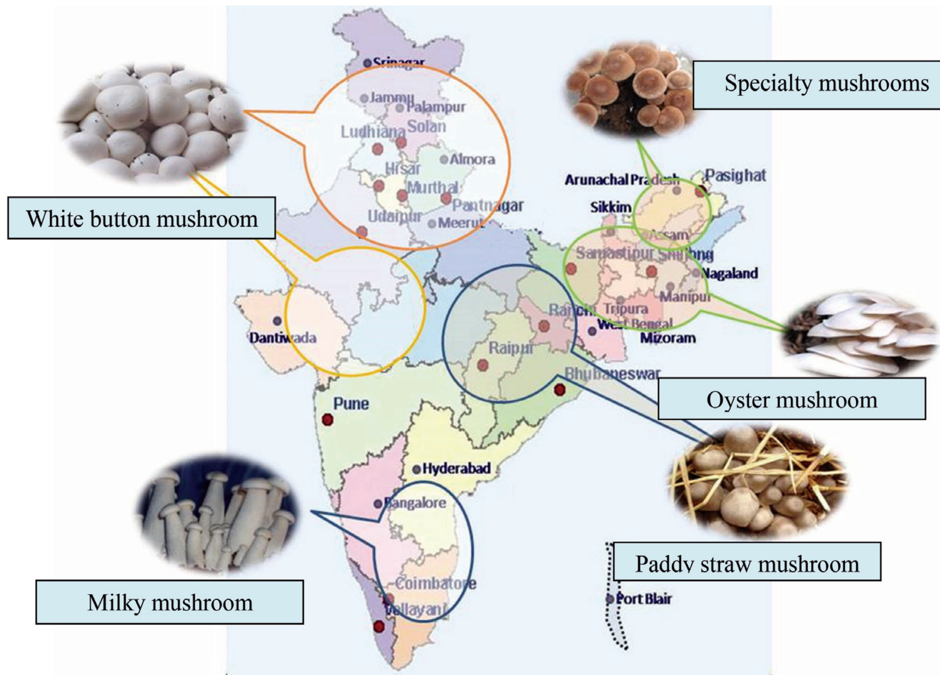

Fig. 2: Suitability of different mushroom species in different regions of India

and demand gap in the world trade of mushrooms and the shrinkage of production in western countries due to high labor costs would result in better market prices for Indian mushroom producers. With a domestic population of more than 1.2 billion, India itself is a large market for mushrooms. The development of rapid infrastructure facilities and well-organized distribution network provides the greater scope for marketing of perishable products in order to meet domestic consumer demands. To be successful in both domestic and export market it is essential to produce quality fresh mushrooms and mushroom fortified value added products at competitive rates without any agro chemical residues. India's potential as a major mushroom producer is its strategic geographical location, making it more convenient to export mushrooms to the Middle East, Southeast Asia and European countries.

Conclusion/Way Forward

It takes approximately 13 weeks (90 days) for button mushroom to complete an entire production cycle, from the start of composting to the final cook out after cropping has ended. For this work, a mushroom grower can expect anywhere from 25 kg to 35 kg per 100 kg compost in a period of 4-6 weeks of cropping. Final yield depends on how well a grower has monitored and controlled the temperature, humidity, pests, and so on. All things considered, the most important factors for good production are experience plus an intuitive feel for the biological rhythms of the commercial mushroom. The production system used to grow a crop can be chosen after the basics of mushroom growing are understood. The international competition has forced mushroom producers to minimize costs and at the same time increase yields per unit weight of compost and improve quality levels. As the upsizing of mushroom farms continues with the change from family scale to industrial scale, logistic and labour/ energy saving alternatives will play a more important role in automation. Automatic climatic control will be an obligatory investment for survival in the competitive mushroom industry in days to come. Indian Mushroom industry has witnessed exponential growth during the last couple of years; however, considering the agro-climatic conditions, availability of raw materials and man power, there is tremendous scope for expansion of mushroom industry in the country.

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Strategies for Climate Resilient and Sustainable Production of Spices

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Introduction

The spice is one of the earliest traded commodities in the world, the history of the cultivation and use of spices is perhaps the most romantic story of any vegetable product. From the earliest known eras of civilization spices were eagerly sought in all parts of the world. It must be noted that the greater part of the spices that have been valued by man are derived from the Asiatic tropics, while the other quarters of the globe have produced comparatively few. Spices played an important role in the evolution of human civilizations. The great navigations by Christopher Columbus, Vasco de Gama, Ferdinand Magellan are in search of spice producing lands, as a result 'Spice route' connecting Asia and Europe were established. Every household in the world irrespective of the ethnicity uses one or other spice every day. Spices are high value and low volume commodities of commerce in the world market. The fast-growing food industry world over depends largely on spices to diversify taste and flavour in their stuff. Spices also import natural colours to food that preferred by health-conscious consumers in developed countries than cheap synthetic ones. Thus, spices play a key role in the food industry world over. Spices are inevitable component in Indian food and people use turmeric, chilli, cumin, coriander, etc.., regularly in daily diet to add flavour, taste, colour and preserve their foods.

Area and production

India is a 'Land of Spices' and spice trade is ancient and has rich history. Out of 109 spices listed by ISO, India produces more than 70 types of spices, however, statistics is available for only around 20 kind of spices. On an average (2017-18 to 2020-21), spices are grown in an area of 4.2 million ha with a production of 39.6 million tonnes (Table 1). Cumin, chillies, coriander, garlic, mint, turmeric, black pepper, ginger and fenugreek occupies major area. In terms of production garlic, ginger, chillies, turmeric, cumin, coriander, fenugreek, tamarind, fennel, black pepper and mint are contributing maximum for total spices production. Positive trend in area and production of spices is noted (Fig. 1).

Table 1: Area and production of spices in India (mean of 2017-18 to 2020-21)

Crops	Area ('000 ha)	Production ('000 tonnes)
Pepper	225.463	431.786
Ginger	171.6408	7365.850
Chillies	684.629	7056.391
Turmeric	271.0085	4100.566
Garlic	375.23	12077.476
Cardamom	83.67275	102.653
Coriander	542.9548	2843.895
Cumin	1127.922	3158.613
Fennel	79.7095	529.565
Fenugreek	132.1908	785.369
Ajwan	37.12775	96.149
Dill/Poppy/Celery	32.27575	127.156
Cinnamon/Tejpat	2.99625	27.732
Nutmeg	23.8285	61.664
Clove	2.17275	4.792
Tamarind	44.74125	645.822
Vanilla	0.18675	0.334
Mint (Mentha)	330.352	157.353
Saffron	3.58975	0.017
Total	4171.692	39573.182

Note: 1. Ginger production in terms of fresh, 2. Turmeric production in terms of dry

Spices are grown in a wide range of climates - from tropical to sub-tropical to temperate, almost all spices grow splendidly in our country. Spices are

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grown as rainfed crop in high rainfall areas and as irrigated crops in less rainfall areas. Like any other crop, spices yield is also a function of factors like weather, soil type and its nutrient status, management practices and pest and diseases attack. Of these, weather plays an important role. With 329 million hectares of the geographical area the country presents a large number of complex agro-climatic situations. The black pepper and cardamom are predominantly grown in Western Ghats and adjacent regions, whereas chillies, ginger and turmeric grown throughout the country in more than 200 districts, the seed spices like cumin, fennel, fenugreek mainly confined to western part of the country in Rajasthan and Gujarat. Saffron is from Jammu and Kashmir and Sikkim is the largest producer of large cardamom. There are efficient production zones within these regions, for example, relative spread and yield of black pepper are high in Idukki and Wyanad districts in Kerala, The Nilgiris district in Tamil Nadu and Kodagu and Chickmagalur districts in Karanataka. Similarly, efficient production zones are there for other spice crops that have to be demarcated.

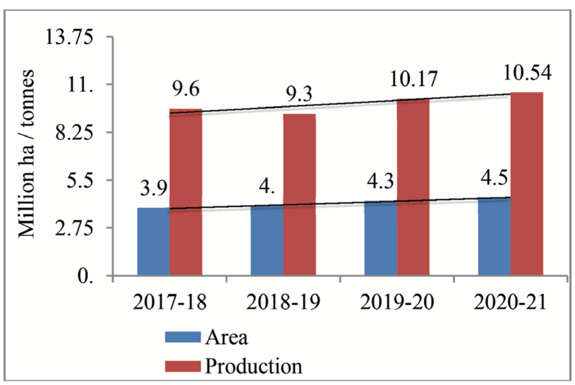

Fig. 1: Recent trend in spices production

Spices Export

India is a second leading exporter of spices to the world market. On an average we export 1.2 million tones of spices to the value of Rs. 21.26 thousand crores (Table 2). The main spices exported are chillies, cumin, turmeric, in terms of value chillies followed by mint products, cumin, spice oil and oleoresins and turmeric are major contributors. The demand for value added products are increasing over the years. There is a positive trend in spices exported from India also seen (Fig 2). Indian spices are exported to 190 countries to the value of 4178.8million US$ during 2020-21.

Table 2: Export of spices from India (Mean of 2016-17 to 2020-21)

ITEM	Quantity (tonnes)	Value (Rs. Lakhs)
Pepper	16991.994	73539.752
Cardamom(S)	4143.280	58313.442
Cardamom(L)	985.986	7348.792
Chilli	491693.022	613798.392
Ginger	54417.754	40960.336
Turmeric	135783.634	134065.874
Coriander	43775.786	36230.152
Cumin	191116.594	296911.916
Celery	6499.684	7112.900
Fennel	30782.300	26750.664
Fenugreek	31604.058	17441.056
Other Seeds (1)	35172.258	22989.508
Garlic	29720.622	22182.288
Nutmeg & Mace	4116.446	18629.258
Other Spices (2)	42791.568	66567.788
Curry Powder/Paste	36443.312	78868.604
Mint Products (3)	23479.848	340086.730
Spice Oils & Oleoresins	14886.926	264433.006
Total	1194405.072	2126230.458

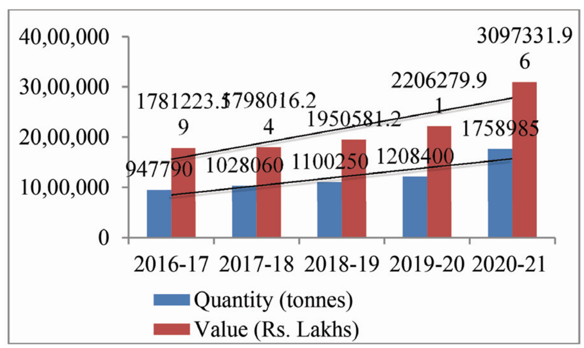

Fig. 2: Spices export from India

Strategies for climate resilient and sustainable spices production

Soil resilience and organic farming: - Soil health is the key factor that determines the resilience of crop production under changing climate. Practice of organic farming would enhance the resilience in the farming system, ensures better soil health with ecosystem services as a result sustainability in the spices production.

Climate resilient varieties: In India, more than 150 spice varieties have been developed over the years through R & D efforts. Climate resilient varieties of turmeric *viz.,* IISR Pragati (short duration variety overcoming drought) and NDH98 (saline tolerant, stable yield across the country), ginger variety - IISR Mahima (nematode tolerant), cumin variety-GC4 (wilt tolerant), dual purpose varieties of coriander and determinate types of fenugreek (suitable for mechanized harvesting) played an important role in increasing the income of farmers.

Seed bank / planting material stock: It is essential to have sufficient quantity of seed / planting materials in reserve to meet weather aberrations and extreme weather. Community nurseries for perennial spice crops are also important to supply continuous requirement of quality planting materials for new planting or gap filling or replacing older varieties.

Capturing the season : Timely operations is a 'non-monetary input', one should select right of planting / sowing, irrigation, plant protection, harvest etc.., Agro-met advisories services (AAS) are available for each district for all the states. It may be utilized for taking crop management decisions.

Water harvesting and irrigation: Spices are cultivated both in rainfed and irrigated lands. Ground water depilation is at an alarming rate and urgent need for community-based groundwater management and an understanding of how to build and maintain the aquifers that hold and supply groundwater. Water harvesting and recycling should be integral part of spices production particularly in rain fed production system. Practice of mulching conserves the moisture in rainfed system. In irrigated system one should adopt efficient water management practices by using drip and sprinkler systems etc.,.

Scientific crop production and protection: The technologies such as seed priming, seed hardening and encapsulation for early germination and express better growth and vigour and drought tolerance; transplanting techniques to reduce the main field duration and save the seed, drip-fertigation to enhance the fertilizer use efficiency and save water, bio-control application for residue free spices etc., has to be used on regular basis for sustaining the production. spraying lime @1.5% or spraying Kaolin @2.0% protects the black pepper crop preventing leaf fall and defoliation due to sun scorching. Providing sprinklers for evaporative cooling or shade net also reduces the heat load on plant.

Protected cultivation: In spices, the poly house / net house structures are used mainly for raising quality planting materials. However, many farmers taken up cultivating ginger, coriander etc., in commercial scale using protected cultivation techniques. It is useful for commercially important low volume and high value spices crop cultivation. Experiments are underway on turmeric vertical farming.

Cropping system / Crop diversification / Integrated Farming System (IFS): Spices are highly amenable for different cropping systems.Practice of cropping system is always better option than monoculture and it is a way to protect the farmers from vagaries of weather / pest and diseases / market fluctuation. When two or more crops grown along with main crop, under unforeseen situations, even one crop fails, some income or produce could be obtained from other crops in the intercropping system. Under favourable condition farmers will get additional income or other economic produces like vegetable, fodder, green manure, etc. The crop based husbandry alone will not generate adequate employment and income to small and marginal farmers in the context of climate change. It is essential to integrate crops with animal husbandry, bee keeping, mushroom production, sericulture, etc.., There are several improved farming systems model for different agro-climatic regions of India is available that has to be adopted to sustain the production and survival of marginal and poor farmers.

Mechanization: Agriculture suffers with non-availability of labour and sustained spices production needs work force. The operations such as planting, intercultural operations and harvesting could be simplified by using machineries.

Institutional support: Institutional support is very much essential in the form crop insurance, marketing, storage infra structures, loans, buy back system, crop advisories, etc.,. Providing machineries to the farmers on nominal rent to practice mechanization and reduce the post harvest loss.

Conclusion

Spices are high value and low volume crops, grown in an area of 4.2 million ha with a production of 39.6 million tonnes. Cumin, chillies, coriander, garlic, mint, turmeric, black pepper, ginger and fenugreek occupies major area. In terms of production garlic, ginger, chillies, turmeric, cumin, coriander, fenugreek, tamarind, fennel, black pepper and mint are contributing maximum for total spices production. India exported around 1.76 million tonnes of spices and value-added products to the value of around Rs.31,000 crores during 2020-21. The demand for spices and its products is increasing and sustaining their production in the era of climate change is a great challenge. The temperature is raising temperature, rainfall is erratic and frequency of extreme weather is increasing. Creating soil resilience, practice of organic farming, growing climate resilient varieties, water harvesting and recycling, efficient irrigation systems and fertilizer use techniques, use of bio-controls, growing multiple cropping with integrated farming system, following crop advisories for timely operations, protected cultivation, mechanization for planting, intercultural operations and harvesting and institutional support would help sustainable spice production in the changing climate in India.

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Strategies Approaches for Climate Resilient and Sustainable Production of Seed Spices

GOPAL LAL

Introduction

Seed spices (viz., cumin, coriander, fennel, fenugreek, ajwain (Carrom seed), anise, caraway, celery, dill and nigella) are annual herbs considered to be high value low volume crops used mainly for culinary, medicinal and cosmetic purposes. Indian arid and semi-arid parts are known as Seed Spices Bowl (Rajasthan and Gujarat) and contribute about 80% of total seed spices production. Seed spices are also grown in some other states on considerable areas such as Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Orissa, Punjab, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu. India is the largest producer, consumer and exporter of these commodities in the world. Seed spices contribute about 51.79 % of total area and 19.06 % of production of total spices in the country (Lal, 2018). The area under seed spices is about 2.15 million hectare and production is about 2.06 million tons with an average productivity of about 960 kg/ha (DASD, Calicut- 2020-21, 2nd Adv. Est.). The country is consistent source of quality seed spices for importing countries worldwide.

This small horticultural segment plays a significant role in the country's economy because of its large domestic consumption and growing demand for export. India is exporting about 23 percent of its production annually and fulfil nearly 50 percent of world demand. The total export of seed spice crops in quantity term is 4,82,550 tones valued Rs 5666 crore, out of which cumin alone contributes 2,99,000 tones valued Rs. 4253 crore annually (Spice Board India, 2020-21). Besides India, seed spices are also being grown in different part of the world covering mainly Mediterranean region, South Europe and Asia.

Climate change refers to an increase in average global temperature which may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014). Natural events and human activities are believed to be contributing to an increase in average global temperature. The increase in the average global temperature is mainly due to emission of greenhouse gases. The effect of global warming is seen in many parts of the world including India causing serious concern for the last few years. Climate change poses a grave threat to the sustainability of agricultural systems and food security worldwide with negative consequences for growing world population in the 21st century. Climate change affects agriculture through changes in average temperatures, rainfall, and extremes heat, extremes cold waves, changes in atmospheric CO_2, changes in pests and diseases and ground-level ozone concentrations, changes in sea level, and changes in the nutritional quality of foods.

Climate change also affects food security at the global, regional and local level. Change in climate can disrupt food availability, its supply and quality. Today's global warming becoming a worldwide concern, particularly, after the (IPCC) 4th Assessment Report in 2007. The increasing in temperature day-by-day due to global warming is 0.76°C since 1850. The rate of warming in the last 50 years is double than that for the last century. There is the prediction in increase in temperature is of 1.8-4°C by the next century. Climate change is not only increase in

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temperature or increase in greenhouse gasses, but also accounts uncertainty in time, amount and intensity of rainfall, occurrence of hailstorms, cloudiness and fog during entire day, high speed winds, occurrence of frost and wide variation in day and night temperature, all are the effects of climate change.

Different seed spice crops are grown in the country and majority of them have location specific requirements, possible impacts of climate change in these crops needs to be thoroughly analyzed for devising the future strategy to enhance the adaptive capacity of growers. Climate change is serious constraint, which accounts for enormous losses in terms of seed yield and quality of seed spice crops. Hence, there is an immediate need to focus the attention on studying the impact of climate change on growth, development, adaptability, yield and quality of these crops.

A. IMPACT OF CLIMATE CHANGE ON SEED SPICES PRODUCTION AND QUALITY

The possible impacts of global warming on seed spices production will depend not only on climate per se but also on the internal dynamics of production systems, including their ability to adopt to the changes like frost, cold winds, unseasonal rains, relative difference in maximum and minimum temperature etc. Due to all these factors there may be decline in productivity and quality, harboring new pest and diseases, new physiological disorders. Seed spices are generally cool season crops and perform well under arid and semi-arid conditions with average day and temperature of 5-27^{0}C. Seed spices perform well even under less moisture conditions with 2-6 irrigation varying from crop to crop. These crops are more susceptible to alterations in normal climatic conditions as compared to their arable crops. As diverse seed spice crops are grown in the country and majority of them have location specific requirements, possible impacts of climate change in these crops needs to be thoroughly analyzed for devising the future strategy to enhance the adaptive capacity of growers.

1. **High/increasing temperature:** The specific temperature requirements of the crops implies that even slight increase in the mean temperatures (maximum and minimum) could result in lower yields and may affect quality of the produce. Seed spice crops are very sensitive to temperature and these affect the production and quality. Being the low temperature requirement for successful production of these crops there is need of specific day and night temperature for germination, growth and seed development. If there is any imbalance in day and night temperature there will be changes in traditional production system. Increase in temperature may reduce the duration of maturity, pollination-pollinators activities, higher evapotranspiration etc. Increase in day temperature with more variation in day and night temperatures adversely affects the growth and brings forced flowering in most of the seed spice crops. Heavy losses have been observed due to combined effect of chilling and frost injury. Cumin, coriander, fenugreek, ajowan and nigella, are very sensitive crops to frost. Incidence of frost causing serious loss in yield almost reaches up to zero. So far no efforts have been made to identify the source of resistance against low temperature injury in available germplasm of seed spices crops (Sastry, 2017).

2. **Influence on PGRs:** Plant materials are also being utilized for developing improved crop varieties for high yield, superior quality and better adaptation to various stress environments (Bansode et al., 2015). Plant genetic resources (PGR) represent the diverse gene pools including landraces, primitive cultivars, varieties of traditional agriculture, wild & weedy relatives of crop plants etc. (IPGRI, 1993). The distribution of germplasm of crops and their relatives which are vital for the breeding of crops may be affected relentlessly.

3. **Effect on adoptability and suitability of crops and varieties:** Since crops and varieties require specific environmental conditions for their growth and development, the adoptability and suitability may be changed due to change in climatic conditions. The area under seed spices cultivation may be changed due to incident of extreme weather condition and occurrence of diseases which will reduce the crop production. During the last few years

there is huge crop loss has seen in cumin due to *Alterneria* blight disease which was mainly spread by air under cloudy weather conditions. If there is a cloudy condition for three to four days there will be more than 90% crop loss has been observed in Rajasthan. Due to climate change cultivated varieties may not adopt itself to that particular location. For example GC-4 is main variety adopted in all cumin growing areas but this variety has failed to adopt itself in Ajmer condition due to occurrence of blight. Many coriander varieties in Kota region of Rajasthan get heavily infested by stem gall which was not previously that much problematic (Anonymous 2017-18).

4. **Changes in rainfall pattern:** Unexpected drought and rainfall are the most important factor affecting global food security from the past. We have experienced this uncertainty in Uttrakhand in 2013, Jammu and Kashmir in 2014, Tamilnadu in 2015 and Kerala in 2018. Uncertainty in time, amount and intensity of rainfall has both positive and negative effects on spice production. Timely normal rainfall has positive effect on growth while, very less and high rainfall will often have destructive consequences for production and productivity of seed spices. Climate change leads to the heavy rainfall which may result in physical damage to the crops. In 2006, Barmer district of Rajasthan flood situation happened due to heavy rainfall. In case of seed spice crops uncertain rains will be expected during February-March during which all the seed spices crops will be in seed setting and maturity stage. If this rainfall occurred there will be huge crop losses in terms of yield and quality. During the month of February and March in 2014 and 2015 rains with heavy hailstorm has damaged the all seed spice crops particularly coriander in Kota, Bhara, Antha districts of Rajasthan and parts of Madhya Pradesh. In the same way cumin, fennel, coriander was damaged in other parts of Rajasthan.

5. **Growth and development of crops, their yield and quality:** Temperatures will be increasing but photoperiods will not change so, crops depend on photoperiod will be affected. Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf abscission, decreased photosynthesis, and loss of cellular integrity. Enhancement in the average temperature leads to faster the growth and development and crop will mature before time. In temperate areas, option of growing vegetables crops in the summer expand and early and late crop can be grown. Increased heat stress will affect production, yield and quality of seed spices. The increase in the temperature drastically affects the oil formation in the seed and reduced the quality. Due to severe cold wave, seed spice crops suffer a yield loss of 10-90 % depending upon crop and variety. Production of cumin is mainly decreased due to frost damage during December –January when there will be very low temperature during night. Rainfall during maturity of coriander and cumin will turn black and become unsuitable for marketing. In case of dill seed untimely rains cause seed shattering.

6. **Change in pollinator behavior and pollination:** Seed spices crops are mainly cross pollinated and pollination is carried out by honey bees other similar pollinators. Bee pollinators includes *Apisdorsata, A. florea, A, mellifera* and *A. cerana*. Change in the climate may be a vast threat to pollination services due to reduced activity of pollinating agents. Among all the climatic factors, increase in temperature has highest adverse effect on pollinator interactions (Hegland *et al*., 2009; Memmott *et al*., 2007). Under high temperature conditions of 40-50^{0}C only *A. dorsata* can work and working efficiency of other bee species will reduce drastically and completes its foraging activity early in the day. In the same way due to climate change event of cloudiness, fog, cold winds may hamper the pollinators in their regular pollination activities (Schweiger *et al*., 2010). In the same way due to climate change event of cloudiness, fog, cold winds may hamper the pollinators in their regular pollination activities.

7. **Influence on soil and water:** Soil is an important and the second largest carbon store, or ‘sink’, after the oceans. Climate change may result in more carbon being stored in plants and soil due to vegetation growth or more carbon being released into the atmosphere.

Soils form through the multifarious interaction of a number of forces, including climate, relief, parent material, organisms, all acting over time. It takes thousands of years for a soil to form and most soils are still developing following changes in some of these soil forming factors, particularly climate and vegetation, over the past few decades. Climate is one of the most important factors affecting the formation of soil with important implications for their development, use and management perspective with reference to soil structure, stability, top soil water holding capacity, nutrient availability and erosion (Asit and Neenu, 2012; Karmakar, *et al*., 2016). So, when temperature is rise Seed spices are mainly grown in arid and semi-arid area of India, demand for the water increases in plants with rising temperature as compared to temperate climatic conditions. Enhancement in transpiration from plants and evaporation from soil causes the shortage of water. Shortage of water increased the moisture stress in the soil resulting more irrigation requirement.

8. **Effect on biotic and abiotic stresses:** Microclimatic conditions of an area and/or any cropping environment, its temperature and relative humidity influence the buildup of insect pests and diseases. Increasing temperatures are likely to enhance new niches for insect pests and diseases of seed spices. Aphid infestation in coriander, cumin, fennel and fenugreek is very high if temperature during the month of January shoots up. More variation in day and night temperature and cloudy conditions during January and February months will favour the aphids to develop faster and leads more blight and stem gall infection and spread. Cumin wilt and blight is a major challenge against changing climatic conditions. Cumin wilt is caused by *Fusaruim oxysporumsp cumini* which is soil born fungal pathogen survives in soil during off season (monsoon) and as soon as cumin crop sown wilt disease will develop. *Alternaria* blight in cumin is most devastating problem in cumin growing areas, where cloudy and high humidly persists. But in Western Rajasthan prevalence of this disease is very less due dry climate. Stem gall disease in coriander which is severe problem in Kota, Barah and some parts of Madhya Pradesh. This disease is mainly spreads through soil, seed and air born. When rainfall occurred during mid-February when crop at seed setting stage will prone to major loss and there will be 100 percent loss may be recorded. Powdery mildew in fenugreek and coriander will favors by high temperature and high humidity. Normally during end of January and starting of February month, if there is any more fluctuation in day and night temperatures will increase the severity of powdery mildew (Khare *et al*., 2014 a&b). Interactions of pathogen or parasite with a plant may change with changing environment. A pathogenic fungus becoming more common in an increasing rainfall area. Under the changing climatic situations existing pathogens (fungi, bacteria, viruses) may cause more damage to the crops, some of the minor pests may become major pests in future. Yellowing and reddening immerged new problems in cumin growing area of western India. Similarly root rot in fenugreek & nigella and root cracking in coriander (physiological problem due to variation in day night temperature and moisture stress) reported recently.

9. **Economic consequences:** The seed spices are export oriented commodity and the price of these commodity may increase under the climate change due to low in the production in long term effect. The increased in temperature leads to increase the frequency of irrigation will be required because of higher evaporative demand. Due to high temperature plants also required high water and nutrients. The activity of insects and diseases will change due to variation in temperature, cloudiness and uncertain rains will increase the use of fungicides and pesticides which will increase the cost of cultivation. The efficacy of fungicides and pesticides will be reduced at high temperature and may cause phytotoxic effect. Even use of some protected cultivation practices to avoid frost and uncertain rains in these seed spices will also add to cost of cultivation.

B. STRATEGIES AND APPROACHES FOR CLIMATE RESILIENT AND SUSTAINABLE PRODUCTION OF SEED SPICES

Climate change is a very serious problem, which accounts for sever losses in terms of yield and quality of seed spices. Hence, there is an immediate need to focus our attention on studying the impacts of climate change on adaptability, growth, development, yield and quality of these crops. Discussed below some measures, which can make the seed spices and their growers more resilient to changing climate.

1. Reduction in emission of Greenhouse Gases

There is urgent need in the cut of CO_2 emission and other greenhouse gases, in this regard Paris Climate Change Conference - November 2015 was held. Many countries promise to cut the emission of CO_2 like China pledges deep cup cut of CO_2 emission, EU wants to cut carbon emission 60% by 2050, India 35% by 2030, Japan 35% by 2030 etc.

2. Intensive germplasm collection and selection of suitable crops and varieties

The increase in global warming may destroy much germplasm line and their wild relative so, intensive germplasm collection is needed to use it in future as per need. Selection of available cultivars which are more adaptable to a changing and variable climate will be the main tool for adaptation in the era of climate change. Breeding of suitable seed spice varieties with respect to particular problem is most important to adopt in climate change scenario. Some of the varieties developed at ICAR-National Research Centre on Seed Spices, Ajmer and AICRPS centers are showing tolerance/resistance and adoptability to climate variations. Adoption of alternate crops such as ajwain and anise in the place of cumin in Ajmer condition. These crops are as good as cumin in terms of duration, price and demand apart from being less prone to pest and diseases and crop loss due to uncertainties.

3. Selection and breeding of resilient crops and varieties

Selection of available cultivars which are more adaptable to a changing and variable climate will be the main tool for adaptation in the era of climate change. Breeding of suitable seed spice varieties with respect to particular problem is most important to adopt in climate change scenario. Some of the varieties developed at ICAR-National Research Centre on Seed Spices, Ajmer are showing tolerance/ resistance and adoptability to climate variations. Recently ICAR-NRCSS has developed 02 stem gall resistant varieties (Ajmer Coriander-1 and Ajmer Coriander-2). Development of new cultivars of seed spice crops tolerant to high temperature, resistant to pests and diseases, short duration and producing good yield under stress conditions should be the main strategies to meet this challenge. Evaluation of available seed spice germplasams for adoptability to varying climate conditions. Development of plant ideotype suitable for climate change. Since the seed spice crops are having very narrow genetic base, hence there is an urgent need to widen the genetic base of seed spices to create more variability in terms of adaptability, resistance to pest and diseases. Therefore, breed such types varieties which can tolerant heat stress and in the high productive and can produce good yields even in arid and semi-arid conditions. The use of molecular markers as a selection tool provides the potential for increasing the efficiency of breeding programs by reducing environmental variability, facilitating earlier selection and reducing subsequent population sizes for field testing. Molecular markers facilitate efficient introgression of superior alleles from wild species into the breeding programs and enable the pyramiding of genes controlling quantitative traits. Thus, enhancing and accelerating the development of stress tolerant and higher yielding cultivars for farmers in developing countries.

Table 1. List of some varieties tolerant to biotic/abiotic stresses

S.No.	Crop	Variety/rootstock	Character(s)
1	Coriander	ACr-1& ACr-2	Resistant to stem gall
2	Cumin	GC-4	Resistance to wilt
3	Fenugreek	AFg-4	Resistant to powdery mildew
4	Ajwain	AA-93	Drought tolerant, photo-thermo insensitive, short duration
5	Celery	ACel-1	Early maturity
6	Coriander for green leaf	Ajmer Green Coriander-1	Suitable for summer cultivation

4. Cultivation under protected structures

Since the seed spices are winter season crops there is need to protect crops from frost and also to boost the growth of crop. Use of temporary plastic/ cloth walls, walk in tunnels or insect proof net house in low statured crops like cumin, fenugreek and coriander will helps in protecting from adverse effects of untimely rains, hail storm, frost and clod waves. In tall crops like fennel, dill use of high walk in tunnel are advisable. It will also advance the crops for 30 days compared to open cultivation. Similarly shade nets (60%-75%) proved to save the crops from high temperature and hot winds in summer (off season) cultivation of leafy seed spices like green coriander and fenugreek.

5. Use of micro irrigation system

Application and utilization of water judiciously in the form of drip, mist and sprinkler will be a key factor to deal with the drought conditions. But to manage few diseases and pests it is necessary to adopt new irrigation technologies that will reduce severity. Raised bed with drip fertigation proved to reduce the damage by weather vagaries like frost, cold waves, hot winds etc.

6. Forecast models for the management of stresses

In the scenario of climate change, there is need to develop crop specific and region-specific forecast models so that farmer can take necessary precautionary measures to protect the crops from stresses (biotic & abiotic). Lot of work is to be done on predicting impact of climate change on seed spice crops accurately on regional scale. All the seed spices like cumin, coriander, fenugreek, fennel, fenugreek, ajwain, nigella etc. urgently need crop robust simulation models. Prediction of vulnerability of existing areas under these crops to climate change scenario can be examined and new target areas for possible shifting of crops and their varieties for cultivation can be identified with the help of these simulation models.

7. Crop diversification

To reduce the effect of climate change and to increase the profitability of farmers, diversification is important. Under intercropping situations, the seed spices being arid land spices grow well as component crop in arid fruit orchards viz. Aonla and ber. Similarly in Fennel, Ajwan, Dill crops, the vegetable crops viz., guar (Cluster bean) for green pods, summer squash, chilies, onion, radish and carrot can be intercropped. The yield advantage of intercropping combination originates either due to higher yield of individual crop or due to higher plant population densities or both. The seed spices crops, known as arid land spices have fairly good production growing them with component crops and vice versa, which shall ultimately contribute towards improving the economy of farmers by giving additional income (Vashishtha and Malhotra, 2003). It is pertinent to know that in degradation of natural resources, mono-cropping plays a crucial role, which led to reduction in sustainable production and income of growers due to negative impact biotic and abiotic stresses in such a fragile eco-system of semi-arid to arid regions. Most of the seed spices crops (particularly cumin, dill seed, coriander, ajwain, nigella) are low input (water & fertilizer) loving crops as compared to other field crops. The returns from such diversification programs have yielded sufficient incomes. With dwindling arable land and increased demand of seed spices, it seems that more land area will not be available exclusively for cultivation of such crops. Therefore, a strategy has to be worked out to incorporate these crops into regular agricultural systems in order that more land use efficiency can be achieved while maintaining the basic agriculture production system (Lal and Verma, 2018).

8. Adoption of GAP and scientific crop production practices

Good Agricultural Practices (GAP) and standard scientific crop production practices like timely sowing, appropriate seed rate, line sowing, sowing on raised beds with MIS system, required & timely irrigation, IPM, IDM and INM practices already proved the sustainable production of these crops with higher yields and quality in the present scenario of climate change.

9. Mechanization

There is a lot of scope in seed spices sector to work upon mechanization right from filed operations to harvesting or after harvest. Farm mechanization or post farm mechanization not only enhance the productivity and quality of produce but also save time and labor.

10. Secondary agriculture

Significant losses (up to 25% in non-perishables) were recorded in agricultural produce including spices after harvesting, during collection, threshing, transportation, storage, distribution etc. due to storms, rains and other vagaries.To save the crop from sudden change in the climate after harvesting, farmers should have the facilities to protect the crop and they can create facilities for farm level processing and secondary processing to enhance the income. There must be focus on secondary agriculture like packaging and processing for value addition (Lal and Mehta, 2013; Lal *et al*., 2015).

11. Government policies

Policies will play a key role in enhancing the ability of agriculture to adapt to climate change, while also contributing to other environmental goals.

Conclusion

Adaptation and mitigation strategies are short and long-term changes to human activities that respond to the effects of climate changes. Adaptation will require cost-effective investments in water infrastructure, emergency preparation for and response to extreme weather events. Intensive research work is needed to widen the genetic base of seed spices, selection and breeding of resilient crop varieties that tolerate temperature and precipitation stresses, short duration, hardy in nature, resistance to pest and disease etc. Development and adoption of climate resilient crop management technologies and development of pest and disease forecast models in seed spices sector is the need of the hour. Standardization and adoption protected cultivation technologies like temporary plastic/cloth walls, walk-in tunnels made of ploythene sheet, high tunnels, insect proof net, shade nets etc. may plaid crucial role in mitigating the uncertain weather vagaries.

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Strategic Approaches for Climate Resilient and Sustainable Production of Plantation Crops in India

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1. Introduction

Plantation crops are though small in the share of horticultural is an important segment sector, essentially and commercially larger agricultural undertakings, which also have certain industrial characteristics and play a vital role in the agrarian economy of many states in India. The major plantation crops in the country include coconut, arecanut, oil palm, cashew, cocoa, tea, coffee and rubber. Besides, spice crops and cocoa are also considered as plantation crops. Plantations provide high level of productivity and employment, apart from their catalyzing contributions towards rural development. Being a labour-intensive enterprise, supplying modern technology and management tactics, plantation crops make the optimum use of the marginal land resources. They generate considerable foreign exchange earnings by way of export. Most of the crops also contributing nutraceutical and pharmaceutical properties and provide health and wellness security. Plantation sector in the country is dominated by millions of small and marginal farmers and mainly confined to economically and ecologically vulnerable regions play an essential role as for as the sustainability is concerned.

According to the Third Assessment Report of Inter-Governmental Panel on Climate Change (IPCC), it was found that average surface temperature of the earth has increased by 0.6 ^{o}C over the 20th century. The sea level rise has also been estimated at a rate of 1 - 2 mm annually during the last century. It further forecasts that globally averaged surface temperature would rise by 1.4 to 5.8 ^{o}C and the global mean sea level may rise by 0.09 to 0 88 mm during 1990-2100 (UNIES 2007). IPCC has already forecasted that in the coming decades, agriculture worldwide will have to face negative aspects of this changing climate. It is anticipated that the effects on crop yields in the mid and high latitude regions would be less adverse than in low latitude regions. Decrease of potential yields in warmer areas is likely to be due to shortening of crop growth period, decrease in water availability due to higher rates of evapo-transpiration and poor vernalization (Chattopadhyay 2005).

Due to climate change, the increase in temperature and variability in rainfall pattern could lead to development of abiotic stresses like heat, drought and flooding. These stresses could occur in varying degrees coinciding with different growth and phenological phases of crops, in turn affecting their productivity and quality. Hence timely and appropriate measures to overcome negative impacts of climate change on oil palm needs to be initiated. In this paper, the potential impacts of high temperature, water stress and elevated CO_2 on plantation crops and possible adaptation strategies to overcome these impacts are discussed.

2. Plantation Crops Status in India

The area and production of plantation crops are given in the table 1. The leading plantation crops being grown in India are coconut, cashew, arecanut and cocoa, which are mainly grown on the fields of small and marginal farmers. The total production of plantation crops during 2020-21 has been 17.9 million

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tonnes from an area of 5.14 million ha. Coconut accounts for the largest share amongst plantation crops in terms of production, followed by cashew nut and areca nut. The major plantation crops producing states are Kerala with 29.66 percent share, Karnataka with 28.80 percent, Tamil Nadu with 25.81 percent share and Andhra Pradesh with 5.89 percent share, which together contribute to about 90 percent of all India production. The productivity of different plantation crops along with its distribution is given in Table 2.

Plantation crops like coconut, arecanut, oil palm, cashew, tea, coffee, rubber and cocoa are high value commercial crops of greater economic importance, occupying an area of 3.7 million ha, with the production of 18.02 M million t (Horticultural Statistics at a glance 2018). Plantation crops are cultivated in an extensive scale in a large contiguous area, owned /managed by an individual small holder's or a company. The plantation crop sector is well integrated with many other sectors of the economy through vertical and horizontal linkages. Their total coverage is comparatively less but they contribute to national economy by way of export earnings to a great extent. Though the production share of plantation crops and spices are small among the horticulture crops, it contributes significantly in terms of export earnings (Fig. 1). The export value of Plantation crops is continuously increasing over the years (Table 3). The export of plantation and spices crops significantly increases more that of vegetables and fruit crops and their processes products.

Export of plantation crops are increasing every

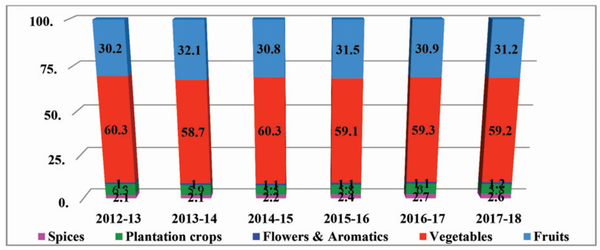

Fig. 1: Production share of horticultural crops
Source: Department of Agricultural Statistics and Ministry of Commerce

Table 1: Area and Production of plantation crops in India (1980-2020)

Crop	1980-81		1990-91		2000-01		2010-11		2020-21	
	Area	Prodn	Area	Prodn	Area	Prodn	Area	Prodn	Area	Prodn
Arecanut	0.19	0.20	0.22	0.24	0.29	0.33	0.40	0.48	0.45	0.73
Cashew	0.46	0.19	0.53	0.29	0.72	0.45	0.95	0.67	1.03	0.74
Coconut	1.08	57.2	1.48	97.3	1.84	125.9	1.90	157.5	2.08	239.1
Coffee	0.19	118.7	0.22	169.7	0.31	301.2	0.41	302.0	0.45	316.0
Rubber	0.19	0.15	0.31	0.33	0.40	0.63	0.48	0.86	0.57	0.63
Tea	0.38	569.6	0.42	720.3	0.50	848.4	0.58	966.7	0.56	1233.0

(Area in Mha and Production in MT. Production of tea and coffee in m kg and production of coconut in '00 M nuts)
Source: Directorate of Economics and Statistics, Ministry of Agriculture, GOI & FAOSTAT

Table 2: Productivity and Distribution of Plantation Crops in India

Crop	Productivity	Major State
Arecanut	1616 kg/ha	Karnataka and Kerala
Cashew	720 kg/ha	Maharashtra, Karnataka, Kerala, Orissa, TN and AP
Cocoa	5.3 q/ha	Karnataka and Kerala
Coconut	11481 nuts/ha/y	Karnataka, Kerala, TN and AP
Coffee	696 kg/ha	Karnataka, Kerala, TN
Oil Palm	2-3 t oil/ha	AP, Mizoram and Karnataka
Rubber	1105 kg/ha	Kerala, Tripura, Karnataka, Tamil Nadu, Assam
Tea	2201 kg/ha	Assam, West Bengal, TN, Kerala

Source: Department of Agricultural Statistics and Ministry of Commerce

Table 3: Export of Plantation crops and its products by India

Crop	1991-92		2001-02		2015-16		2020-21	
	Qty. ('000 t)	Value[1] (millions)	Qty. ('000 t)	Value[1] (millions)	Qty. ('000 t)	Value[1] (millions)	Qty. ('000 t)	Value[1] (millions)
Arecanut/Cacao	0.21	111.0	-	140.0	-	-	26391.02	2294.81
Coconut & Products	31.00	74.5	-	34.58	-	131.24	110	3112.22
Cashewnut & Products	47.74	44.22	99.36	17810	42.34	131.24	70.088	420.41
Spices	142.10	381.0	243.2	19405	821.0	1053.1	1565	27193.20
Tea	216.45	12123	190.00	16960	232.92	449.31	202 m kg	54519.0
Coffee	111.45	3490	213.00	10500	562.0	517.59	310.691	52316.9
Natural Rubber	5.83	-	13.35	-	-	-	11.343	-
Total	1130.88	29723	1451.29	903.15	203940	1203.45		139856.54

Source: Department of Agricultural Statistics and Ministry of Commerce

year and there is larger demand for these crops. Among the horticultural crops spices has earn high foreign exchange than fruits and vegetable. Plantation Crops earn more export earning than the other horticultural crops even though they have small area compared to other horticulture crops.

3.0 Climate Requirements of Plantation Crops

Plantation crops are grown in varied climatic conditions. However, they are sensitive to extreme climatic conditions. In general, climate influences the yield to the extent of 50%. Climatic requirement *viz.,* altitude, optimum temperature, relative humidity and rainfall required for various plantation crops are presented below:

Table 4: Climatic requirements of plantation crops in India

Crop	Altitude (MSL)	Optimum Temperature (oC)	Relative Humidity (%)	Rainfall (mm)
Arecanut	1000	25-27	70-80	1000-2500
Cashew	750	24-28	40-50	600-1500
Cocoa	600	25-27	70	1250-3600
Coconut	450	24-26	70	1300-2500
Oil Palm	300-400	24-28	45-50	2000-3000
Rubber	450	24-26	70	1800-2500
Tea	650	20-22	60-70	1250-2000

Coconut: Coconut is mostly grown between 20^{o} N and 20^{o} S latitudes. The optimum weather conditions for good growth and nut yield in coconut are well distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27^{o}C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least

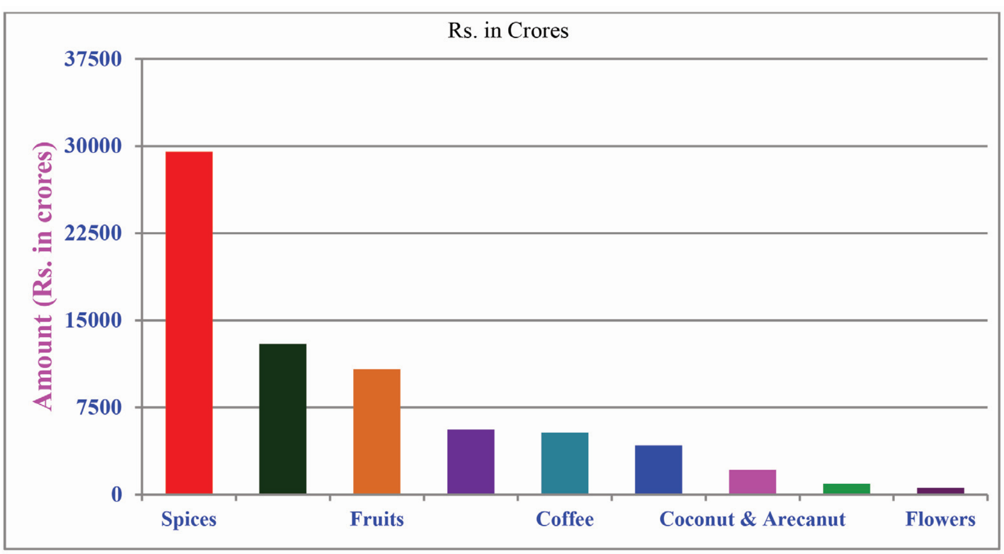

Fig. 2: Export earnings by India from horticulture crops
Source: Department of Agricultural Statistics and Ministry of Commerce

120 hours per month of sun shine period. Since, it is humid tropical crop it grows well above 60% humidity (Child, 1974, Murray, 1977). Coconut is versatile crop provide lot of products essential for human life. The export of valueadded products are also on the increase.

Arecanut Arecanut is grown within 28° N & S of equator. Rainfall, relative humidity, altitude, evaporation and temperature affect the yield of arecanut (Sunil et al. 2011). Lower temperatures at higher elevation are unsuitable for arecanut. In north east region of India, the crop is grown in plains. Even though the crop can be grown at altitudes of 1000 MSL, it is seen that the quality of the nut deteriorates as altitude increases (Nambiar, 1949). The temperature range of 14°C-36°C is optimum for better growth of arecanut. In India, the crop is being grown in temperatures ranging from 5°C (as in places like Mohitnagar, West Bengal) and at 40°C (Vittal in Karnataka and Kannara in Kerala).

Oil Palm: The ideal climatic requirements for oil palm are an annual rainfall of 2000 mm or greater, evenly distributed, preferably at least 100 mm in each month and without a marked dry season, mean maximum temperature of 29 – 33°C, mean minimum temperature of 22 – 24°C, relative humidity above 45 per cent, low vapor pressure deficit, sunshine of 5 – 7 h day^{-1} in all months and solar radiation of 15 MJ m^{-2} day^{-1}(Suresh et al., 2016). This is a potential crop for increasing the vegetable oil pool of the country and thereby reducing the import bill on vegetable oils.

Cocoa: Cocoa is generally grown as an intercrop in coconut, arecanut, and oil palm plantations in India. The annual rainfall in most of the cocoa growing areas lies between 1,250- 3,600 mm. Cocoa growing areas have uniformly high humidity, often 100% during night falling to 70-80 per cent by day. Cocoa can be successfully grown up to 300 m above MSL. The temperature in most of the cocoa growing areas lies between a maximum of 30-32°C and a minimum of 18-21°C. High temperature reduces the pod growing period and in turn the yield and bean size are compromised.

Cashew: Cashew is a tropical crop growing between 28°N and S latitude. The phenology of cashew is very much influenced by the altitude of the region. Though cashew grows at an elevation ranging from 0 to 1000 m above mean sea level (MSL), but the productivity is the highest up to the altitude of 750 m above MSL. Low temperatures at higher altitudes have adverse effect on the crop. Flowering and fruiting are delayed irrespective of latitude at higher altitude. Areas with low altitude and mean rainfall of 1500 to 2000 mm are excellent for cashew cultivation. Damage to young trees or flowers occurs below the minimum temperature of 7° C and above the maximum of 45° C. Only prolonged cool temperatures will damage mature trees; cashew can survive temperatures of about 0° C for a short time (Ohler, 1979). Environments with maximum temperature ranging from 28 to 32 °C, minimum winter temperature around 19 °C and 70 to 80 per cent relative humidity are satisfactory for better output. Frost is detrimental to the crop (Mandal, 1992). Cashew contribute very greatly to the export income of the country.

Coffee: Coffee production in India is predominantly in the hill tracts of South Indian states, with Karnataka accounting for 71%, followed by Kerala with 21% and Tamil Nadu (5% of overall production with 8,200 tonnes). Indian coffee is said to be the finest coffee grown in the shade rather than direct sunlight anywhere in the world. There are about 250,000 coffee growers in the country; 98% of them are small growers. As of 2009, Indian coffee made up just 4.5% of the global production. Almost 80% of Indian coffee is exported. Ideal climatic conditions to grow coffee are related to temperature and rainfall; temperatures in the range of 73 °F (23 °C) and 82 °F (28 °C) with rainfall incidence in the range of 60–80 inches (1.5–2.0 m) followed by a dry spell of 2–3 months suit the *Arabica* variety. Cold temperatures closer to freezing conditions are not suitable to grow coffee. Where the rainfall is less than 40 inches (1.0 m), providing irrigation facilities is essential. In the tropical region of the south Indian hills, these conditions prevail leading to coffee plantations flourishing in large numbers.[27] Relative humidity for *Arabica* ranges 70–80% while for *Robusta* it ranges 80–90%. India is the third-largest producer and exporter of coffee in Asia, and the sixth-largest producer and fifth-largest exporter of coffee in the world. The country accounts for 3.14% (2019-20) of the global coffee production. The coffee production stood at 299,300 million tonnes (MT) during 2019-20. The coffee production during 2020-21 is estimated at 342,000 (MT).

Rubber: Rubber is a perennial rainfed crop being cultivated in India since the beginning of the 20th century (Sethuraj and Jacob, 2012). Traditionally this crop has been cultivated along the foothills of the Western Ghats up to an altitude of about 450-500 m above MSL in Kanyakumari district of Tamil Nadu and Kerala. In recent decades its cultivation has expanded to further North along the Western Ghats as well as in parts of North East India and pockets along the Eastern Ghats (Krishan, 2013). The quantity of natural rubber which was exported from India accounted for over 12 thousand metric tons during fiscal year 2020. This was a significant increase from the previous fiscal year.

Tea: Tea crop is generally cultivated in tropical and sub-tropical climates. Tea needs a hot, moist climate. Its specific requirements for growth and development are temperature ranging from 10 to 30 °C, minimum annual precipitation of 1250 mm, preferably acidic deep and well-drained soil with pH of 4.5-5.5 and adequate organic matter content. The Assam-type is believed to have originated under shade of humid, tropical forests. China-type is thought to have originated under cool open conditions, humid tropics (Carr and Stephens, 1992). Because of the distinct difference in geographical and ecological origins of ecotypes, they exhibit considerable variations in their physiological, yield and quality traits (De Costa et al. 2007). India stands fourth in terms of tea export after Kenya (including neighbouring African countries), China and Sri Lanka.

Spices: Indian spices include a variety of spices grown across the Indian subcontinent (a sub-region of South Asia). With different climates in different parts of the country, India produces a variety of spices, many of which are native to the subcontinent. Others were imported from similar climates and have since been cultivated locally for centuries. Pepper, turmeric, cardamom, clove, nutmeg, cinnamon all spice and cumin are some examples of Indian spices. In fiscal year 2021, the export value of spices from India amounted to over 295 billion rupees. It was a consistent and significant increase in export value from about 78 billion rupees in fiscal year 2011.

4.0 MAJOR CHALLENGES IN PLANTATION CROPS

The plantation crops have been continuously facing the problem of under investment and low capital formation. The yield levels of coffee and arecanut continue to be well below the desired levels in comparison to the global average productivity level. The plantation crop sector has shown considerable inertia to adopt modernization. This is visible across the prevalent practices followed in post harvest operations, level of technology adoption, mechanization and cultivation practices. There is an urgent need for modernization of the plantation crop sector and allied activities. The small size of the holdings in plantation crops presents both challenges and opportunities for sustainable growth. Developing suitable marketing channels and value chains suited for widely disaggregated production environment is one of the biggest challenges faced in almost all the plantation crops. The technologies available, especially in mechanization of operations, are often not suitable for adoption in small holdings. This presents considerable challenges for increasing the efficiency of production through mechanization. The products from the plantation crops have an essentially international character and the move towards open economy means that the international prices of the commodities and the price shocks are easily transferred to the domestic markets.

Over the last five decades, the prices of the commodities from the primary sector showed a declining trend in real terms. This was especially true in case of the products from the plantation crop sector. The increase in demand for the products did not translate to higher prices due to the rise in productivity of the crops and consequent increase in supply of the commodities. In short, the productivity enhancement did not benefit the primary producer of the commodity and the benefits mainly went to the consuming classes. The depressed prices of the commodities continue to be a major challenge in plantation crop sector.

Yield gaps in Plantation crops: The yield gap is difference between a crop's maximum potential yield and actual realized yield. Understanding the yield gap helps to feed the world's growing population. Following are the yield gaps with respect to Plantation crops.

- Basic physiological processes underlying the production of plantation crops are not well understood due to perennial nature.
- Dearth of quality seed or planting materials.
- Lack of genetically pure varieties.

- Lack of supplementary irrigation during initial crop establishment.
- Lack of pest and disease control at right time.
- Imbalanced use of organic and inorganic fertilizers.
- Non-efficient canopy management
- Prone to climate change effects (drought, high temperature, waterlogging, frost)

5.0 RESEARCH INSTITUTES WORKING ON PLANTATION CROPS IN INDIA

Crop	Research Institute in India
Arecanut	Central Plantation crops Research Institute, Kasaragod, Kerala
Cashew	Directorate of Cashew Research, Puttur, Karnataka
Cocoa	Central Plantation crops Research Institute, Kasaragod, Kerala
Coconut	Central Plantation crops Research Institute, Kasaragod, Kerala
Coffee	Central Coffee Research Institute, Chikmagalur, Karnataka
Oil Palm	Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh
Rubber	Rubber Research Institute of India, Kottayam, Kerala
Tea	UPASI Tea Research Foundation, Coimbatore, Tamil NaduTocklai Tea Research Institute, Jorhat, Assam

Besides these institutes there are All India network coordinated projects on Palms (Coconut, arecanut and oil palm). State Agricultural Universities'are also taking up research on species and cashew.

6.0 Effect of Climate Change on Plantation Crops

The threat of climate change is projected to be more in coastal tract and foot hills of Western Ghats of India where plantation crops are the predominant crop and provides sustenance to millions of people. The climate change will affect plantation crops through higher temperatures, elevated atmospheric CO_2 concentration, rainfall changes (*El Nino* and *La Nina*), increased weeds, pests, and disease pressure.

6.1 Atmospheric Carbon dioxide concentrations

Though increased CO_2 enhances the productivity of the C_3 plants in the arid regions of India, the increase in temperature may offset the beneficial effects of CO_2. Observations on oil palm CO_2 enriched seedlings indicated increased photosynthetic rate (12 folds) as attributed to higher intercellular CO_2 level, increased both stomatal conductance and transpiration (3 folds), and water-use-efficiency (4 folds) as compared to the control. Hence, CO_2 enrichment technique for the tropical lowlands under the Growth house prototype controlled environment is technically feasible and has a great application potential in the seedling/nursery industry (seedlings and advanced planting materials), production research and development study, and in the climate change impact analyses for possible enhanced bio-productivity and income generation (Hawa 2006).

Oil palm enriched with high CO_2 concentrations of 800 PPM recorded an increase in photosynthesis as a result of reduced light compensation point and dark respiration rate (Kubiske and Preigitzer 1996). After exposure of coconut seedlings for three years in an OTC, results indicated that in general, elevated [CO_2] at 550 and 700 µmol mol^{-1} benefited the growth and development as they assimilated more carbon dioxide, due to higher photosynthetic rates and larger leaf area, resulting in significant increase in shoot and root biomass (Hebbar et al. 2013).

6.2 Temperature

The climate projection studies indicate a general increase in temperatures in the order of 3-6°C over the base period average, depending on the scenario, with more warming in northern parts than southern parts. High temperature can have both positive and negative impacts on growth and production in plantation crops. The negative impacts such as added heat stress especially in areas at low to mid latitudes already at risk today but also may lead to positive impacts in currently cold limited high latitude regions. In seedlings high temperature increases both photorespiration and dark respiration in addition to decreasing photosynthesis thus the total biomass production go down. Palms like coconut, arecanut and oil palm are highly sensitive. Higher temperatures can reduce or even halt photosynthesis, prevent pollination and anthesis; decrease number of female inflorescences, abortion of bunches leading to bunch failure. As temperature rises, photosynthetic activity in oil palm increases until the temperature reaches 20°C. The rate of photosynthesis then plateaus until temperature reaches 35°C, where it begins to declines and at 40°C, photosynthesis ceases entirely (Suresh et al., 2010). High temperatures can also dehydrate oil palm. When oil palm folds its leaflets to reduce exposure to the sun, photosynthesis is reduced. When the stomata on abaxial side of leaflets close to reduce the transpiration load, CO_2 uptake is also reduced and thereby photosynthesis. Diurnal variations in oil palm under irrigated conditions also explains the sensitivity of stomata leading to decreased photosynthetic rates after 10.00 AM due to increase in ambient and leaf temperatures (Suresh et al., 2012). Higher temperature (> 38°C) might cause early ripening of bunches in the same whorl of palm (pseudo-ripening) during summer (1-2 weeks) leading to drastic reduction in oil extraction rates (< 8 %).

In an OTC study with elevated temperature of 3°C from ambient, the Pn of coconut seedlings reduced to 2.5 from 5 u mole m-2 s-1of ambient grown seedlings (32 to 34°C). Similar decline was seen in cocoa too, but the negative effect of temperature to certain extent was alleviated with [ECO_2] treatments (Hebbar et al. 2016). Rubber latex yield has been found to decline in the traditional rubber growing regions because T max and T min had a negative impact on rubber yield (Jacob et al. 2012). In Kerala and the Konkan regions, the prevailing temperatures are already at the higher side of the temperature threshold for rubber cultivation (Jacob et al. 1999) and therefore any further warming can become harmful in these regions. According to Satheesh and Jacob, (2011), if both Tmax and Tmin rose by 1 °C, natural rubber productivity will reduce by 9-16% in the agro-climatic conditions of Kerala and by 11% in the hot and drought-prone North Konkan region. However, in the Northeast, climate warming can improve rubber yield, because T max had a positive impact on rubber yield.

6.3 Rainfall

The climatic models predict a change in precipitation by 5-25 percent over India by the end of the century with more reductions in winter rainfall than summer monsoon leading to droughts during summer months. The major effects of global climate change on crop water relations are likely to occur due to more erratic rainfall patterns and unpredictable high temperature spells. As most of the plantation crops except arecanut and oil palm are mostly rainfed, their productivity is low in these areas by ~50% of irrigated gardens. Being perennial in nature, plantation crops had a long duration from the juvenile to adult stage and hence, the impact of drought occurring at any of the critical stages of the development will be high.

The whole plant water use efficiency of young coconut seedlings grown under well watered condition was 2.8 and it increased to 3.8 g biomass L^{-1} water with 25% available soil moisture (Hebbar et al. 2016). If the water deficit increases to more than 500 mm y^{-1}, in oil palm young fronds will not open, leaf bud cracks, becomes defective and breaks (Luibis et al. 1993). To understand plant stress responses in the form of sap flux and transpirational adjustments made by oil palm under Indian conditions, sap flow studies have been undertaken (Suresh et al. 2006; Suresh and Nagamani 2007) and results revealed that sap flux increased gradually from 9.00 AM reaching a peak during 1.00 to 2.00 A.M and decreased as day progressed. Evapo-transpiration and vapor pressure deficit also showed similar trend as that of sap flux.

The increasing frequency of dry conditions during recent years in Kerala, necessitated the growers to provide life saving irrigation to young rubber plants during first summer after field planting, which otherwise is a rainfed crop throughout the world (RRII 2015). Yield reduction in pepper was more dependent on the distribution of rainfall rather than the quantity of rainfall (Krishnamurthy et al. 2016). Cashew needs a clearly defined dry spell from January to May with occasional light summer rains ensures better production (Rupa 2016), but heavy rains during this period affect flowering. Unusual heavy rainfall between January and March may encourage high incidence of pest like tea mosquito bug and reduce yield and quality.

6.4 Climatic variability, extreme events and sea level rise

Climate change is characterized by an increase in climate variability (IPCC 2013). This may increase the risks of crop failures, often connected to speciûc extreme events during critical crop phases like heat waves or late frosts during ûowering. In addition, increase in temperature and precipitation variability would put pressure on crops grown on their marginal climate ranges. Precipitation extremes like droughts or ûoods are also detrimental to crop productivity. Higher heavy precipitation and ûooding could increase crop damage in some areas, due to soil water-logging, physical plant damage, and pest infestation (Rosenzweig et al. 2002a, b). At the opposite extreme, greater drought frequency and increased evaporative demands may increase the need for irrigation in speciûc regions, further straining competition for water with other sectors (Rosenzweig et al. 2004). In regions lacking additional water resources, entire cropping systems may go out of production. In coastal agricultural regions, sea-level rise and associated saltwater intrusion and storm-surge ûooding can harm crops through diminished soil aeration and salinity.

6.5 Pests

Pests associated with speciûc crops may become more active under climate change (Coakley et al. 1999; IPCC 1996). Increased use of agricultural chemicals might become necessary, with consequent health, ecological, and economic costs (Rosenzweig et al. 2002a, b; Chen and Mc Carl 2001). Warmer temperatures may speed development rates of some insect species; resulting in shortened times between generations and improved capacity for over-wintering at northern latitudes. Some insect populations may further become established and thrive earlier in the growing season, during more vulnerable crop stages. The emergence of two new pests viz., palm aphid and whitefly in arecanut is a consequence of either climate change or pest resurgence in perennial ecosystem (Joseph Raj Kumar 2013).

In Andhra Pradesh incidence of slug caterpillar occurs during the summer months (April – May), causing severe defoliation and reduction in yields of coconut and oil palm. The insect-crop relations are also indirectly modified with elevated CO_2; increased C:N ratio in crop leaves renders them less nutritious per unit mass and further stimulates increased feeding by insects, leading to more plant damage (Salt et al. 1995). Excessive rains leads to severe incidence of Abnormal Leaf Fall disease caused by the fungus, *Phytophthora* sp. in rubber (Pradeep et al. 2014). High rainfall with high intensity rains results in spread of fruit rot (*Phytophthora palmivora*) leading to yield reduction in arecanut (Sujatha et al. 1999). In black pepper, foot rot caused by *Phytophthora capsici* was negatively correlated with maximum and minimum temperatures and positively correlated with rainfall, number of rainy days and relative humidity. In cashew, tea mosquito bug pest and inflorescence blight disease cause considerable damage in the years of excess rain.

7.0 Strategic Approches for Climate Resilient and Sustainable production

The strategic approaches for climate resilient and sustainable production in plantation crops can be divided into parts namely Adaptation strategies and Mitigation strategies.

7.1 Adaptation Strategies

Cumulative past emissions have already committed the planet to a certain degree of climate change and associated impacts over the coming decades regardless of what local, regional and global actions are taken and which policy recommendations are adopted to slow anthropogenic emissions of greenhouse gases and thus to reduce the magnitude of climate change, Climate actions taken today will determine how such changes will further evolve in the second half of this century. Recent observations of increased frequency of climate extremes worldwide, as well as shifts in eco-zones, might be an indication of global warming-related changes already under way (IPCC 2001a, b, c; Milly et al. 2002; Root et al. 2003). Sectoral adaptation is thus very likely in the future and integral to the study of climate change impacts on agriculture (IPCC 2001a, b, c; Smit and Skinner 2002; Smith et al. 2003).

Adaptation in agriculture is the norm rather than the exception. In addition to changes driven by several socio-economic factors like policy frameworks and market conditions, farmers always had to adapt to the vagaries of weather, on weekly, seasonal, annual and longer timescales. The real issue in the coming decades will be the degree and nature of climate change compared to the adaptation capacity of farmers. If future changes are relatively smooth, farmers may successfully adapt to changing climates in the coming decades by applying a variety of agronomic techniques that already work well under current climates, such as adjusting the timing of planting and harvesting operations, substituting cultivars and modifying or changing their cropping systems. Adaptation strategies will vary with agricultural systems, location, and scenarios of climate change considered. The following factors play an important role in adaptation of plantation crops to climate change

1. Genetic factors like growing of drought tolerant varieties/hybrids
2. Crop diversification like growing short duration crops, by product utilization and value addition, etc.
3. Agronomic factors like soil moisture conservation, fertigation, micro-irrigation systems, In situ water harvesting measures, recycling of farm wastes, cropping systems, etc.
4. Socio-economic factors like income diversification, awareness campaigns, capacity building programmes and regional management programmes on watershed management, water management aspects, etc.

A. Adoption of climate resilient germplasm

The selection of crops and cultivars with tolerance to abiotic stresses like, drought, flooding, high salt content in soil, high temperature, pest and disease resistance allows utilizing genetic variability in new crop varieties if national programmes have the required capacity and long-term support to use them. To strengthen capacity of developing countries to implement plant breeding programmes and develop locally-adapted crops, FAO and other like-minded institutions have started Global Initiative on Plant Breeding Capacity Build initiative during June 2007 to implementation of Article 6 of the Treaty for supporting the development of capacities in plant breeding. It emphasizes: conserving diversity, adapting varieties to diverse and marginal conditions, broadening the genetic base of crops, promoting locally adapted crops and underutilized species and reviewing breeding strategies and regulations concerning variety release and seed distribution. FAO's work on adapted crops includes decision-support tools such as EcoCrop to identify alternative crops for specific ecologies.

All the plantation crops have rich source of germplasm accessions and they have been evaluated for different biotic and abiotic stress characters. Some of the drought tolerant varieties developed in coconut are Chandra Kalpa, Kalpatharu, Kera Keralam, Kalpa Mitra, Kalpa Dhenu, Kera Sankara, and Chandra Laksha. Utilization of identified *in situ* drought tolerant plants in population improvement programme is very important for making the crop more resilient to climate change conditions. Tall genotypes Kalpadhenu and FMST had high WUE due to better root system. On the other hand, under water deficit stress dwarf maintained higher WUE due to better stomatal regulation. Stress tolerant plants in addition to possessing higher photosynthesis, accumulated more epicuticular waxes on the leaves for better conservation of moisture.

B. Adoption of Plantation crops based cropping/farming Systems

Cropping/farming system approach is the best adaptation strategy to overcome the effect of climate change. Appropriate, site specific cropping system management practices like inter/mixed/ multistoryed cropping systems /mixed farming systems have been developed which help alleviate the effects of abiotic and biotic stresses on crop productivity and yield. Adaption of cropping system and integrated farming approaches is very important for combating the risks of mono cropping and climate change (Sujatha et al. 2016). Palms such as coconut, arecanut and oil palm trees do not have branches and grow straight vertically upwards providing more space under their canopy. Their leaves are such that it allows sun light to the crops grown under it. Growing field crops (groundnut, black gram and green gram), vegetables (cucumber and bottle gourd), tuber crops and fruit crops (pineapple), spices (turmeric, ginger and pepper) are suitable and profitable intercrops in cashew plantations. Farming systems have dramatic powers to stabilize eroding farmland, especially sloping lands. Practices like using nitrogen fixing perennials, ploughing, and intensive livestock rotation have fantastic soil building abilities. Plantings of useful trees can protect coastlines from damage caused by increased storm activity.

C. Soil and land management techniques

Adaptation to climate change for oil palm cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil for during extended drought. Low tillage and maintenance of permanent soil cover are to be promoted that can increase soil organic matter and reduce impacts from flooding, erosion, drought, heavy rain and winds. Soil conservationmeasuresviz.terracing the palm basins in sloppy lands to interrupt run off of water and catch pits across slope to enhance soil moisture, rain water harvesting: in-*situ* (land configuration, mulching etc.) and *ex-situ* (ponds, micro water harvesting structure -*jalkund* etc), bunding the field to prevent runoff of water. These measures would help to increase the moisture availability in rain fed orchards.

Crops like coconut, cashew and rubber are often planted in areas which are totally dry and less fertile. Under such situations mulching is highly useful to conserve the soil moisture for a long period, protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status. The basin area of plants can be mulched either with green leaves or dry leaves and weeds soon after planting. Black polythene mulch was helpful to conserve soil moisture (Nawale et al. 1985). Using coconut coir pith as soil mulch in cashew plantations resulted in 14.15 per cent more water retention and suppression of weeds to an extent of 73.52 per cent (Kumar et al. 1989). Formation of terrace and crescent bund and mulching the base area with cashew leaf litter and other jungle growth available in the garden are helpful.

Growing green manure crops like *glyricidia*, *sesbania*, sunhemp, pureria, desmanthus, desmodium and cover crops between two rows of trees have potential to improve soil moisture retention capacity and nutrient content through bio mass recycling and nitrogen fixation. Higher soil moisture content was observed in cashew orchard with *glyricidia*, sunhemp, sesbania compared to that of control. Among areas which can be explored are conservation agriculture, organic agriculture and risk-coping production systems. Intensive soil tillage reduces soil organic matter through aerobic mineralization, low tillage and the maintenance of a permanent soil cover through crop residues or cover crops increases soil organic matter. Conservation agriculture and organic agriculture are promising adaptation options in oil palm for their ability to increase soil organic carbon, reduce mineral fertilizers use and reduce on-farm energy costs.

D. Efficient use of water

Enhancing residual soil moisture through land conservation techniques assists significantly at the margin of dry periods while buffer strips, mulching and zero tillage help to mitigate soil erosion risk in areas where rainfall intensities increase. With climate change, water supplies are expected to become threatened in certain regions of plantation cultivation, but water management strategies, such as drip irrigation, can conserve water and protect from water shortages. Water management techniques likedrip irrigation (two to three drippers per palm to wet subsoil layer) or if adequate water is available irrigate with 200 liters water/palm once in four days and mulching the basin with dry leaves facilitate the retention of soil moisture and achieve the better efficient use of water and thereby increasing the water use efficiency of system.

E. Balance used of nutrients

It is another approach with potential to mitigate effects of climate change. The site specific nutrient management is critical for GHGs mitigation so as to reduce input cost and enhance nutrient use efficiency considerably. This approach facilitates grower to invest only on deficient nutrients and omit nutrient application which was in sufficient range in soils. Various benefits of such practice include lowering in input cost, higher nutrient use efficiency, and reducing GHGs particularly N_2O. Application of fertilizers particularly N during water stress escalates water stress problem further as higher N improves leaf canopy which results higher evapotranspiration. Using nitrification inhibitors and fertilizer placement practices need further consideration for GHGs mitigation. Management of soil in combination with optimum soil moisture is essential to protect the plants during weather aberrations and overall reduction of CO_2, N_2O and CH_4 from soil. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. Large increases in fertilizer applications would be necessary to restore productivity levels. Placement of fertilizer materials and split application of nutrients into soil will substantially improve both nutrient and water use efficiency.

II. Mitigation Strategies

Production of plantation crops is likely to be affected by projected climate change, but it has been a source of greenhouse gases to the atmosphere, thus itself contributing to climate change. Clearing and management of land for food and livestock production over the past century was responsible for cumulative carbon emissions of about 150 GT C, compared to 300 GT C from fossil fuels (LULUCF 2000). At present, agriculture and associated land use changes emit about a quarter of the carbon dioxide (through deforestation and soil organic carbon depletion, machine and fertilizer use), half of the methane (via livestock and rice cultivation), and three-fourths of the nitrous oxide (through fertilizer applications and manure management) annually released into the atmosphere by human activities. Modifying current management of agricultural systems could therefore greatly help to mitigate global anthropogenic emissions. Many see such activities in the coming decades as new forms of environmental services to be provided to society by farmers, who in turn could additionally increase their income by selling carbon-emission credits to other carbon-emitting sectors.

A. Carbon sequestration

Absorbing CO_2 from air and injecting it into the biomass is the only practical way of removing large volumes of green house gases from the atmosphere. The processes that remove carbon from the biosphere are termed as Carbon Sequestration. Standing crops like oil palm serve as net accumulators of carbon, thereby offsetting carbon emissions, arising mainly from fossil fuel consumption. With respect to the net fixation or sequestration of carbon, there are possibilities of financial gains by developing countries like India through carbon trading, under the terms of Kyoto Protocol. Most of the plantation crops are trees and have long life span and hence store large amount of carbon in their vegetation. This knowledge is important as tree crop plantations could be a more feasible mitigation solution in many parts of developing countries compared to pure afforestation and reforestation projects, since tree crop plantations also provide work, income and food, especially when established in smallholder systems where local people have control over production.

To use tree crop plantation to sequester C and at the same time increase sustainable development would link climate change mitigation and adaptation, and an enhancement of this link has been called for by several authors (Ayers and Huq 2009). The amount of carbon sequestered by eleven year old oil palm hybrids under irrigated conditions ranged between 17.98 and 35.44 T C ha^{-1} with Papua New Guinea and Ivory Coast hybrids sequestering the highest and lowest carbon contents respectively. (Suresh and Arulraj, 2010)

B. Zero burning

Zero burning involves chipping or stacking the material cleared from a site being prepared for oil palm cultivation between the palm rows and leaving it to decay. This technique mitigates carbon dioxide emissions released from burning vegetation to clear land, however it should be mentioned that unless a significant portion of the biomass from land clearing is used to manufacture wood products with a long useful life (instead of simply decaying) mechanical land clearing methods will only have a short-term effect on carbon emissions. Zero burning is now a well-established policy adopted by the majority of reputable estate companies to clear their land in Indonesia. Nevertheless, there remains a clear gap between stated company policies of zero burning and the interpretation of middle management on the ground and contractors engaged to clear land on behalf of oil palm companies (Sargent 2001).

Satellite imagery continues to prove that large scale estates use fire to clear land. Estate companies still continue to use fire to clear land because it is easier to flick a match than to undertake manual land clearing. Many companies also continue to use fire rather than zero burning because it is thought to be a cheaper method of clearing land at the onset. This was confirmed by Guyon and Simongkir (2002) who undertook extensive economic analysis on the costs and benefits of zero burning versus burning in commercial oil palm plantations.

C. Improve water management in existing plantations

Appropriate drainage system must be designed to remove excessive water in heavy soils but maintain the water table at 0.5-0.7 m from the soil surface to prevent excessively rapid depletion of the soil layer in existing oil palm plantations. A good drainage system will not only retard oxidation, but also improve the yields and performance of the palms because palms tend to fall over and the stem becomes bent as the palm re-establishes growth in a vertical plane. This results in an uneven canopy and reduced yield. It also makes harvesting and other field operations difficult (Ng et al. 2003).

D. Reduce chemical inputs to reduce other greenhouse gas emissions

Chemical inputs, such as fertilizers, pesticides and herbicides, release a host of greenhouse gases (carbon dioxide, nitrous oxide and methane) into the atmosphere. It is important to consider the emissions of other greenhouse gases resulting from chemical inputs applied to oil palm plantations as the global community ultimately aims to identify strategies that can mitigate global warming. Greenhouse gases (GHGs) are atmospheric compounds that store energy, thus influencing the climate. Each of the GHGs has a different global warming potential that takes into account the effectiveness of each gas in trapping heat radiation and its longevity in the atmosphere. Oil palm is one of the largest consumers of mineral fertilizer nutrients in Southeast Asia (Hardter and Fairhurst 2003). A typical oil palm plantation planted on mineral soils requires around 1114 kg/ha of nutrient inputs over the first 5 years of planting. The most relevant nutrient input from a climate point of view is nitrogen. A typical oil palm plantation planted on both mineral and peat soils requires around 354 kg/ha of nitrogen over the first five years. This is usually applied with the use of a number of nitrogen based fertilizers—NPK (ammonium nitrate), ammonium sulphate and urea. In addition to this, pesticides and insecticides are also used liberally in oil palm plantations to control fungal diseases, weeds and other pests commonly found in oil palm plantations (rhinoceros beetle). All of these pests and diseases are more prevalent in oil palm plantations that use zero burning rather than fire to clear land. In the short term, zero burning can also require higher fertilizer requirements during the early years (0-2) because fire is an efficient means to convert nutrients contained in the standing biomass into nutrients. However, mechanical land clearing may result in lower fertilizer application because the nutrients from decaying wood debris left after zero burning are released very slowly into the soil (Guyon and Simorngkir 2002).

8.0 Future Research Needs

The available resilient technologies in plantation crops can address to mitigate the climate change on a short-term basis. But due to vagaries and unpredictability of weather variables, more focus is needed in developing different crop adaptation strategies in a sustainable manner. The way forward should be on the lines as per given below:

- Basic understand of the physiological, biochemical, genetic, and molecular basis of adaptation to biotic and abiotic stresses;
- Development of innovative soil and land management technologies for adaptation and mitigation of climate change;
- Development of regional plantation crops based cropping/farming models for profitability and sustainability;
- Developing harvest and post-harvest technologies in plantation crops for enhanced income;
- Capacity building programmes for disseminating innovative technologies developed in plantation crops for the benefit of stakeholders;

9.0 Summary and Conclusions

Plantation crops like coconut, oil palm, cocoa, rubber and arecanut are likely to be more vulnerable due to excessive use of natural resources particularly water with poor adaptive mechanisms. The consequences of climate change could be severe on livelihood security of the poor in the absence of better adaptation strategies. Strategies to enhance local adaptation capacity are therefore required to reduce climatic impacts and maintain regional stability in oil production. At the same time, plantation crops offer several opportunities to mitigate the portion of global greenhouse gas emissions that are directly dependent upon land use and land-management techniques. Adaptation and mitigation strategies in oil palm could be carried out to alleviate the potential negative effects of climate change. However, important synergies need to be identiûed as mitigation strategies may compete with local agricultural practices aimed at maintaining production. The specific research priorities for plantation crops to combat climate change have also been highlighted. There is an urgent need to investigate the possible regional impacts of climate change on oil palm to address the impact of climate change. The scenarios project that increasing temperature and precipitation patterns would be different over the agro-ecological regions of the country. Hence the oil palm growing regions will be differentially impacted due to climate change. Depending on vulnerability of individual crop and agro-ecological region, crop based adaptation strategies need to developed, integrating all the measures available for sustainable productivity.

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Climate Resilient Approaches for Sustainable Coconut Production

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INTRODUCTION

Agriculture practices in India had gone through several changes that can be attributed to many factors like adoption of scientific cultivation practices, creation of infrastructure for production of farm inputs, irrigation, transport, marketing, farm mechanization, enacting farmer friendly policies, and put in place a proactive research-education-extension system. No more the Indian agriculture is thus considered as a gambling with the 'monsoon winds'. But the fact that human activities are accelerating the shifts in temperature and weather patterns in the recent decades, making the sector more vulnerable than ever before. To overcome this challenge, sustainable and higher productivity has to be achieved in long-term using existing natural resources. Scope of this climate resilient approach, has further defined under the frame work of climate smart agriculture (FAO, 2010; World Bank, 2011) which is aiming to achieve (i) increased productivity for nutrition and income security; (ii) enhanced climate resilience for abiotic stress (due to drought, floods, and cyclones) and biotic stress; and (iii) reduced emission of greenhouse gases. The widely used cultivation practices such as conservation tillage, agroforestry, recycling crop residues, weed control, water harvesting, and increase in water use efficiency are part of climate smart agriculture but it also deals with ways for improvement in the context of a changing climate (Scherr et al., 2012). Beyond this, climate smart agriculture examines synergies and trade-offs between productivity, adaptation, mitigation, and investment opportunities (https://www.worldbank.org/en/topic/climate-smart-agriculture; date 22.3.22). Another distinction to be noted is its scale of operation. World Bank (2011) considered watershed level planning (agriculture and fisheries) but its scope further defined to ecosystems, working at landscape scale and ensuring intersectoral coordination and cooperation (FAO, 2010). When confined to research Institute mandate, emphasize should be on evaluation and refinement of crop production technologies that are climate resilient, ensuring sustainable production and energy conservative. How far the coconut production technologies are meeting these requirements and approaches to address the emerging research issues are discussed in this paper.

INDIAN COCONUT SECTOR

With over 30% share of world's production and consumption, Indian coconut sector has a decisive role as any large aberrations in production will affect the livelihood of farmers and other stake holders associated with industry and trade across the world. Coconut production in the country is chiefly confined to four states viz., Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh, accounting for 89.5% area and 90% production. These states respectively account for 36.09, 25.23, 23.24, and 7.35% of the coconut production in the country and 35.38, 20.31, 28.82 and 5.2% of area: In the year 2021-22 coconut production in India was 21288 million nuts from an area of 2.151 million ha. The asymmetry in area and production statistics is expected to be widened in the event of any adverse extreme weather. Average coconut productivity in India is higher than the world (9897 nuts/ha against world average of 5777), but it can be further enhanced through better resource management. Nevertheless the structural constraints like fragmented land holdings and high labour wages will remain as a hurdle for achieving this.

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The World Trade Agreement (WTA) and ASEAN Treaty had a toll on coconut sector in India as the sector faced fierce competition among producing countries. In the global trade, India is a very small player (coir is an exception). The country witnessed very high price volatility in the post WTA but now seems to be stabilized to some extent. However, the price wedge between domestic and international prices continued to be high and integration is inevitable which may once again lead to price crash (Jayasekhar et al., 2019). The price volatility is a major constraint to achieve higher productivity (Kappil et al., 2021). A positive stride in this regard is that the sector is showing certain level of competitiveness in the trade of selected coconut products such as activated shell charcoal and desiccated coconut in the recent years.

EXTENT OF CULTIVATION

Coconut is cultivated in the tropical region located between 23°052 north and south of the equator. It grows well in the Tropical Monsoon Climate Region having high temperature (average annual temperature 27.05°C), annual temperature range of 3.6 °C, heavy precipitation during summer Monsoon (3115.9mm), and 293.3mm winter precipitation (The Köppen classification https://en.wikipedia.org/wiki/Tropical_ climate# Tropical_ monsoon_climate date 26.3.2022). The western coast of India, Lakshadweep Is., and Andman and Nicobar Is. are belonging to this climate region where coconut is traditionally cultivated or grown in abundance. Coconut also grows in the Tropical Wet and Dry Climate zone characterized in Koppen classification with summer temperature 25 to 30°C, winter temperature 20 to 30°C and annual precipitation between 700 to 1000mm. Coconut growing areas in the eastern coast up to Odisha, Chhattisgarh, and interior regions of Karnataka and Tamil Nadu are belonging to this climatic region (with slight variation in weather parameters). Coconut is observed to be growing with satisfactory yield levels in areas adjacent to tropical climate that include parts of Odisha, West Bengal, Jharkhand, parts of Bihar, Assam, Meghalaya, Tripura, Mizoram and Gujarat. Coconut is thus grown in India under wide a range of climate and soil conditions.

EFFECT OF WEATHER ON COCONUT GROWTH AND REPRODUCTION

Variation in number of nuts in different bunches of coconut palm was observed by Patel (1938) and later confirmed by Marar and Pandalai (1957), Lakshmanachar (1963) and Satyabalan (1997). Insights on association of coconut production with weather variables can be seen in the works of Patel and Anandan (1936), Balasubramaniam (1956), Abeywardena (1968), Rao (1986), and Mathew et al. (1988). Salient findings from these studies are: (i) There is no linear correlation between annual yield with either total precipitation or total number of rainy days in the corresponding year; rather the yield has high correlation with summer rains of one- and two-year lag and lesser extent with three-year lag. (ii) Effect of drought may reflect on yield obtained in 8 to 20 months after the drought; it may not be the case, if drought occurs in consecutive years (as happened in some parts of Karnataka in the recent past). (iii) The reproductive behaviour of coconut makes it necessary to model seasonal yield data with lagged weather variables. Every leaf axil of a bearing coconut palm will have an inflorescence. The primordium of inflorescence is formed about 32 months prior to opening and fertilization; pistils and stamens are formed respectively after 20 and 21 months and ovary differentiation after the 26th month (Patel, 1938). It requires another 12 months for fruit development of which the first 3 months are crucial as immature nut fall (or button shedding) taking place in this period (Mathew et al., 1991). Thus it makes a long duration of 35/44 months between inflorescence primordium initiation and harvesting. Peiris et al. (1995) had reviewed studies on the effect of weather variables viz., rainfall, relative humidity, temperature, sunshine hours, pan evaporation, evapotranspiration, solar radiation, vapour pressure and wind velocity on coconut yield, button shedding and premature nut fall.

Drought remains to be the most frequent weather extreme that is adversely affecting coconut production in all growing regions. Effect of dry spell is seen mainly on three stages of fruit development: Primordium initiation, ovary development and button-size nuts (Rajagopal et al., 1996). Kasturibai et al. (2003) studied factors associated with button shedding in 16 coconut varieties including tall and dwarf types and observed significant difference only for season. On analysing coconut productivity in different agro-climatic zones Kumar et al. (2007) found that total rainfall and length of dry spells over preceding 4 years are the significant factors. Kumar (2009 a & b) reported yield reduction when the dry spell is more than 200 days and temperature more than 33°C.

Experiments conducted at ICAR-CPCRI to understand the effects of drought on coconut had provided substantial information on related physiological and biochemical aspects. Kasturibai et al. (1988) observed increase in stomatal resistance and reduction in leaf water potential when solar radiation, temperature and vapour pressure deficit are high. Under moisture stress (with 0.5 and 0 as the ratio of irrigation water to cumulative pan evaporation), Rajagopal et al. (1989) observed increased stomatal resistance (111%) and epicuticular wax content (32%) and reduced transpiration rate (10%), leaf water potential (68%), and reproductive dry matter production (22%), compared to fully irrigated palms. Critical level of soil water deficit in sandy loam soil was worked out to be 110mm at which stomata is closed. High stomatal resistance and low water potential was found in palms under rainfed condition in comparison with irrigated condition (Shivashankar et al., 1991). Kurup et al. (1993) reported low leaf water potential and high electrolyte leakage in the hybrid with dwarf type as female parent compared to the reciprocal hybrid and tall parent during the moisture stress period. Variation in photosynthesis efficiency in irrigated and rainfed coconut which in turn affecting dry matter production and yield was elucidated by Rajagopal et al. (2000): Rainfed palms were found to have low carbon assimilation efficiency, high leaf to ambient temperature difference and high air vapour pressure deficit. Thomas et al. (2008) indicated about photosynthesis limitations in coconut under moisture stress due to stomata and non-stomata factors. Studies conducted elsewhere on drought-physiology on coconut is reviewed by Hebbar et. al. (2017).

Temperature vulnerability of progamic phase of reproduction in coconut was investigated by Hebbar et al. (2018; 2020). They observed that pollen germination is varied among cultivars. Under high temperature and low humidity, pollen tube growth is not enough to reach the ovule on time to effect fertilization. Further, nectar secretion is advanced and receptive stigma dried up to reduce the activities of insect pollinators. However, under high humidity pollen tube growth was satisfactory.

OBSERVED AND PROJECTED CLIMATE CHANGE IMPACT ON COCONUT SECTOR

Climate change over the Indian subcontinent and projections based on forcing scenarios called Representative Concentration Pathways (RCPs) 4.5 and 8.5 are discussed in Krishnan et al. (2020). They have reported after analysing time series data on weather parameters that (i) rise in average temperature by 0.7°C during 1901-2018 but with an increased rate of warming of 0.15°C per decade during the period 1986-2015; (ii) increase in frequency and intensity of warm days; (iii) reduction in summer monsoon precipitation (6% from 1951 to 2015); (iv) more dry spells and more intense wet spells; (v) rise in sea levels; and (vi) increase in intensity of cyclones. Projection for temperature in India under RCP 4.5 and 8.5 is reported to be 2.3°C and 4.4°C. These changes are unevenly distributed across India. For instance, increase in temperature is 0.15°C per decade for India as a whole while it is less than 0.1°C per decade in the coconut growing regions in the Southern peninsula. Frequency of droughts is observed to be more in central India, southwest coast, southern peninsula and north-eastern India. Projection for temperature under RCP 4.5 and 8.5 is reported to be 2.3°C and 4.4°C respectively by the turn of twenty-first century. Because of changes in precipitation pattern and increase in dry spells, frequency of drought is projected to be increased. Another extreme weather event is intense wet spells which may result in floods. Raising sea levels may adversely affect coconut plantations in the coastal belt, especially the northern side of the east coast and some parts of Kerala coast.

Kumar et al. (2009b), Kumar and Aggarwal (2013) and Hebbar et al. (2022) attempted analysis of time series data on weather parameters in different coconut production zones in the country (10 to 20 locations). Conclusions drawn from these studied are: (i) annual precipitation is below 1000mm in Arsikeri, Chitradurga, and Chikmagalur in Karnataka state, Coimbatore and Dharmapuri in Tamil Nadu, and Junagad in Gujarat; (ii) maximum temperature crosses 40°C in Ambajipeta and Anakapalle in Andhra Pradesh, Bhubaneswar and Cuttak in Odisha, Kolkata in West Bengal, Junagad in Gujarat, and Kovvuru and Tanjavur in Tamil Nadu; and (iii) prolonged dry-spell of over six months in all locations except those in South-Kerala.

To study the impact of climate change on coconut production in India Kumar and Aggarwal (2013) used 'InfoCrop' model: Results indicated increase in coconut productivity in west coast, NEH, parts of Tamil Nadu, Karnataka and Maharashtra, Andaman & Nicobar Is. and Lakshadweep Is. On the other hand in the eastern coast, productivity is likely to be decreased. Hebbar et al., (2022) examined vulnerability of coconut growing regions to climate change scenarios under the RCP 4.5 and 8.5. According to them, south interior Karnataka and Tamil Nadu may become unsuitable for coconut cultivation, east coast and south interior plains may require appropriate adaptation techniques for sustainable coconut production, and west coast may become most suited for coconut. Beyond these indicators, shifts in trend (presence of change points) and presence of extreme data points in the respective time series may influence in a complex manner the projected climate change scenarios and coconut production.

COCONUT PRODUCTION TECHNOLOGIES FOR CLIMATE CHANGE ADAPTATION

Based on field experimentation, a combination of the following technologies are suggested for sustainable coconut production: (i) cultivation of varieties identified to be tolerant to moisture stress; (ii) adopt soil and water conservation techniques in coconut gardens; (iii) adopt drip irrigation/fertigation; (iv) evolve most appropriate cropping system for each coconut holding; and (v) Integrated pests and diseases management.

Varieties: Based on physiological, biochemical and anatomical characteristics observed during moisture stress period, seven varies and three hybrids of coconut were released (Table 1). As the varieties rank differently for different characters considered, average rank was used for identification. Further not all of them were in the same comparative evaluation and therefore will have environmental bias.

Soil and water conservation techniques: Managing the soil moisture is critical for coconut production in almost all coconut growing areas in the country. It involves prevention of soil erosion, rain water conservation, reducing soil moisture evaporation and adopting efficient irrigation methods. Field evaluation of these techniques was chiefly done under the National Technology Development Project during 1998-2002 (Dhanpal et al., 2005).

For *in situ* water harvesting and prevention of soil erosion two interventions are suggested: (i) appropriately shaping the coconut basin; (ii) making trenches (preferably filled with coconut husk) in the interspaces. The soil removed while re-shaping the basin or making the trenches is placed in the downstream so as to arrest the run-off water. To stabilize the soil-bunds (30-50cm height and 50cm width), two rows of pineapple are to be planted. Mathew et al. (2018) made an impact assessment

Table 1: Moisture stress tolerant coconut varieties/hybrids released by ICAR-CPCRI*

Variety/Hybrid	Year of release	Copra (kg/palm)	Leaf water potential (MPa)	Epicuticular wax content ($\mu g\ cm^{-2}$)	WUE ($\mu mol\ CO_2\ mmol\ H_2O^{-1}$)
Varieties					
Kalpa Dhenu	2007	20.81	-1.24	91.9	1.64
Kalpa Pratibha	2007	23.25	-1.27	110.4	
Kalpa Mitra	2007	19.25	-1.41	116.2	
Kalpa Ratna	2019	12.70	-1.10	116.7	
Chandra Kalpa	1985	17.60			
Kera Keralam	2007	19.18	-1.17	117.4	1.55
Kalpatharu	2009	20.50			
Hybrids					
Chandra Laksha	1985	21.30	-1.26	120.7	1.94
Kera Sankara	1985	20.20	-1.19	116.7	1.66
Kalpa Samrudhi	2009	25.72			

*Kera Keralam is released jointly by TNAU and Kapatharu jointly by UHS of these two technologies. To reduce evaporation loss, mulching with available organic materials (coconut leaves, husks, coir pith etc.) is to be done well before the end of rainy season. This technology was tested in different coconut growing areas and found to be useful (Kumar et al., 2006). Maheswarappa et al. (1998) noted 4.3°C reduction in temperature in plots irrigated and mulched in comparison with rainfed and not-mulched plots in littoral sand soil (coastal region). Growing leguminous cover crops is another component of the technology package for preventing soil erosion.

Rainwater harvesting/conserving is pivotal in soil moisture management in drought prone areas. Ferro cement rain water harvesting tanks, ferro cement check dams across streams, and inner lining ponds with silpaulin like material are some of the low-cost technologies that can be easily adopted (Mathew et al., 2008). Making large size percolation tanks in barren fields will improve ground water availability.

Irrigation: It is noticed that farmers provide water more than the requirement to coconut wherever water is available in abundance. They often adopt flood irrigation. But in the event of prolonged dry spell, source of water may get dried up and leave the palms to undergo moisture stress. Under this kind of uncertainties, farmers should adopt drip irrigation. Based on large number experiments conducted in different agro climatic zones, the irrigation requirement of coconut is worked out to be 66% of the daily open pan evaporation (Dhanapal et al., 2000). Number of dripping points recommended for sandy loam soil is four (Mathew et al., 1999) and for laterite and sandy soils, it is six (Dhanapal et al., 1995; Maheswarappa et al., 1997).

Cropping systems: Coconut is being recognized as a multi-purpose tree crop ever since its cultivation. Traditionally coconut was grown under homestead agroforestry system in India, especially in the western coast. One of the earlier interventions in coconut cultivation was thus associated with cropping systems. Based on the distribution of roots in vertical and horizontal direction (Kushwah et al., 1973; Anilkumar and Wahid, 1988), transmission of sun light through coconut canopy at different coconut growth stages (Nelliat et al., 1974) and crop compatibility, various cropping systems were experimented and recommended for different coconut growing regions. A review on these aspects can be seen in Reddy and Biddappa (2000). Productivity of coconut based cropping systems would be benefitted with increase in CO_2 as coconut and most of the component crops are C3 plants. However, in regions where temperature exceeds 40^{o}C, and availability of water is limited, C4 and CAM crops should be grown as intercrops. Among the recommended intercrops, maize, sorghum, Napier grass, and amaranthus are C4 crops and Pineapple, dragon fruit, and aloevera are CAM crops. From the climate change perspective, cropping systems offers flexibility in choice of crops thereby reducing the risk. Besides meeting the primary needs of farmers, cropping systems also enable organic recycling that helps to retain soil fertility and increased microbial load.

Integrated pests and diseases Management: Farmers often notice coconut pests and diseases only at the advanced stage of infection by which any time is left for adopting control measures. Non-availability of skilled labourers, especially palm climbers, is another constraint in proper adoption of coconut health management. Owing to these reasons, adoption of plant health management of coconut is very low.

Major coconut diseases found in India are root(wilt), leaf rot, bud rot, stem bleeding, basal stem rot, and leaf blight. For the phytoplasma borne root(wilt) disease, economic production is achievable by adopting integrated management practices (Krishnakumar and Maheswarappa, 2010). Effective biocontrol measures are available for the fungus borne diseases: Srinivasan and Bharathi (2006) reported for leaf rot; *Trichoderma* enriched neem cake application for controlling the soil borne pathogens of stem bleeding (Srinivasulu et al., 2006) and basal stem rot diseases (Bhaskaran et al., 1989); coir pith cake formulation of trichoderma (Chandra Mohan, R., patent application number 4310/CHE/2011) for control of bud rot; and microbial consortia consists of *Pseudomonas fluorescens, Bacillus subtilis* and *Trichodermaviride* for control of leaf blight (Johnson et al., 2017).

Coconut pests causing economic loss are *Oryctes rhinoceros Linn, Rhynchophorus ferrugineus Olivier* (Red palm weevil), *Opisina arenosella* Walker (black headed caterpillar), *Aceria guerreronis* Keifer (eriophyid mite), *Leucopholis coneophora* Burm (white grub), and *Aleurodicus rugioperculatus* (rugose spiraling whitefly).

Rhinoceros beetle is found in all coconut growing areas and its control measures include placing repellents (i.e., 250g powdered botanical cakes of neem oil, marotti or pongamia mixed with 250g sand or botanical cakes made out of extracts from *Clerodendron infortunatum* Linn. and *Chromolaena odorata* Linn. or perorated sachets containing chlorantraniliprole (3g) or fipronil (3g)) in the top most leaf axils at quarterly interval; and community/area wide adoption of bio-agent Green muscardine fungus (*Metarhizium anisopliae*) for prevention of breeding of the pest in organic decaying sites.

As the infestation of red palm weevil is difficult to notice, the best approach is prevention of its entry (Anithakumari et al., 2017). A nanomatrix that enhances the effectiveness of pheromones against red palm weevil is developed and commercialized (M. Eswaramoorthy, K. Subaharan, and B. V. V. S. Pavan Kumar: patent number 354729)

Biocontrol agents are highly successful to control *Opisina* and white grub. *Opisina* infestation can be successfully controlled with stage-specific parasitoids viz., *Goniozus nephantidis* (Bethylidae) and *Bracon brevicornis* (Braconidae) for larva; and *Elasmus nephantidis* (for pre-pupae); and *Brachymeria nosatoi* (Chalcididae) for pupae (Chandrika et al., 2010). Drenching coconut basins with aqua formulation of entomopathogenic nematode, Kalpa EPN (CPCRI-SC1) (*Steinernema carpocapsae*) is effective for controlling whitegrub (Patil et al., 2015).

Eriophyid mite and Rugose spiraling whitefly (RSW) are two invasive pests presumably introduced due to inadequate quarantine at ports. Neem based biopesticides (Nair et al., 2003) biocontrol agent *Hirsutella thompsoni* (Chandrika et al., 2016) are found to be effective in controlling eriophyid mite. For control of RSW two biocontrol agents *Encarsia guadeloupae* (Srinivasan et al., 2016) and *Simplicillium lanosoniveum* (Sujithra et al., 2021) were identified but field trials are yet to complete.

RESEARCH PRIORITIES

Developing drought tolerant varieties: Screening for drought tolerance based on the physiological, biochemical, and anatomical characters is a short-term strategy for variety identification. Measurement on leaf water potential was suggested as a rapid method of screening for drought tolerance in coconut by Rajagopal et al. (1988). For comparison of cultivars for drought tolerance Rajagopal et al. (1990) used an index based on ranks assigned to three sensitive parameters viz., stomatal resistance, leaf water potential, and epicuticular wax content. The desired biochemical traits are peroxidation of cell wall lipids coupled with enzyme activities (Chempakam et al., 1993). Summary results of these studies are provided in Table 1. Anatomical features of drought tolerant genotypes are (i) thick leaflets; (ii) thick cuticle on both surfaces of leaflets; (iii) large palisade and spongy parenchyma cells; (iv) large hypodermal- and water-cells; and (v) large sub-stomatal cavity (Kumar et al., 2000; Rajagopal et. al., 2005). A distinction for drought tolerance for all these characters may not observe for all coconut genotypes in a study making it difficult for grouping. Rajagopal et al. (1990) used average of ranks to arrive relative tolerance of genotypes. The usefulness of a discriminant function or a selection index for the same may be explored. Kasturibai et al. (2010) reported heterosis for lipid peroxidation during non-stress phase and for leaf water potential in the recovery phase, but no heterosis for photochemical efficiency. They also estimated heritability of these characters. For easy and consistent screening for drought tolerance, it is necessary to develop molecular markers. Only limited studies were published in this field. Through genome-wide analysis, Santhi et al. (2021) identified 20 Auxin response factors (ARFs) and reported their stress-specific transcriptional response in zygotic embryos exposed to temperature and osmotic stress. Leaf transcriptome profiles of coconut seedlings of two varieties having contrasting WUE trait indicated a total of 7312 differentially expressed genes (Ramesh et al., 2021) but with varying response. For instance in the variety Kalpasree, upregulation was for PHLOEM PROTEIN 2-LIKE A1-like and WRKY transcription factor 40 isoform X1 whereas in Kalpatharu, upregulation was for polyamine oxidase and arabinose 5-phosphate isomerase. Difference in downregulation transcript noticed for glycerol-3-phosphate acyltransferase 3 in Kalpasree and aquaporin PIP1-2 in Kalpatharu. Aisha et. al. (2015) attempted selective fertilization technique in which selection pressure is artificially imposed during the events of pollen germination and fertilization in

Table 2: Physiological and biochemical parameters of drought tolerance measured during moisture stress period (adapted from Kasturibai and Rajagopal, 1996 and Chempakam et al., 1993)

Parameters	Tolerant		Susceptible	
	Threshold	Degree	Threshold	Degree
Stomatal resistance (Sec.cm^{-1})	>7.0	High	<3.0	Low
Transpiration rate (μg.cm^{-2} s^{-1})	<2.5	Low	>5.0	High
Leaf water potential (MPa)	>-0.95	High	<-1.0	Low
Osmotic potential (MPa)	<-1.16	Low	>-1.09	High
Turgor potential (MPa)	>0.23	High	>0.1	Low
Soluble sugars (mg.g^{-1} dwt)	>15.1	High	<14.6	Low
Free amino acid (mg.g^{-1} dwt)	>0.53	High	<.0.48	Low
Epicuticular wax content (μg.cm^{-2})	>95	High	<75	Low
Electrolyte leakage (%)	<32	Low	>40	High
Lipid peroxidation (absorbance value)	<0.22	High	>0.25	High
Super oxide dismutase(units/mg protein/minute)	>2.5	High	<2.3	High
Catalase (10^{-3}units/mg protein/minute)	>2.6	High	<2.52	High
Peroxidase (10^{-3}units/mg protein/minute)	>54.0	High	<39.0	High
Polyphenol oxidase (10^{-3}units/mg protein/minute)	<47.0	High	>56.0	High

coconut and observed significant difference for relative water content, proline content and activity of enzymatic antioxidant catalase compared to the normal. However, validation of this method to screen drought tolerance in coconut seems to be difficult.

Adoption of the recommended varieties by farmers is limited for reasons of non-availability of planting material: Number of seedlings from a mother palm would only be 50 or less. In the absence of any clonal propagation technique, it thus required to identify more drought tolerant palms to augment the seedling supply. Kumar et al. (2002) suggested identification of apparently tolerant and high yielding palms from drought affected regions to augment the supply of planting material.

Resource management: Changes in soil nutrient constitution will reflect in crop productivity. Low organic matter level is one of the major limiting factors of crop production in many soil types. Availability and interaction of carbon, nitrogen, and water are intricately linked to soil health and thus calls for close monitoring of the effect of climate change on N cycle and C storage in soils and plant-response to increased level of atmospheric CO_2 under limited availability of N and P (Brevik, 2013). It is seen that many coconut growing soils are seriously deficient for K and micro nutrients. Long term prospects of natural farming, reduced or no tillage, growing cover crops, and organic recycling with regard to coconut production are to be looked into.

Sustainable crop production largely relies on conservation, use and reuse of water. Number of technologies and concepts are emerging for efficient use of water that include precisely estimating crop water requirement, ground water recharge, reuse/ multiple use of water, irrigation scheduling, and adopting zero tillage. Evaluation of these practices is to be carried out for different cropping systems and agro-climatic conditions. A related research question is how the water use efficiency (WUE) (i.e., amount of carbon assimilated as biomass per unit of water used) of crops is affected. Hatfield and Dold (2019) distinguished WUE measured at leaf and canopy: At leaf level, WUE is related to physiological process but at canopy level, factors like soil water evaporation rate, transpiration from the leaves, and the growth pattern of the crop are also to be taken into account. Agronomic practices dealing with reduction in soil water evaporation and diverting more water into transpiration (i.e., mulching, planting geometry and irrigation) are to be developed for enhancing WUE at the canopy level. Gago et al. (2014) proposed the use of UAVs (Unmanned Aerial Vehicles) equipped with remote sensors to regulate irrigation to achieve efficient water use and also to identify genotypes with improved WUE.

Climate change is going to get reflected in the soil microbe dynamism too. As soil microorganisms regulate nutrient transformations, understanding and predicting the impact of climate change on soil microbiomes need attention (Classen et al., 2015). A recent review on impacts of climate change on soil microorganisms and potential ways to harness them for mitigating the negative consequences of climate change on crop production can be seen in Jansson and Hofmockel (2020).

Pests and Diseases: Occurrence and distribution of pests and diseases are greatly influenced by the climatic factors. Elad and Pertot (2014) described effects of pathogens and their ability to infect plants with regard to changes in temperature, CO_2 and ozone concentrations, precipitation, and drought. They opined that the changing climate will affect both pathogens and crops thereby making it necessary to examine and monitor the host-pathogen interaction in every agro-climatic zone of interest. Further, pathogens may also be more adaptable to changes in the environment. To study the microbial responses to climate and microbial effects on plant health, Garrett et al. (2012) proposing two approaches based on genomics tool: Analysis of quantitative trait microbial taxa from new soil mixing experiments; and characterisation of the extended phenotype or phenome of soil microbial communities. Cilas et al. (2016) discussed the impact of climate change on tropical pests and proposed agroecological protection strategies. Josephrajkumar (2018) described ecological engineering in coconut garden with crop pluralism, bee-pasturage and eco-feast plants and reported a reduction of pest incidence (80, 91 and 100% reduction respectively for rhinoceros beetle, red palm weevil and rugose spiralling whitefly) in comparison with coconut mono crop. Lamichhane et al. (2015) proposed the following strategies to reduce crop loss due to pests from climate change perspectives: (i) address the unpredictability of spatial and temporal interactions between weather, cropping systems, and pests; (ii) contingency plans to face the worst-case scenarios; (iii)) developing robust cropping systems (iv) exchange of updated information quicker and easier; and (v) skill development for better adoption of crop protection strategies.

Cropping systems: Studies on coconut based cropping systems confined at present to develop models for economic returns and to assess crop compatibility. More rigorous evaluation of cropping systems is required in terms of better pest management, adaptation to climate change, energy saving, reduction in greenhouse gases, and carbon sequestration. When Improved and better adaptable varieties of component crops are evolved, the same has to be tested for their suitability under coconut. Both conventional experimentation and crop simulation models are to be used to generate information in this regard.

COP26 Commitments: Plantation crops, coconut in particular can contribute significantly to achieve India's commitments in COP26, the 26th United Nations Climate Change Conference (31 October to 13 November 2021, Glasgow, UK) specific to (i) reduction of carbon emission; and (ii) achieving net-zero emissions by 2070. Coconutbased cropping systems enhancing carbon sequestration through different crop combinations involving both annual and perennial crops. Adoption of high-density multi-species cropping systems will also mitigate the negative effects of climate change. Bhagya and Maheswarappa (2017) studied the carbon sequestration in coconut based cropping systems. It was estimated that coconut palm alone had sequestered 51.14 C t/ha (above ground carbon); below ground soil carbon stock in the rhizosphere of 0-60 cm depth was 47.06 C t/ha. One of the major components to achieve net-zero emissions by 2070 is increasing the forest or tree coverage. The relevance of plantation crops in this regard needs no mention as they assure much needed employment generation, income and food, especially when established in smallholder systems where local people have control over production.

Technology dissemination: Increasing incidence of natural calamities and extreme weather events, and rapid technology generation call for faster technology dissemination and skill upgrade. Demand for refinement of technologies and tailor-made technology products is likely to increase.

CONCLUSIONS

Technology generation for sustainable coconut production in the face of climate change is challenging. Conventional research objectives and methods may not provide satisfactory solutions to the complex problems arising in this context. Nevertheless, many of the available technologies are climate resilient; which are to be properly adopted by farmers as a short-term strategy for coconut production. Cutting across disciplines, there is a need for utilization of advances in Internet-of-things to provide timely solutions to farmers.

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Current and Future Climate Suitability Prediction for Plantation Crops (Coconut and Arecanut) Using Maxent and Adaptation Strategies for Sustainable Production

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Introduction

Plantation crops are those that are grown on a large scale in a contiguous region and are owned and managed by an individual or a company. Coconut and arecanut are high-value commercial crops with more economic significance, and they play an important role in boosting the Indian economy, notably in terms of export potential, job creation, and poverty alleviation, particularly in the rural sector. Plantation crops are mostly grown in coastal belts and hilly terrains in between 8.4°N and 20°N latitudes of India apart from north east regions.

In India, coconut is cultivated in an area of 2.1 m ha and almost occupies the entire coastal belt. Major share goes to Kerala, Karnataka and Tamil Nadu followed by Andhra Pradesh, Goa, Maharashtra, and Orissa and to a small extent in North East. The long spells of hot and dry weather, severe winters and extremes of temperatures are not favourable for coconut growing. In the west coast of Karnataka and Kerala climate is humid and Tmax goes as high as 34 to 36°C while in the east coast of TN, AP, Orissa the climate is dry and Tmax reaches as high as 42 to 44°C. In south interior parts of Karnataka (Tumkur, Hasana, Ramanagara) and Tamil Nadu (Coimbatore, Theni, Erode) which is a major coconut belt the weather is dry and Tmax reaches up to 38°C to 40°C and the humidity is low. Both in south interior Karnataka and Tamil Nadu which is mainly rainfed, precipitation is a major constraint for production (Hebbar *et al*., 2017; 2022). High temperature coupled with low humidity not only affects the seedling growth but also in adult palm the effect is more severe on reproductive phase. The progamic phase of coconut is highly sensitive, viz. pollen germination is reduced (Hebbar *et al*., 2018), pollen tube growth and the time required to reach the ovule is prohibitively high (Hebbar *et al*., 2020) resulting in poor fertilization and reduced nut set. Therefore, devising strategies with wider adaptability of coconut to these changing climates is important for sustainable production

Arecanut is grown in high rainfall areas such as Malnad of Karnataka (ε 2500 mm) and in low rainfall areas like plains of Karnataka or parts of Coimbatore district in Tamil Nadu (750 mm). Higher rainfall during nut development stage (June to July) reduces the yield. Annual rainfall above 2000 mm has detrimental effect on arecanut yield, while this crop needs higher relative humidity during the morning hours throughout the year. In another study (Jose *et al*., 2019) observed that Tmax, Tmin, rainfall and RH could determine more than 97% variation in arecanut yield.

Though few studies have been conducted to study the impact of climate change on coconut and arecanut, however the understanding on the processes in response to drought, high temperature, flooding, salinity etc., is very much limited to develop mechanistic models. Hence, in this study a niche model Maxent is used to predict the future suitable climate for coconut and arecanut which requires only occurrence data along with bioclimatic variables as inputs (Phillips *et al*., 2004). This paper describes

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the climate of current and future scenarios suitable for cultivation of coconut and arecanut, and region wise shift in suitability under two scenarios of RCP 4.5 and RCP 8.5 for the years 2050s and 2070s with the adaptation strategies for vulnerable regions.

Materials and Methods

Study area

The coconut palm in India is grown under varying climatic and soil conditions mostly between 8°42 N and 20°N latitudes. The study area and occurrence points of coconut and arecanut used for model running are shown in Fig.1. Of the total coconut cultivation area in India, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh share 35%, 28%, 20.3% and 5,2% respectively. The west coast, with its high rainfall (annual rainfall is >2000 mm) and moderate temperature (Tmax, maximum temperature of 34 to 36 °C), is ideal for coconut cultivation. However, on the east coast, the rainfall is low (around 1000 to 1200 mm) and Tmax reaches a maximum of 40 to 42 °C in some of the coconut growing regions.

In India, arecanut is cultivated in an area of 473 thousand ha with an annual production of 703 thousand tonnes. Karnataka is the major producer and occupies 59.32 % of crop followed by Kerala, Assam and West Bengal. Unlike coconut, which is mostly found in coasts, arecanut is mostly seen in hills and plains. It can be seen up to an attitude of 800 m msl. Though it is suggested optimum temperature range of 14°C to 36°C is better for growth but it performs well at 28 to 30°C. It could tolerate Tmin of 5°C (as in places like Mohitnagar, West Bengal) and Tmax 40°C (Vittal in Karnataka and Kannara in Kerala) for few days.

For each of these study area GIS shape file was generated and the same shape file was used for extracting the environmental variables, topographical variables and soil data.

Occurrence points

The data on major coconut growing states and districts was sourced from Coconut Development Board (CDB, https://www.coconutboard.gov.in) website. Similarly, state and district wise data of arecanut was collected from Directorate of Arecanut and Spices Development (DASD). The name of the village having large cultivation area were obtained from the agriculture/horticulture officer of the respective district. The Google earth platform provides high spatial resolution images of coconut and arecanut orchards and hence it was used for identifying cultivation areas. These data along with the point data collected using Global Positioning System (GPS) in previous studies constituted the occurrence points. To reduce the issue of spatial sampling biases caused by multiple auto correlated locations, occurrence points were spatially rarefied at 5 km using SDM Toolbox 2.0 (Brown *et al*., 2017) in ArcGIS v. 10.0. The final occurrence dataset used for building SDMs included 1008 and 297 occurrence points of coconut and arecanut respectively (Fig.1).

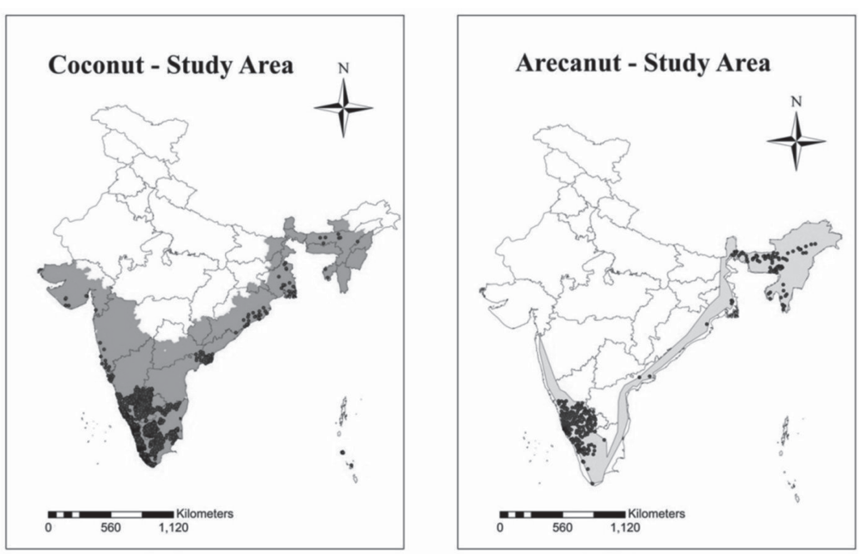

Fig.1: Study area of coconut and arecanut and points indicate the occurrence data used for model running.

Climate data

Nineteen bioclimatic variables from Paleoclim.org (Brown *et al*., 2018) for current climate (1979-2013) data and World Clim.v1.4 database (http://www.worldclim.org/download) for future periods in the 2050s (average for 2041-2060) and 2070s (average for 2061-2080) were used as environmental predictors (Hijmans *et al*., 2005). Variables representing the two future scenarios ((Representative concentration pathway RCP 4.5 (intermediate scenario) and RCP 8.5 (very high emission scenario)) were ensemble of 7 GCM Models (BCC-CSM1-1, GFDL-CM3, HadGEM2-ES, MIROC5, MIROC-CHEM, MIROC-ESM, NorESM1-M) were used. Also included soil as well as two topographical variables, elevation and land cover, which have a significant impact on coconut and arecanut cultivation in India.

Selection of climatic variables

To select distinct sets of variables that contributed the most to the models we used correlation analysis in SDM Tool 2.0 by eliminating one variable per pair with correlations of (*r*> 0.85). The variables used for final model running with their description are listed in Table 2.

Modeling

The future distribution of coconut and arecanut was studied using Maxent 3.4.1. This software is based upon the maximum-entropy principle, freely available online (url:http://biodiversityin for matics.amnh.org/open_source/Maxent /).

For extensive calibration of the Maxent model, its selection, final model generation, and evaluation in the R package using kuenm is described in Hebbar *et al*.(2022). Candidate models were built by integrating 31 different feature classes, distinct sets of environmental predictors (16 for coconut, 10 for arecanut), and different regularisation multiplier values in kuenm_cal function. The candidate model performance was evaluated based on significance (partial ROC, with 500 iterations and 50% of data for bootstrapping), omission rates (E =5%), and model complexity (AICc). Models with the lowest omission rates from this set and models with delta AICc values of d”2 were chosen as final models. After the creation of the final model with the parameter sets selected as best, the model projections were made for RCP 4.5 and 8.5 for the years 2050s and 2070s using the kuenm_mod function.

Threshold selection

The current climatic range and projected future expansion and contraction were mapped using binary model projections from each scenario in Arc-GIS v. 10.0. To provide an objective numerical overview of potential climatic suitability contraction and expansion, binary suitable/unsuitable areas were calculated for each scenario (Current, RCP 4.5, and RCP 8.5) using ‘maximum training sensitivity plus specificity’ as the logistic threshold cut off value (Al Ruheili *et al*., 2021).

Results

Generated models and its statistics.

A total of 2480 and 1240 candidate models were generated for Coconut and arecanut respectively (Table.1). All the models are statistically significant and better than null expectations. For coconut, none of the models met the omission rate criterion; however, two models had delta AICc values d”2. Applying the three evaluation criteria together, one candidate model M_0.1_F_qp_set_6 met the full suite of selection criteria for coconut (Fig.2). Whereas 3 models met omission rate and AICc criteria for arecanut and the model M_1_F_t_set_5 which had the lowest value for omission rate and AICc criteria was selected (Table. 1).

Table 1: Generated and selected candidate models and their fit and validation statistics for coconut and arecanut

Criteria	Coconut	Arecanut
All candidate models	2480	1240
Statistically significant models	2480	1240
Models meeting omission rate criteria	0	590
Models meeting AICc criteria	2	1
Statistically significant models meeting omission rate criteria	0	590
Statistically significant models meeting AICc criteria	2	1
Statistically significant models meeting omission rate and AICc criteria	0	3
Selected model	M_0.1_F_ qp_set_6	M_1_F_t_ set_5
Statistics of the selected model		
Mean AUC ratio	1.501	1.386
Rate of omission>0.05%	0.057	0.0286
AICc	18636.44	5460.96
Delta AICc	0	0

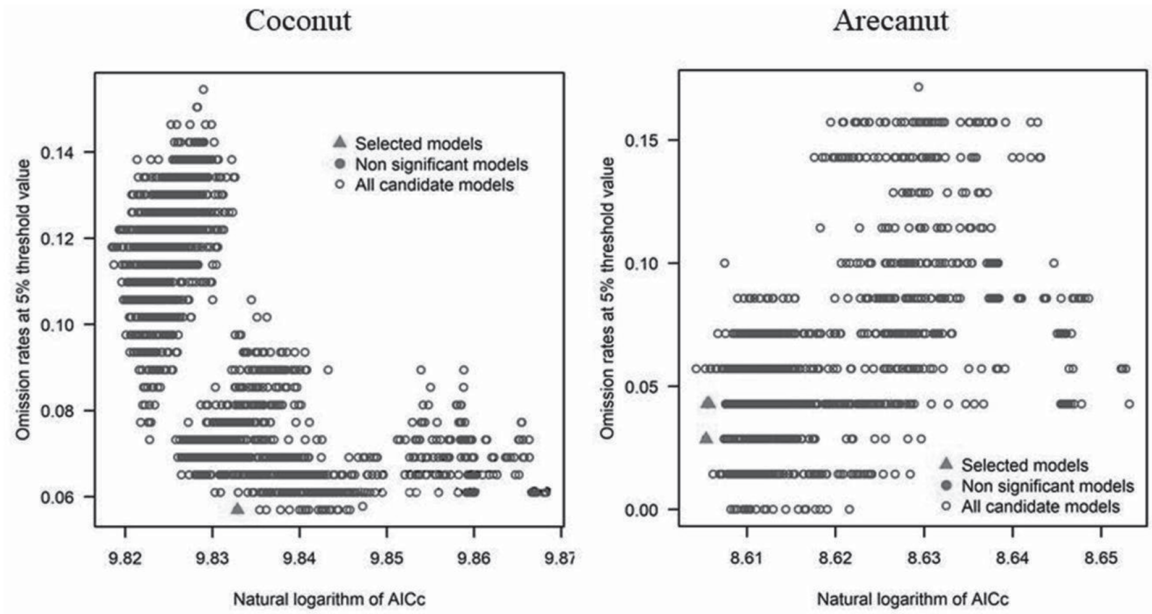

Fig. 2: Omission rates at 5% and AICc values for all, non-significant, and selected 'best' candidate models for coconut and arecanut. Models were selected based on statistical significance, omission rates, and AICc values

Model performance

Models performed well and the accuracy of the models was evaluated with the area under the curve (AUC index). Average AUC of 10 repetitions was 0.899 and 0.878 for coconut and arecanut respectively, which shows high accuracy of the model and the results are robust for the future predictions.

Table 2: Important bioclimatic variables and their percentage contributions to the distribution of crops

Bioclimatic variables	Percentage Contribution	
	Coconut	Arecanut
Bio 1 (Annual mean temperature)	1	13.7
Bio 2 (Mean diurnal range)	3.1	1.7
Bio 3 (Isothermality)	5.6	3.9
Bio 4 (Temperature seasonality)	34.4	-
Bio 7 (Temperature annual range)	28.7	20.5
Bio 12 (Annual precipitation)	2	3.4
Bio 14 (Precipitation of driest month)	4..2	6.4
Bio 15 (Precipitation seasonality)	8.6	13.9
Bio 18 (Precipitation of warmest quarter)	1.1	-
Bio 19 (Precipitation of coldest quarter)	2.2	27.3

The percentage contribution of environmental variables utilized in Maxent model were identified and listed for both species (Table 2). The potential distribution of coconut and arecanut are more strongly influenced by bioclimatic factors than soil and topographic factors. Bio 4 (Temperature seasonality, 34.4%) had the greatest influence followed by Bio 7 (Temperature Annual Range, 28.7%). These two together contributed 63.1% which along with Bio 15 (Precipitation Seasonality, 8.6 %) determined 71.7 % of climate suitability for coconut in India. Similarly, arecanut distribution was influenced by Bio19 (Precipitation of the coldest quarter, 27.3), Bio 7 (Temperature annual range, 20.5), Bio 15 (Precipitation seasonality, 13.9), and Bio 1(Annual mean temperature, 13.7), and these variables together contributed > 75%.

Current and future suitable area for coconut

The maps of potential distribution of coconut at a national level (in India) under the current climate and RCP 4.5 and 8.5 for 2050s and 2070s generated by the Maxent model are shown in Figure 3. The model projected, 7% of the area is on the west coast of Karnataka and Kerala which is highly suitable, South Interior Karnataka and TN are moderate to high suitable, while the east coast and north east are low to very low suitable. The area suitable for coconut cultivation in India has dropped to 11.6%, 12.1%, 12.4%, and 12% for RCP 4.5, 2050s, RCP 4.5, 2070s, RCP 8.5, 2050s, and RCP 8.5, 2070s, respectively. The maximum decline was seen in the south interior regions.

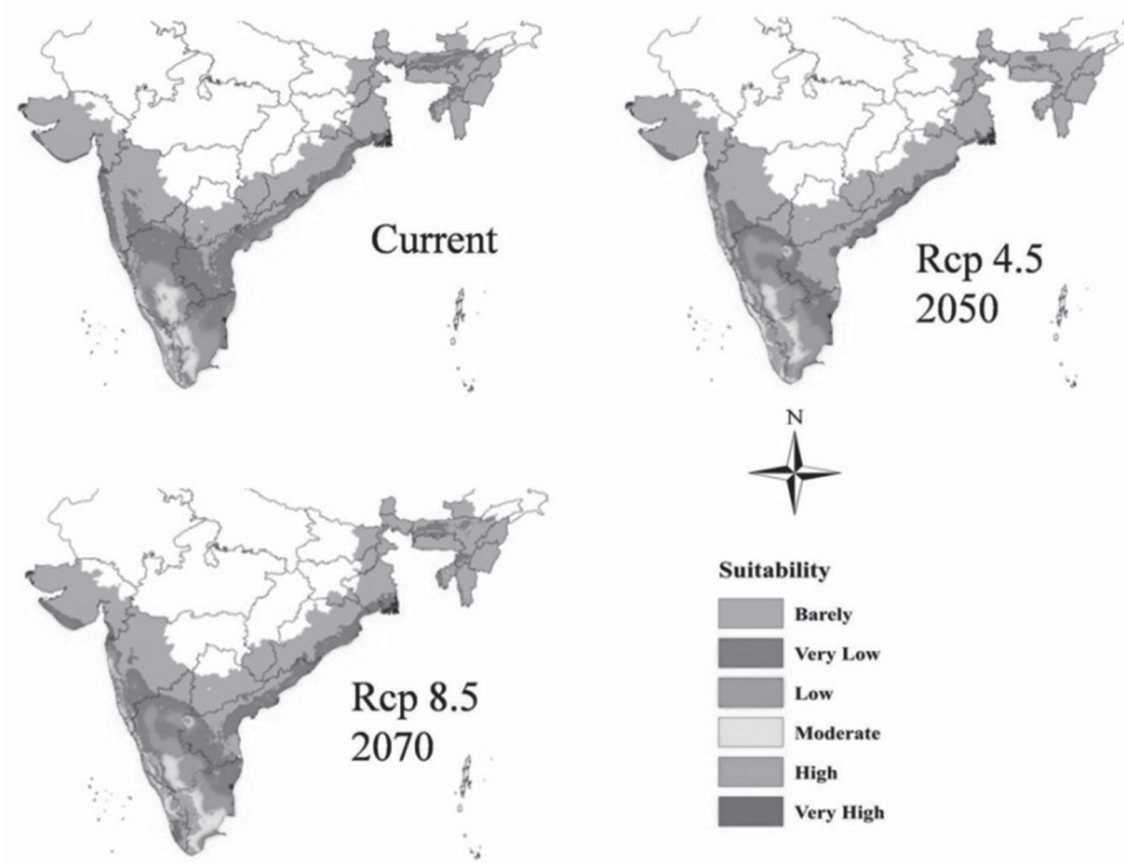

Fig. 3: Model prediction of current and future (RCP 4.5, 2050s and RCP 8.5, 2070s) coconut distribution within coconut growing regions of India.

As per model projection in Karnataka currently a small portion of west coast is high suitable and rest of west coast and south interior are moderate suitable for coconut. Under future scenarios, moderate suitable area of west coast shifts to high suitable; while in south interior it shifts to low suitable (Fig.4). Similarly, all along the west coast of Kerala is high suitable while interior and hilly areas are moderate to low suitable (Fig.4). Under future climate there is much scope for area expansion (2.2 - 4.9%), than area contraction (1.5-2.8 %). South Kerala may become very high suitable for coconut cultivation under RCP 8.5 2070s. On the other hand, East coast and north east are low suitable for coconut.

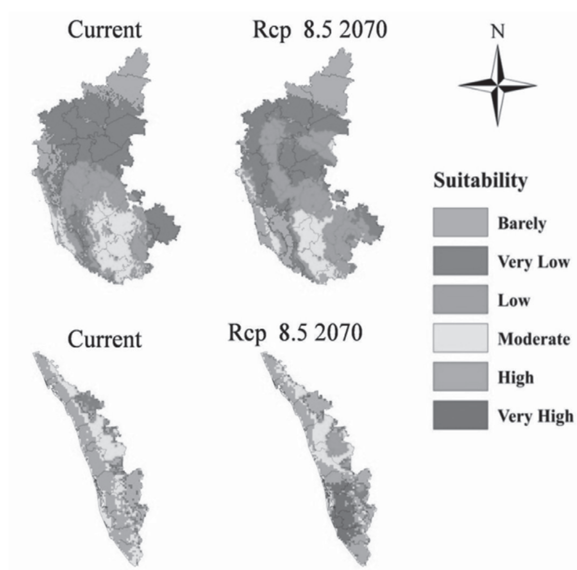

Fig. 4: Model prediction of current and future (RCP 8.5 2070s) coconut distributions of Kerala and Karnataka.

Current and future suitable area for arecanut

At all India level model projected 169977 km^2 of area as climatically suitable for cultivation of arecanut of which maximum area is in Karnataka (84942 km^2), followed by North East states (48033 km^2) and Kerala (18449 km^2). From the current unsuitable area, 6- 7 % area may become suitable under future scenarios, while large area (18% to 20 %) may become unsuitable from the current suitable area (Fig.5). South interiors of Karnataka is highly vulnerable under future climate. Range contraction projected could be as high as 60% for Karnataka under RCP 8.5 2070 while it was 66% for Kerala.

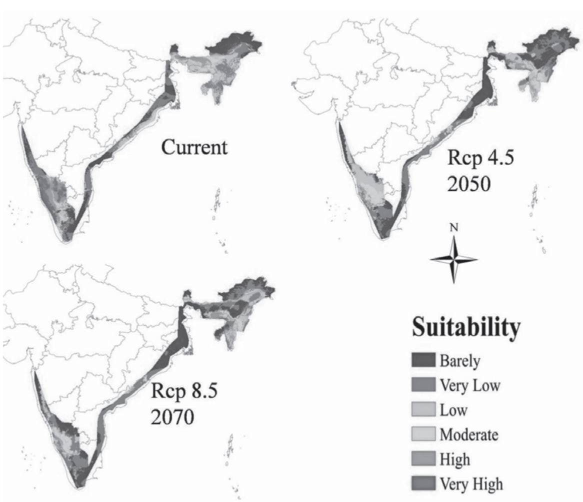

Fig. 5: Model prediction of current and future (RCP 4.5 2050s and RCP 8.5 2070s) arecanut distribution within arecanut growing regions of India.

In Karnataka as per model projection most of the districts which are currently highly suitable Viz. Chikmagalore, Shimoga, Uttara Kannada (UK), Dakshina Kannada (DK), Mysore, Mandya and Hasana are expected to become moderately suitable. However, some districts like Davanagere, Chitradurga and parts of Tumkur becomes low suitable. In North East, Goalghat, Cachar, Kamrup, Nagaon are some of the major districts growing arecanut in Assam under current climate. Under future scenarios, a shift is observed in which Meghalaya and Tripura become suitable in all the scenarios while Assam climate becomes low suitable (Fig. 6).

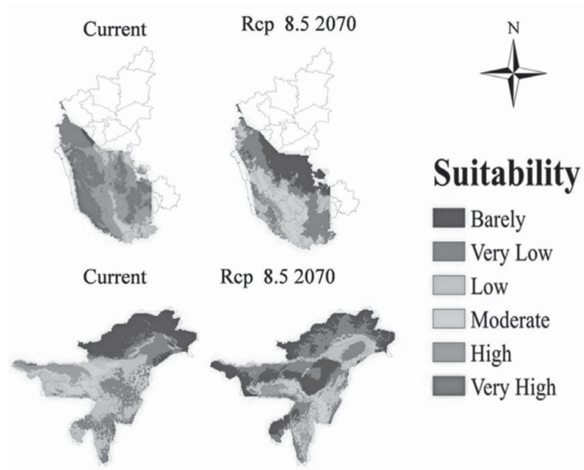

Fig. 6: Model prediction of current and future (RCP 8.5 2070s) Arecanut distributions of Karnataka and North Eastern States.

Discussions

The model predicted the current and future climatic suitability for 2 plantation crops and analysed the predicted climatic shift of both species for RCP 4.5 and 8.5 of 2050s and 2070s. As coconut and arecanut are grown across different agro-ecological zones of India, evaluating the impacts of climate change scenarios on the potential cultivable area will be helpful in understanding the relationships between crops niches and the corresponding environment, identifying priority cultivation areas, planning adaptation strategies (Davies *et al*., 2009; Zhang *et al*., 2016; Xu *et al*., 2018). Species distribution models like Maxent are extensively used to predict the change in climate of some of the plantation growing areas like cocoa in African countries (Läderach *et al*., 2013; Schroth *et al*., 2016), coffee at Zimbabwe (Pham *et al*., 2019) coconut in India (Hebbar *et al.,* 2022) and other agricultural crops (Kogo *et al*., 2019, He and Zhou, 2016; Jayasinghe and Kumar, 2019). In this study the MaxEnt model prediction for coconut having the mean AUC values of coconut 0.899$\pm$0.002 and arecanut 0.878 $\pm$0.005 indicating the model prediction comes under the excellent category, which is consistent with previous studies (Xu *et al*., 2018).

The model prediction for current climatic suitability for the coconut and arecanut are consistent with the actual distributions. Temperature and rainfall are the most important climatic factors contributing towards the distribution rather than topographical and soil, as in conformity with the earlier work on rubber (Ray *et al*., 2014). Temperature seasonality (Bio 4) has more percentage contribution in coconut model whereas precipitation during coldest month (Bio 19) had higher influence in arecanut model. Andhra Pradesh and Tamil Nadu where the crop is more vulnerable also had higher temperature seasonality followed by Karnataka, whereas the least was found for Kerala. As a result, more contraction in suitable climate is seen in east coast while in west coast sizable area is under high category. In south interior Karnataka it was low precipitation with differential temperature between day and night (Bio 3) makes it more vulnerable. Though precipitation change is minimal, still the temperature induced rise in evapotranspiration might subject the plants to drought in low rainfall areas of eastern region and south interior Karnataka. Both for TN and AP most of the current suitable areas become unsuitable. TN south and south western parts are suitable for coconut.

Similar to coconut, south interior Karnataka where there is extensive cultivation of arecanut under current climate, the climate under future scenarios may likely become moderate to low suitable especially in Chitradurga, Davangere, Shimogga, and parts of Tumkur. Similarly in Kerala, northern districts which are found to be currently highly suitable are likely to become low suitable. In North east, climate of Assam which is high suitable at present may become moderate to low suitable while adjoining states of Meghalaya and Tripura may emerge as new climatically suitable areas.

Thus, as per the model projection there is shift in suitability of climate for the cultivation of coconut and arecanut under future scenarios. Some of the areas where the climate is likely to become very low suitable it is better to go for alternate crops. In some of the areas where there could be shift in area with high suitable to moderate suitable, moderate to low needs adaptive measure for sustained production. Therefore, high priority to be given to extensive coconut and arecanut cultivation areas of south interior regions where high temperature and low humidity are the problem, so as to ensure sustainable cultivation of coconut at least in presently cultivated areas. High temperature effect to a certain extent could be alleviated either by planting genotypes with wider adaptability for water deficit and high temperature or by adopting some of the agro techniques of fertigation along with soil moisture conservation practices like mulching, bunding, cropping systems (Subramanian *et al*., 2012). Soil moisture retention, summer irrigation, drip irrigation, and fertilizer application are only a few of the agronomic adaptations that can not only reduce losses but also boost productivity in the majority of coconut and arecanut growing areas. In the eastern regions where T_{max} is the major issue adopting genotypes with wider adaptability to high temperature may sustain the crop under future climate. Arecanut is also found to be sensitive to rain during flowering, and therefore, breeding varieties with wider adaptability would alleviate the problem of flower and young fruit shedding.

Conclusion

In this study, a niche model Maxent had predicted the climate suitable to cultivate coconut and arecanut under future climate scenarios of 2050s and 2070s for RCP 4.5 and RCP 8.5 of India. Model projection suggested that there could a small contraction of area suitable for coconut cultivation. However, most notable finding is shift in suitability especially in south interior where most of the regions currently are moderate suitable becomes either low or others very low suitable. Similar is the case with arecanut in these regions. In north east there could be shift in suitability from current areas of Assam towards Meghalaya and Tripura. Therefore, to ensure sustainable cultivation and production in these current cultivation areas adaptive measures are to be followed immediately. Emerging climate suitable areas are to be considered in future expansion programs.

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Strategies for Climate Resilient and Sustainable Development of Oil Palm

MANORAMA, K. AND MATHUR, R.K.

Introduction

Oil palm produces on an average 4 to 6 tonnes of crude palm oil (CPO) per hectare per year. Oil palm is native to West African rain forests where the climate is humid tropical with high rainfall. It is a perennial crop with an economic life span of 25 to 30 years. Its commercial cultivation started in South-East Asia during late 20^{th} century largely as rainfed crop except in India and few parts of Thailand. Oil palm productivity is likely to get influenced by different factors of climate change differentially. Change in rainfall quantity and seasonality either increases or decreases yield levels corresponding to change either in favourable side or not. Increase in CO_2 concentration is likely to increase yield levels in oil palm. Climate change is expected to greatly influence areas of suitability for oil palm cultivation, especially in areas of rainfed cultivation. In India also, change in rainfall is expected to influence the ground water level and thereby its suitable locations. Further, change in minimal temperature is likely to cause shift in suitable areas for oil palm cultivation. Even now, there is a great variation in average productivity of oil palm between different states and between different locations within the same state. One of the reasons for these differences in productivity levels could be growing oil palm in moderately suitable and marginally suitable locations. Therefore, better knowledge on suitable locations is very much essential to grow oil palm in future. Climate change is inevitable and its effects on different crops are variable depending up on their climatic requirements and adaptive characters. Through prediction models it is reported that suitability locations for growing oil palm are likely to shift away from equator and to higher elevations in high altitude regions. To achieve better productivity by mitigating the impacts of climate change, it is highly essential to know about the crop, its climatic requirements, growing conditions, response to management etc.

Oil Palm in India

Edible oil demand in 2030 is expected to be around 34 million tonnes per annum. In comparison with other countries, India imports large quantities of palm oil followed by European union, China, Pakistan, Bangladesh and USA.Edible oil demand in India has been increasing progressively since last one decade, primarily due to population growth, improved standard of living and also changes in food habits. Presently, the area under oil seed production is between 26 and 27 million ha with an average yield of 1000 to 1100 kg ha^{-1}. This accounts to 7.5 to 8.0 million tonnes of vegetable oil production locally, as against the current demand of 22.5 to 23 million tonnes per annum. India imports around 50 to 60 per cent of its edible oil demands and the major contribution is from palm oil. Among different oil producing crops, oil palm (*Elaeis guineensis* Jacq) with its potential to produce highest oil yield, is the right option to plug the gap between demand and supply of edible oil in India. It is known to be the highest edible oil yielding perennial crop and produces 4 to 6 tonnes of crude palm oil ha^{-1} yr^{-1} and 0.4 to 0.6 tonnes of palm kernel oil ha^{-1} yr^{-1} from 4^{th} to 30^{th} year of its productive life span. Oil palm has the maximum potential of theoretical yield upto 18 tonnes per hectare per annum and therefore, our dependence on this crop to meet edible oil demands is obligatory.

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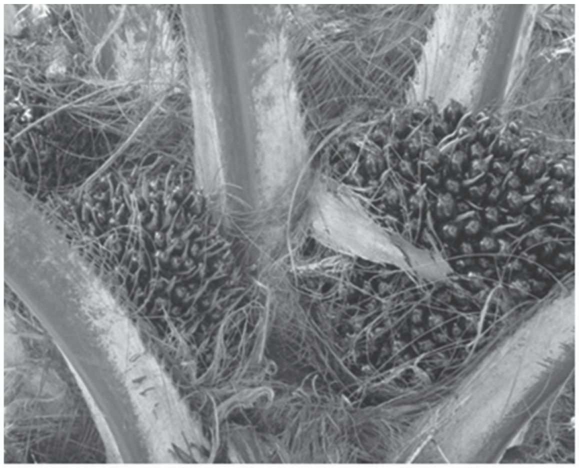

Oil palm Vs Climate change

If we look at the present distribution of this crop, 95% of plantations are located around 10 degree of north and south of equator. A study by Paterson *et al* (2017) on climate change predictions impacts revealed that suitable area for oil palm cultivation is going to turn unsuitable in most parts of the world. Using Climex model, projections were made for its suitability in 2050 and 2100. In this model a parameter "Ecoclimatic index" is estimated which is the product of annual growth index and stress indices. In 2050, the unsuitable climate increases by 6% at global level and highly suitable climate decreases by 22%. By 2100 most highly suitable area becomes unsuitable in Americas.

Table 1: Global scenario (% change in suitable area for oil palm)

Climate	2050	2100
Unsuitable	6·4	11·1
Marginal	52·4	61·1
Suitable	39·1	16·0
Highly suitable	“22·0	“267·6

If we look at the continent wise, in Latin America, Brazil and Columbia are badly affected. The red colour became almost nil by 2100. In Africa, by 2100 Nigeria got badly affected but not Madagascar. South-East Asia is the worst affected where the present giants of oil palm cultivation i.e., Indonesia and Malaysia are located, becomes totally unsuitable.

This is mainly because of stress factors viz., heat, dry and cold stresses. By 2050, the stress factors are very minimal in all the oil palm growing areas and India has none. But by 2100, much of India is becoming heat stressed. But some studies indicate that climate change has already occurred. In a recent study on 10 global crops viz., barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat for the period of 1974 to 2013, indicated a change in yield levels ranging between -13.4% in oil palm to +3.5% in soyabean. If we look at the yields as such, averaged globally, yields changed between -2551 (oil palm) to +982 (sugarcane) kg/ha/year. Among the top three global cereals, recent yields have decreased for rice (-0.3%) and wheat (-0.9%) and increased negligibly for maize. On positive side, in a study in oil palm nursery, on impact of CO_2 concentration on seedling growth indicated that the nursery period got reduced by 27 weeks instead of 52 weeks.

In India, oil palm is grown in 18 states and there are huge variations in productivity levels among these states. The state of Andhra Pradesh occupies the prime position in oil palm area as well as production. The production has enhanced 5 times in Andhra Pradesh during last 10 years whereas in rest of India the increase is only 3 fold. The productivity levels of Andhra Pradesh, Kerala, Telangana and Goa are encouraging whereas, rest of the states are showing either stagnant yield levels or lowered yield levels.

Climate Change Impact

1. Moisture availability: A reliable parameter to represent continuous water supply to irrigate the crop is ground water condition. Because, the main means of irrigation in the country are canals, tanks and wells, including tube-wells. Of all these sources, ground water constitutes the largest share. Wells, including dug wells, shallow tube-wells and deep tube wells provide about 61.6% of water for irrigation, followed by canals with 24.5% (CGWB report 2010). As oil palm is grown mostly under irrigation in India, water availability for irrigation assumes greater significance. Average actual transpiration rates in oil palm plantations are 4.0–6.5 mm day$^{”1}$in the rainy season and 1.0–2.5 mm day$^{”1}$on dry days (Carr, 2011). Oil palm leaves do not wilt, but the opening of new leaves is delayed in response to water stress, and stomatal opening is strongly affected by air vapour pressure deficit (VPD) and soil water availability (Smith, 1989; Caliman, 1992). There are no absolute figures quantifying the yield responses to irrigation but they are in the region of 20–25 kg fresh fruit ha”1 mm”1, equivalent to a yield loss of about 10% for every 100 mm increase in the potential soil water deficit (Carr, 2011). Ground water condition reflects an indirect indication of water availability in general. However, there are exceptions where aquifer conditions influence water percolation causing difficulties in ground water recharge. Changes in rainfall (quantity and distribution), temperature, extreme events due to climate change phenomenon are likely to impact the ground water situation which influences the stage of development (SD). This SD is nothing but recharge capacity of ground water against its draft.

2. Rainfall

Under rainfed conditions, oil palm requires around 1800 mm of rainfall at the rate of 150 mm per month. The overall contribution of rainfall to the country's annual ground water resource is 68% and the share of other resources, such as canal seepage, return flow from irrigation, recharge from tanks, ponds and water conservation structures taken together is 32% (Ground water year book, 2014).According to different estimates, every 100 mm of water deficit reduces yield by 8%-10% in the first year, and 3%-4% in the second year after the stress event (Caliman and Southworth, 1999; Hartley, 1988; Ochs and Daniel, 1976). Corley and Tinker (2016), citing Tittinutchanon et al. (2008), suggest that the yield loss even doubles, with each 100 mm increase in mean water deficit resulting in a 5.9 t/ha or about 20% decrease of a 30 t/ha yield over 2 years after the event. Mean temperatures below 17^0 C will result in more than 50% growth reduction, and at maximum daytime temperatures of 15^0 C, no growth occurs anymore (Corley and Tinker, 2003).). FFB yield reduced if monthly rainfall is < 100mm (Hartley, 1988). Goh (2000) noticed 10-20% yield reduction when 100 mm deficit in rainfall occurred after threshold. If water deficit is >500 mm per annum, yield reduction was exponential up to <10t/ha.

3. Minimum temperature

Low minimum temperatures are found in the tropics where the elevation exceeds 200 m, and there are reports from Sumatra that palms planted above 500 m come into bearing up to one year later than palms in the lowlands (Hartley, 1988). Prolonged low minimum temperatures of less than 21^oC may increase abortion of inflorescences before anthesis and slow down the ripening of fruit bunches. This may account for the very irregular distribution of bunch yield in Honduras where 90% of the crop is harvested in the seven months of June to December (Hartley, 1988). A similar response was reported when oil palm was grown in the Hainan Island of China where the minimum temperatures are commonly below 18^oC. Ferwerda and Enrencron (1975) demonstrated that palms exposed to a day temperature of 22^oC and a night temperature of 8^oC for 4 months practically stopped growing and became very chlorotic but they were still able to resume development when put under normal temperature conditions. The growth rate of young seedlings is inhibited at temperatures of 15^0C or lower. Growth of seedlings starts at about 17.5^o C and increases three times at 20^o C and seven times at 25^o C (Henry, 1957). Therefore, the areas with low minimum temperature may become suitable if climate change causes improvement in these values.

4. Atmospheric CO_2 concentration

Enhanced atmospheric CO_2 levels are expected to improve gas exchange parameters especially in C_3 plants (Hanstein and Felle, 2002). Exposure of C3 plants to elevated [CO2] generally results in stimulated photosynthesis and enhanced growth and yield. For many plant species, the long exposure to elevated [CO2] has also resulted in a down-regulation of Rubisco (Mohanty and Boyer, 1976). In a nursery study, when the plants were exposed to higher levels (800 μmol mol-1 CO2) of CO_2, nursery period got reduced by 27 weeks instead of 52 weeks, due to improvement in total biomass, relative growth rate, plant height, leaf area and number of leaves (Jaafar and Ibrahim, 2012). The positive impact of oil palm seedlings to CO2 enrichment was shown by enhancement of the leaf gas exchange characteristics of oil palm. The positive responses have been shown to cause increases in net photosynthesis, Asat, apparent quantum yield and reduction of dark respiration rate and light compensation point. The findings suggest that in the next 22nd century, it would be expected that oil palm to benefit from changes in the climate as long as temperature does not increase beyond the palm optimum level.

Climate Smart Strategies for Oil Palm

To combat the climate change influence on oil palm productivity, two pronged strategy could be followed viz., 1. Germplasm enhancement 2. Resource management. Under germplasm enhancement, drought tolerant dura crosses (ZS-1 x CA-12, ZS-8 *inter se*cross) have been identified from Zambian selections and these are being utilized in breeding programme. Also identified 2 dura crosses with better water stress tolerance coupled with slow vertical growth. With respect to development of dwarf plants, dura selections from Zambian sources are found promising. Two SSR markers (mEgCIR0059 and mEgCIR3328) have been identified for differentiating short statured palms.

Varietal Development

Through conventional breeding, three tenera hybrids with desirable characters (high FFB yield, high oil yield and high sex ratio) have been identified for release at CVRC in 2020 and one (Godavari Swarna) among them has been recommended for release. The characteristics of these hybrids are;

Godavari Swarna (NRCOP-4): With high fresh fruit bunch yield (26.87 t/ha/ yr) and high mesocarp oil yield (5.71 t/ha/year). Suitable for coastal ecosystem with moderate humidity and temperature under assured micro-irrigation system recommended for cultivation in Andhra Pradesh.

Godavari Ratna (NRCOP-2): With a fresh fruit bunch yield of 22.44 t/ha/yr average bunch weight of 18.31kg, high sex ratio (0.70), high mesocarp oil yield (5.36 t/ha/year) and high oil/bunch ratio (24.1), Suitable for high rainfall and assured irrigated conditions of coastal region of Maharashtra and Goa States.

Godavari Gold (NRCOP-17): It has special traits such as high fresh fruit bunch yield (27.23 t/ha/yr), more bunches/palm (11.74), high sex ratio (0.72), mesocarp oil yield (5.79t/ha/year) and oil/bunch ratio (21.28); suitable for coastal Tamil Nadu region under assured irrigated conditions.

RESOURCE MANAGEMENT STRATEGIES

1. **Growing oil palm in suitable areas:** Huge differences exist in productivity levels of Fresh Fruit bunches (FFBs) of oil palm among different states in India. One probable reason for this difference is that the crop is grown in moderately and marginally suitable areas in some of the locations. Further, climate change predictions indicate possible changes in suitable locations towards higher altitudes and away from equator. Right selection of site plays a crucial role in oil palm productivity as it is a long duration crop with an economic life span of 25 to 30 years. ICAR-IIOPR in collaboration with ICAR-NBSS & LUP developed suitability maps for oil palm in India both under irrigated and rainfed conditions through multi-criteria overlay analysis. ICAR-IIOPR developed an android based mobile application for scientific evaluation of suitable site for growing oil palm by considering all factors that influence its growth and development. Site suitability plays a crucial role in determining oil palm productivity. This mobile based application has been developed considering soil, water and climatic factors into consideration. It is placed in google play store, ICAR Krishi portal and web site of ICAR-IIOPR for free download. This OPSSE helps in taking appropriate decisions at individual farm level for cultivation of oil palm under irrigated as well as rainfed conditions.

2. **Scientific water management:** Drip system of micro irrigation at 70% deficit of crop water requirement proved more economical for achieving higher water use efficiency in oil palm. Palms need continuous irrigation excepting rainy days with four drippers in basin area (Rao *et al*., 2019). Root distribution studies indicated that large volume of effective roots exists within 2 metre radius from the base of the trunk (Suresh et al., 2003). Three static android mobile apps on Water Requirement for oil palm have been developed for Andhra Pradesh, Tamil Nadu and Karnataka. With the help of this app, oil palm farmers can know the amount of water to be given to their plantations. The water requirement (per palm per day) can be calculated for a particular day or week or month, depending on their requirement (Suresh et al, 2019: Suresh et al, 2020b; Suresh et al., 2020c)). For location specific water requirement, a web based application (https://

play.google.com/store/apps/details?id = iiopr. waterrequirement. andhrapradesh&hl=en_IN) has been developed by ICAR-IIOPR. This mobile application has been tested in farmers' fields and it proved to save around 25% of irrigation water in comparison with farmers' practice and the saved water could facilitate growing of additional crop along with oil palm and thereby enhancing the livelihood security of the farmers.

3. **Site-specific precise nutrient management:** Soil and leaf analysis based nutrient recommendations are to be followed for better nutrient use efficiency (Manorama *et al*., 2019). Diagnosis and Recommendation Integrated System (DRIS) norms and optimum leaf nutrients concentration of oil palm plantations in states of Karnataka, Gujarat, Goa, Mizoram, Tamil Nadu and Andhra Pradesh have been established for routine diagnostic and advisory purpose for balanced utilization of fertilizer. Assessment of soil properties and leaf nutrient concentration in oil palm plantations is required for effective nutrient management and higher crop yield. In West Godavari district of Andhra Pradesh, the leaf nutrients requirement order was B > Mg > K > N > P. The optimum concentration of leaf nutrients were 1.57-2.63% for N, 0.08-0.16% for P, 0.48- 0.88% for K, 0.25-0.71% for Mg and 22.6-60.2 mg kg-1 for B. Information about soil nutrients status and nutrient requirement order and optimum leaf nutrient ranges can be used for effective management of nutrients in the OPP of study region (Behera et al , 2019). In Cauvery delta zone of Tamil Nadu, the order of requirement of leaf nutrients was found to be K > P > N > Mg > B. Optimum leaf nutrient range for N, P, K, Mg and B were estimated as 1.61 to 2.11%, 0.10 to 0.12%, 0.33 to 0.81%, 0.23 to 0.73% and 30.6 to 54.8 mg kg-1, respectively, which could be used for guiding balanced application of fertilizers. On the whole, 15, 31, 2, 8 and 10% of leaf samples had below optimum concentrations of N, P, K, Mg and B, respectively (Behera *et a*l., 2018). Research studies on fertigation with NPK@600:300:600g/palm/year at monthly intervals coupled with irrigation based on Potential Evapo-transpiration (PET) is recommended for adult oil palm

4. **Mulching in combination with improved management:** Oil palm generates huge quantities of plantation waste in the form of cut fronds, male inflorescences and failed bunches (15 to 17 tonnes per hectare). Mulching with these plantation wastes in palm basins is reported to mitigate water stress by improving MWHC (maximum water holding capacity) by 72% over non-application. Addition of mulching material also improves soil physical, chemical and biological properties. Mulching and improved management in sole (monocropped) OP and intercropped OP (with cocoa) stands had better SOC content, CEC, water retention, nutrient availability and FFB production when compared with conventional system of OP production. Oil palm intercropped (with cocoa) with mulching and improved management recorded higher SOC content than sole crop within a time span of 6 years. From PCA analysis, FFB yield was found to be greatly influenced by MWHC, SOC, available K, exch Mg and available S. Mulching alone was also effective in intercropped OP stand in enhancing SOC content; the intercrop also contributed to the organic waste addition. Path analysis indicated that treatments with mulching and improved management could influence sustainability (Table 1). Decline in SOC content of soil in conventional cultivation (farmers' practice) is a sign of soil degradation. This knowledge is useful in redesigning management options to slow or avert land degradation and for sustainable production of oil palm in the tropics.

5. Oil palm based farming/cropping systems

Standardized and perfected different oil palm based cropping systems (oil palmcocoa, oil palm-red ginger, oil palm-heliconia, oil palm-bush pepper, oil palmbanana, oil palm-ornamental crops) in mature plantations. The cost benefit ratio for the above cropping systems varied from 1:2.38 to 1:2.86 and the net returns ranged from 1457 to 1771 US$ per ha. Oil palm based integrated farming system with fodder crops, dairy and back yard poultry has been found to be the most suitable and profitable system with a cost benefit ratio of 1:3.28. The technology

Table 1 Soil organic carbon (SOC), maximum water holding capacity of the soil (MWHC), soil pH and electrical conductivity (EC) as influenced by different management interventions. Soil organic carbon content, MWHC, pH and EC were estimated in 2013 i.e., before implementing improved technological interventions and after a time lag of 6 years in 2019. The letters $^{a,b,c...g}$ indicate significant difference of different treatments. The * and **indicate significance at p (<0.05) and both at p (<0.001) and p (<0.05)

	Treatments	SOC (%)		MWHC (%) at saturation		pH		EC (dS/m)	
		2013$^{\$}$(after 13 years of planting)	2019$^{\$\$}$ (6 years after trt)	2013(after 13 years of planting)	2019(6 years after trt)	2013(after 13 years of planting)	2019(6 years after trt)	2013(after 13 years of planting)	2019(6 years after trt)
T1	FP	0.48^{c}	0.46^{g}	19.2^{b}	16.8	6.8	6.8	0.32^{a**}	0.33^{a}
T2	SC + II	0.48^{c}	0.52^{g}	19.2^{b}	20.8	6.8	6.9	0.32^{a**}	0.32^{a}
T3	SC+II+Nut	0.48^{c}	0.67^{f}	19.2^{b}	26.8	6.8	7.1	0.32^{a**}	0.32^{a}
T4	SC+II+Nut+Fer	0.48^{c}	0.72^{ef}	19.2^{b}	27.4	6.8	7.1	0.32^{a**}	0.31^{a}
T5	SC (FP)+*mul*	0.73^{b**}	0.75^{ef}	28.3^{a}	29	7.0	7.0	0.18^{c**}	0.16^{c}
T6	SC+*mul*+II	0.73^{b**}	0.82^{de}	28.3^{a}	31	7.0	7.2	0.18^{c**}	0.15^{c}
T7	SC+*mul*+II+Nut	0.73^{b**}	0.88^{d}	28.3^{a}	33.2	7.0	7.2	0.18^{c**}	0.15^{c}
T8	SC+*mul*+II+Nut+Fert	0.73^{b**}	1.02^{c*}	28.3^{a}	37.5	7.0	7.3	0.18^{c**}	0.14^{cd}
T9	IC (FP)+*mul*	0.85^{a**}	1.19^{b**}	30.7^{a}	38.2	7.2	7.2	0.15^{d}	0.13^{cd}
T10	IC+Mul+II+Nut+Fert	0.85^{a**}	1.33^{a*}	30.7^{a}	47.4	7.2	7.3	0.15^{d}	0.11^{d}
T11	*Aban*	0.42^{c}	0.40^{g}	16.8	16	6.3	6.2	0.22c**	0.22^{b}
	F value	54.07	49.12	40.79	50.75	1.80	0.60	46.5	55.1
	Prob >F	0	0	0	0	0.19	0.79	0	0
	CD (P =0.001)	0.11	0.17	4.24	4.31	NS	NS	0.01	0.05
	CD (P = 0.05)	0.08	0.12	3.12	3.2	NS	NS	0.008	0.04

$^{\$}$ Before imposing technological interventions, $^{\$\$}$ After imposing technological interventions in 2014

T1=FP: Farmers' practice; T2=SC + II: Sole crop of oil palm + improved irrigation; T3=SC+II+Nut: Sole crop of oil palm + improved irrigation + Soil and leaf test based nutrient management; T4=SC+II+Nut+Fer: Sole crop of oil palm + improved irrigation + Soil and leaf test based nutrient management through fertigation; T5=(FP) + *mul*: Farmers' practice under mulching; T6=SC+*mul*+II: Sole crop of oil palm under mulching + improved irrigation; T7=SC+*mul*+II+Nut: Sole crop of oil palm under mulching + improved irrigation + Soil and leaf test based nutrient management; T8=SC+*mul*+II+Nut+Fert: Sole crop of oil palm under mulching + improved irrigation + Soil and leaf test based nutrient management through fertigation; T9=IC (FP)+mul: Oil palm with cocoa inter crop under farmers' practice: T10=IC+*mul*+II+Nut+Fert: Oil palm with cocoa inter crop + improved irrigation + Soil and leaf test based nutrient management through fertigation; T11=*Aban*: Abandoned plantation has been spread to an area of 2900 ha in oil palm growing States of India. Hybrid Napier grass varieties DHN-6 (36.15t/ha) and KKM (34.18t/ha) and guinea grass varieties BG-1(38.38t/ha), DGG-1(28.67t/ ha) and Co3(32.25t/ha) have been found as suitable shade tolerant and high fodder yielding varieties in mature oil palm plantations (Ramachandrudu, 2019b).

Future Thrust

Genetic enhancement

Since oil palm is being grown on a wide variety of soil and climatic conditions and non-traditional climatic conditions like high temperature and low humidity, it is necessary to introduce some stress tolerant materials having high water use efficiency/ tolerance to drought and cold. The future thrust areas should be 1. Strengthening of Indian Oil Palm Genetic Resource base 2. Collection of elite palms from commercial plantations with exotic sources in India 3. Evaluation of available germplasm, their characterization, documentation and utilization in oil palm breeding programmes 4. Identification of promising germplasm for use in improvement programme 5. Selection of germplasm in development of pre-breeding populations / introgression/ improvement of Indian materials 6. Shortening the breeding cycle of oil palm by integrating conventional and molecular techniques like speed breeding.

Resource management

Water requirement per tonne of FFB needs to be minimized by avoiding losses. The waste generated in oil palm gardens if properly made use of for mulching and recycling, it can increase the water use efficiency through reduced evaporation while adding nutrients to the soil. Similarly, efficient nutrient management techniques through precision farming which considers the intrinsic variability with spatial dimension need to be given emphasis for enhancing productivity from oil palm gardens. A large amount of variability is observed in soils of different parts of the country, state, mandal, village and even within a single farm. A common recommendation of fertilizers and even water does not hold good and even it leads to deficiencies of certain nutrients while causing toxicities of others. The techniques of variable rate application of critical inputs like water and nutrients need to be developed and its importance need to be explained to the farmers for their applicability.

Farming system approach

When oil palm was introduced in India, the conditions were different with respect to wages, labour availability and government policies on imports. But today, the wages have increased and labour is not available for harvesting in tall trees. Monocropping of oil palm is not much profitable unless it is combined with intercropping and also dairy component. Diversifying and intensifying the oil palm cultivation through suitable component crops and other components like dairy, poultry birds or goats etc would definitely enhance the income.

Conclusion

The results of climate change prediction models indicate a change in suitable areas for oil palm cultivation from the current existing locations towards poles. It is expected that tropical areas would become hotter with severe heat stress making them unsuitable to grow oil palm. Suitable areas are likely to move to temperate regions and in hills to upper elevations. Therefore, it is wiser to find out the most suitable locations for growing the crop from time to time through multicriteria overlay techniques and shift the crop accordingly with a well-planned strategy. Further, mitigation strategies need to be strengthened to continue the crop in present suitable areas which would become less suitable with climate change. Efforts need to be focused to reduce the ill effects of climate change with concerted co-operation from all the corners, with which it is possible to postpone climate change impacts for a considerable time lag.

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Economically Important Endangered, Rare and Threatened Medicinal Plants and their Conservation

A.K. JOHRI

Summary

About 85% of the people in the world's developing countries rely on traditional medicine for their primary health care, and about 85% of traditional medicine involves the use of plant extracts. India has 2.4% of world's area with 8% of global biodiversity and it is one of the 12^{th} mega diversity hotspot countries of the world with a rich diversity of biotic resources. The rich resource is disappearing at an alarming rate as a result of over-exploitation. Therefore, the management of traditional medicinal plant resources has become a matter of urgency. An ever increasing demand of uniform medicinal plants based medicines warrants their mass propagation through plant tissue culture strategy. Tissue culture technology is potent and has opened extensive areas of research for biodiversity conservation. Plant in vitro regeneration is a biotechnological tool that offers a tremendous potential solution for the propagation of endangered and superior genotypes of medicinal plants which could be released to their natural habitat or cultivated on a large scale for the pharmaceutical product of interest. Tissue culture protocols have been developed for a wide range of medicinal plants, which includes endangered, rare and threatened plant species. Some of these endangered medicinal plants are Bacopa monnieri, Berberis aristrata, Celastrus paniculata Ginkgo biloba, Glycyrrhiza glabra, Gymnema sylvestre, Holostemma, Nardastchy jatamansi, Oroxylum indicum, Picorrhiza kurroa, Rauwolfia serpentine, Rheum emodi, Salaca oblonga, Saussaurea lappa; Swertia chirata Taxus baccta, Tinospora cordifolia, Tylophora indica,. Conventionally, there are two methods of conservation: in situ and ex situ conservation, both are complementary to each other. In situ methods allow conservation to occur with ongoing natural evolutionary processes ex situ conservation via in vitro propagation also acts as a viable alternative for increase and conservation of populations of existing bioresources in the wild and to meet the commercial requirements. A review highlighting various in vitro protocols developed for selected medicinal plant species of India has been done to highlight the significance of ex situ conservation in cases where regeneration through conventional methods is difficult to undertake and species are left with low population in the wild. Thus in vitro cell and tissue culture methodology is envisaged as a mean for germplasm conservation to ensure the survival of endangered plant species, rapid mass propagation for large scale re-vegetation and for genetic manipulation studies.

Almost all civilization has a history of medicinal plant use. Approximately 85% of the people in the world's developing countries rely on traditional medicine for their primary health care, and about 85% of traditional medicine involves the use of plant extracts (Vieira and Skorupa, 1993). India has 2.4% of world's area with 8% of global biodiversity and it is one of the 12^{th} mega diversity hotspot countries of the world with a rich diversity of biotic resources. Out of 34 hotspots recognized, India has two major hotspots - the Eastern Himalayas and the Western Ghats. The bio-geographic position of India is so unique that all known types of ecosystems range from coldest place like the Nubra Valley with57°C, dry cold deserts of Ladakh, temperate and Alpine and subtropical regions of the North-West and trans-Himalayas, rain forests with the world's highest rainfall in Cherrapunji in Meghalaya, wet evergreen

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humid tropics of Western Ghats, arid and semiarid conditions of Peninsular India, dry desert conditions of Rajasthan and Gujarat to the tidal mangroves of the Sunderban which harbours about 47000 species of plants of which 17 000 are angiosperms (Bapat *et al.,* 2008). India is also rich in medicinal plant diversity with all the three levels of biodiversity such as species diversity, genetic diversity, and habitat diversity (Mukherjee and Wahile, 2006). Across the country, the forests are estimated to harbour 90% of India's total medicinal plants diversity. Only about 10% of the known medicinal plants of India are restricted to non- forest habitats (Wakdikar, 2004). Concerning the total number of flowering plant species, although only 18,665, the intraspecific variability found in them makes it one of the highest in the world. Out of 18,665 plants, the classic systems of medicines like Ayurveda, Siddha, and Unani make use of only about 3000 plants in various formulations (Schippmann *et al.,* 2006). Although, there is no reliable figure for the total number of medicinal plants on Earth, and numbers and percentages for countries and regions vary greatly but estimates for the numbers of species used medicinally include: 35,000-70,000 or 53,000 worldwide (Schippmann *et al.,* 2002); 10,000-11,250 in China (Pei, 2002); 7500 in India (Shiva, 1996); 2237 in Mexico (Toledo, 1995); and 2572 traditionally by North American Indians (Moerman, 1998). The World Health Organization (WHO) has estimated that the present demand for medicinal plants is approximately US $14 billion per year. The demand for medicinal plant based raw materials is growing at the rate of 15 to 25% annually, and according to an estimate of WHO, the demand for medicinal plants is likely to increase more than US $5 trillion in 2050. In India, the medicinal plant-related trade is estimated to be approximately US $1 billion per year (Kala *et al.,* 2006). According to Schippmann *et al.* (1990), one fifth of all the plants found in India are used for medicinal purpose. The world average stands at 12.5% while India has 20% plant species of medicinal value and which are in use. But according to Hamilton (2003), India has about 44% of flora, which is used medicinally. Although it is difficult to estimate the total number of medicinal plants present worldwide, the fact remains true that India with rich biodiversity ranks first in per cent flora, which contain active medicinal ingredient (Mandal, 1999).

A total of 560 plant species of India have been included in the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened species, out of which 247 species are in the threatened category. On a global basis, the IUCN has estimated that about 12.5% of the world's vascular plants, totalling about 34 000 species are under varying degrees of threat (Phartyal *et al.,* 2002). IUCN recognises the following categories: extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient and not evaluated. Species with small populations that are not at present endangered or vulnerable but are at risk are called rare. (Singh *et al.,* 2006). Many of them are facing extinction. In the past few decades, there has been an ever-increasing global inclination towards herbal medicine, followed by a belated growth in international awareness about the dwindling supply of the world's medicinal plants (Bodeker, 2002). The plants used in the phytopharmaceutical preparations are obtained mainly from the naturally growing areas. The genetic diversity of medicinal plants in the world is getting endangered at alarming rate because of ruinous harvesting practices and over-harvesting for production of medicines, with little or no regard to the future. Also, extensive destruction of the plant-rich habitat as a result of forest degradation, agricultural encroachment, urbanization etc. is other factors, thus challenging their existence (Gupta *et al.,* 1998). In view of the tremendously growing world population, increasing anthropogenic activities, rapidly eroding natural ecosystem, etc the natural habitat for a great number of herbs and trees are dwindling and of *per capita* consumption has resulted in unsustainable exploitation of Earth's biological diversity, exacerbated by climate change, ocean acidification, and other anthropogenic environmental impacts (Rands *et al.,* 2010). A large sum of money is pumped every year to replenish the lost biodiversity and large numbers of protocols are available at present. Unfortunately, we are not witnessing any improvement in the status of these plant species in nature and the number of threatened plant species is increasing gradually (Tripathi, 2008). In order to safeguard this knowledge, it should be documented, preserved and patented (Mukherjee, 2009). Even the United Nations Conference on Environment and Development (UNCED), held recently at Rio de Janeiro, Brazil helped to place the loss of biodiversity and its conservation on the global agenda. Therefore, the management of traditional medicinal plant resources has become the matter of urgency. Hence, conservation of such a buffer is considered fundamental and provided priority in all sectors of global development (Tandon *et al.,* 2009). Although species conservation is achieved most effectively through the management of wild populations and natural habitats (*in situ* conservation) but most of the medicinal plants either do not produce seeds or seeds are too small and do not germinate in soils. Even plants raised through seeds are highly heterozygous and show great variations in growth, habit and yield and may have to be discarded because of poor quality of products for their commercial release. Likewise, majority of the plants are not amenable to vegetative propagation through cutting and grafting, thus limiting multiplication of desired cultivars. Moreover many plants propagated by vegetative means contain systemic bacteria, fungi and viruses which may affect the quality and appearance of selected items (Murch *et al.,* 2000). Thus mass multiplication of disease free planting material becomes a general problem. In order to overcome these barriers, *ex situ* techniques can be used to complement *in situ* methods and, in some instances, may be the only option for some species (Sarasan *et al.,* 2006; Negash *et al.,* 2001). Therefore, conservation of medicinal plants can be accomplished by the *ex situ*, that is, outside natural habitat by cultivating and maintaining plants through long-term preservation of plant propagules in plant tissue culture repositories (Rands *et al.,* 2010).

In vitro techniques have been increasingly applied for mass propagation and conservation of germplasm as it has superiority over conventional method of propagation and offer some distinct advantage over alternative strategies. Some of these are as follows: (1) collection may occur at anytime independent of flowering period for each species (this assumes that seed material is not required), (2) there is the potential of virus elimination from contaminated tissue through meristem culture, (3) clonal material can be produced where this is useful for the maintenance of elite genotypes, (4) rapid multiplication may occur at any time where stocks are required using micropropagation procedures, (5) germination of difficult or immature seed or embryo may be facilitated for breeding programmes, and (6) distribution across the border may be safer, in terms of germplasm health status using *in vitro* cultures. Some more general positive advantages of *in vitro* techniques include the fact that storage space requirements are vastly reduced compared with field storage. Storage facilities may be established at any geographical location and cultures are not subject to environmental disturbances such as temperature fluctuation, cyclones, insect, pests, and pathogen (Shibli *et al.,* 2006). In this regard the micro-propagation holds significant promise for true to type, rapid and mass multiplication under disease free conditions. Besides, the callus derived plants exhibit huge genetic variation that could be exploited for developing superior clones/varieties particularly in vegetatively propagated plant species. Tissue culture has emerged as a promising technique for multiplying and conserving the medicinally important species within short period and limited space, which are difficult to regenerate by conventional methods and save them from extinction. In recent years, *in-vitro* cell and tissue culture methodology is envisaged as a mean for germplasm conservation to ensure the survival of endangered plant species, rapid mass propagation for large-scale re-vegetation and for genetic manipulation studies under precisely controlled physical and chemical conditions. Combinations of *in vitro* propagation techniques (Fay, 1992) and cryopreservation may help in conservation of biodiversity of locally used medicinal plants (Singh *et al.,* 2006).

Important medicinal plants of India

Aegle marmelos

Aegle marmelos (L.) Corr., (Family *Rutaceae*) commonly known as "Bael Tree" is a popular vulnerable medicinal plant mostly found in tropical and subtropical regions. Almost all parts of the tree are used in preparing herbal medicines for treating diarrhea, dysentery, dyspepsia, malaria, fever, jaundice, and skin diseases such as ulcers, urticaria, and eczema. The plant is rich in alkaloids, among which aegline, marmesin, marmin, and marmelosin are the major ones (Kala, 2006).

Acorus calamus

Acorus calamus Linn. Belongs to the family *Araceae* commonly known as "sweet flag" or "Bach" is an important endangered medicinal plant. It is a semi aquatic herb with creeping rhizomes and sword shaped long leaves. The rhizomes possess anti-spasmodic, carminative and anthelmintic properties and also used for treatment of epilepsy, mental ailments, chronic diarrhea, dysentery, bronchial catarrh, intermittent fevers and tumors (Anon, 2000).

Bacopa monnieri

Bacopa monnieri belonging to the family *Scrophulariaceae* is a very popular herb in India for longevity and mental function. It is used to decrease fatigue and depression, and to stimulate the sex drive. It energizes the central nervous system, and aids the circulatory system, soothes and minimizes varicose veins and helps to minimize scarring. It is also useful in repairing skin and connective tissues and smoothing out cellulite. It is generally considered an Ayurvedic "age tonic" restoring youth and vitality. Brahmi has been used by Ayurveda in India for almost 3000 years. The Ayurvedic treatise, the Charaka Samhita (100A.D.), recommends Brahmi in formulations for a range of mental conditions including anxiety, poor cognition and lack of concentration. In India, Brahmi is currently recognized as being effective in the treatment of mental illness and epilepsy.

Celastrus paniculatus

Celastrus paniculatus Willd. belonging to the family *Celastraceae* commonly known as Malkangni, Jyotishmati and Bitter sweet is a rare and endangered important medicinal plant believed to sharpen the memory and also used to cure a number of diseases. It is a large, woody, unarmed climbing shrub occurring naturally in hilly parts of India up to an altitude of 1200 m. This plant is widely used to cure depression, paralysis, leprosy, fever, abdominal disorders and cancerous tumors. Chemical constituents of seeds as revealed by phytochemical analysis were sesquiterpene alkaloids like celapagine, celapanigine and celapanine (Sharma *et al.,* 2001).

Commiphora mukul

Commiphora mukul (Hook. ex Stocks) Engl. (Family *Burseraceae*) popularly known as "Guggul", is an important endangered medicinal plant species. It is widely distributed in tropical regions of Africa and Asia. It grows wild in the arid, rocky tracts of north- western regions of India. The plant exudes a medicinal oleo-gum resin ('Guggul') from incisions made on the bark in cold season. Gum is bitter, acrid, aromatic, pungent, carminative and stomachic stimulating the appetite and improving digestion. It is astringent, expectorant, anthelmintic, antispasmodic, antiinflammatory, diuretic, depurative, anodyne, vulnerary, themogenic, antiseptic, nervine tonic, aphrodisiac, stimulant, emmenagogue and diaphoretic (Sosa *et al.,* 1993). It also possesses strong purifying and rejuvenating properties and is said to be a uterine stimulant. The main constituents of guggul include phytosterols, gugulipids and the ketonic steroid compound (guggulsterones) mainly E and Z gugguisterones. These are responsible for the lipid lowering effects of guggul (Singh *et al.,* 1997).

Glycyrrhiza glabra

It was one of the most widely known medicines in ancient history, and records of its use include Assyrian tablets of around 2000 BC and Chinese herbals of the same period. Theophrastos of Lesbos, writing in the fourth century BC wrote that 'it has the property of quenching thirst if one holds it in the mouth'. Dioscorides gave the plant its botanical name (Greek glukos = sweet, riza = root). Its 13th century English name was Lycorys, a corruption of glycyrrhiza. Liquorice (*Glycyrrhiza glabra*) belonging to the family *Fabaceae* has long been used for both culinary and medical purposes. Used for flavoring and sweetening candies and medical remedies, licorice also has potent effects of its own, particularly for ulcers and adrenal insufficiencies. It is also used for asthmatic coughs, as an antispasmodic and ulcer remedy, and to cool 'hot' conditions.

Holostemma ada-kaodien

Holostemma ada-kodien (Synonym – *Leptadenia reticulate*, W & A) commonly known as jivanti belongs to family *Asclepiadaceae*. Jivanti is sweet in taste, sweet in the post digestive effect and has cold potency. It alleviates all the three doshas, namely, vata, pitta and kapha. It possesses light and oily attributes. It is a rejuvenative, heart (caksusya and hrdya). It is used in diseases like fever, tuberculosis, burning sensation of the body and raktapittal. Mainly the roots and the whole plant are used for medicinal purposes. Externally the paste of its leaves and roots alleviate oedema due to vitiation of pitta dosa. The herb is beneficial for external use in various skin diseases, wounds and inflammation of the skin.

Peganum harmala

Peganum harmala L. (Syrian Rue), a medicinally important perennial herb of family *Nitrariaceae*, distributed over semi arid areas of North-West India, North-Africa and central Asia. Medicinally the fruits and seeds of this plant are digestive, diuretic, hallucinogenic, hypnotic, antipyretic, antispasmodic, nauseant, emetic, narcotic and uterine stimulant (Chatterjee, 1997). A red dye obtained from seeds is widely used in Turkey and Iran for colouring carpets. Leaves are useful in asthma, colic, dysmenorrhea, hiccup, hysteria, neuralgia and rheumatism. The plant has also been used as antimicrobial, antitumoral, in curing malaria and has insecticidal potential (Kiritikar, 1995).

Prosopis cineraria

Prosopis cineraria belongs to the family *Fabaceae*, *Prosopis* species are the dominant species in Indian desert commonly known as Jhand or Khezri. *P. cinerarium* has a very good economic importance in arid regions and is assumed to treat snake bite and scorpion stings. Green pods of this plant are used as food. This species is highly drought tolerant and can withstand in the area having 50mm rainfall annually.

Nardostachys jatamansi

Nardostachys jatamansi is a flowering plant of the honeysuckle family that grows in the eastern Himalayas, primarily in a belt through Kumaon, Nepal, Sikkim and Bhutan.[3] The plant grows 10–50 cm (4–20 in) in height and has pink, bell-shaped flowers.[4] It is found at an altitude of 3,000–5,000 m (9,800–16,400 ft). Rhizomes (underground stems) can be crushed and distilled into an intensely aromatic amber-colored essential oil, which is very thick in consistency. Nard oil is used as a perfume, an incense, a sedative, and an herbal medicine said to fight insomnia, birth difficulties, and other minor ailments. It is considered endangered due to overharvesting for folk medicine, overgrazing, loss of habitats, and forest degradation.

Oroxylum indicum

It belongs to family *Bignoniaceae*. Syonaka is astringent and bitter in taste, pungent in the post digestive effect and has cold potency. It possesses light and dry attributes. It is used in rheumatic disorders, diarrhea, cough, diabetes and cystitis. The skin of roots of syonaka is used for medicinal purpose, both, externally as well as internally. Used externally as a paste of its skin of roots, it dries up the discharges and promotes the wound healing. The tub bath with its decoction relieves the swelling and pain in rheumatic disorders. The medicated oil of syonaka in sesame oil base instilled into ears mitigates the pain in otitis. The decoction of its sroot-skin is an effective gargle in stomatitis. The root skin is also useful in dressing the wounds in soft chancre (upadamsa). Internally, syonaka is a panacea for arthritis and rheumatism. The decoction of the roots is commonly used for arthritis. In diarrhea and dysentery, the decoction combined with mocarasa (gum of samali *Bombax malabaricum*). It is given along with honey. Syonaka also stimulates appetite, improves digestion and is vermicidal.

Picrorhiza kurroa

Kutki or *Picrorhiza Kurroa* is a herbal medicinal plant from *Scrophulariaceae* family. It is also known as hellbore, katuka, kurri, Katuko, Kuru, Katukarogani. It is found in Himalayan region in India. According to Ayurveda the plant has utility as laxative, liver-stimulant, appetite and stimulant, febrifuge. The plant is also beneficial in bronchial asthma and epidemic jaundice. It is also used to ease stomachache, and is believed to promote appetite. The herb is also effective in 'Kapha' disorders, billow fever, urinary discharge, hiccup, blood troubles, burning sensations and leucoderma.

Sapindus mukorossi

Sapindus mukorossi (Family: Sapindaceae) popularly known as 'Ritha' and 'Soapnut', is a most important deciduous tree of tropical and sub- tropical regions of Asia. The fruit of this tree contains saponins, the most active secondary metabolites extracted from this plant. It is a good substitute for washing soap and is as such used in preparation of quality shampoos, detergents etc. The fruit is of considerable importance for its medicinal value for treating a number of diseases like common cold, pimples, epilepsy, constipation, nausea etc. It is also used as expectorant and anthelmintic in small doses (Anon., 1992).

Simmondsia chinensis (Jojoba)

It is an evergreen, dioecious desert shrub which grows wildly in Sonora desert of Arizona, northern Mexico, southern and Baja California. Jojoba is now cultivated commercially in Argentina, Australia, Chile, Egypt, India, Israel, Mexico, Peru, South Africa and the USA. Jojoba seed oil is being utilized in industrial lubricants, and in pharmaceutical and cosmetic industries. The liquid wax that makes 40–60 % of seed dry weight has properties similar to sperm whale oil. Due to the ban on the import of sperm whale products into USA and other countries, jojoba is gaining commercial importance at international level (Reddy and Chikara, 2010). It belongs to family *Simmondsiaceae*.

Spilanthes acmella Murr

It belongs to the *Asteraceae* family and is commonly known as Akarkara or Toothache plant. This plant is widely distributed in the tropical and subtropical regions. The flowers and leaves of this plant have been used as traditional medicine for stammering, toothache, stomatitis and throat complaints. It has potent diuretic activity and the ability to dissolve urinary calculi. The plants have shown anti-inflammatory, antibacterial and antifungal properties. Spilanthol, the most active antiseptic alkaloid extracted from this plant, is found effective at extremely low concentrations against blood parasites, and indeed is a poison to most invertebrates while remaining harmless to warm-blooded creatures (Anon., 1989).

Stevia rebaudiana Bertoni

It belongs to the *Asteraceae* family, a natural sweetener perennial herb commonly known as "Sweet Herbs" and "Honey Leaf". The leaves of this plant are estimated to be 300 times sweeter than sucrose and the sweetness is due to glycosides of which the most abundant is stevioside (Dushyant *et al*., 2014). The increasing consumption of sugar (sucrose) has resulted in several nutritional and medical problems, such as obesity. Therefore, low caloric sweeteners have been investigated to substitute sugar. The refined extracts of leaves of this plant are officially used as high potency natural-source, low calorie (non sucrose) sweetener in processed foods, artificial diets and pharmaceuticals. The sweet compounds pass through the digestive process without chemically breaking down, making it safe for diabetic and obese people (Mizutani and Tanaka, 2002).

Saussurea lappa

Saussurea lappa (Family *Asteraceae*) is a tall, robust perennial Herb; leaves simple, large pubescent, heart shaped radical leaves with long petiole. The genus Saussurea has many endemic species in Hindukush, Himalayan region. The species is mainly confined to Kashmir. In the northern areas, it is confined to Astore and Minimerg forest ranges. The most important locations where these species grow wild include Kalapani, Kamari and Thanknala, Mapno and Kilshai where this species is found growing in betula forests on hill slopes at a height of 2438-3657 meters in Himalayas. Roots is tonic, stomachic, stimulant, carminative, used for asthama, diuretic, antiseptic, cough, cholera, aphrodisiac, anthelmintic and also used to insecticide, pesticide. The roots are highly aromatic used in perfumeries, also used for skin diseases. Locally it is used against the heart diseases of cattle and for toothache. The powdered roots are sprinkled over crops as insecticides. Externally the roots are used as an ointment or powder for the treatment of maggot infested wound.

Swertia chirata

Swertia chirata (Family *Gentianaceae*) is found is in the temperate Himalayas at an altitude of 1,200-3,000m from Kashmir to Bhutan and in the Khasi hills in Meghalaya at a height of 1,200- 1,500 m. According to Ayurveda, this herb is a bitter tonic, stomachic. It is useful in liver disorders, eyes, heart. It is an excellent remedy for a weak stomach, especially when this gives rise to nausea, indigestion and bloating and it has also been shown to protect the liver.

It is best known as the main ingredient in Mahasudarshana churna, a remedy containing more than 50 herbs. It also contains xanthones which are reputedly effective against malaria and tuberculosis, and also amarogentin, a glycoside that may protect the liver against carbon tetrachloride poisoning. It is used in the liquor industry as a bitter ingredient.

Taxus baccata

Taxus baccata is a species of evergreen tree in the family Taxaceae, native to western, central and southern Europe (including the British Isles), northwest Africa, northern Iran, and southwest Asia. It is the tree originally known as **yew**, though with other related trees becoming known, it may now be known as **common yew**, **English yew**, or **European yew**. It is primarily grown as an ornamental. Most parts of the plant are poisonous, with toxins that can be absorbed through inhalation and through the skin; consumption of even a small amount of the foliage can result in death *T. baccata* is native to all countries of Europe, the Caucasus, and beyond from Turkey eastwards to northern Iran. Its range extends south to Morocco and Algeria in North Africa. A few populations are also present in the archipelagos of the Azores and Madeira. The limit of its northern Scandinavian distribution is its sensitivity to frost, with global warming predicted to allow its spread inland.[1] It has been introduced elsewhere, including the United States.

Tinospora cordifolia

Tinospora cordifolia commonly known as Guduchi belonging to the family *Menispermaceae* is a famous plant of traditional use and also a powerful rasayana mentioned in Indian ayurvedic literature. Guduchi is a perennial plant of weak and fleshy stem found throughout the India. The aerial roots that arise from the stem are thread like. The leaf is heart shaped and smooth. The flowers are yellowish in colour emerges in bunch in rainy season. The fruits of guduchi are pea like which are seen in winter in India. Guduchi acts as a diuretic and found to be effective against renal obstruction like calculi and other urinary disorders.

Guduchi is regarded as a liver protector. CAMP workshop was held during December 2007 at Kolkata to assess the threat status of prioritized Medicinal plants. During this process 43 species were assigned the Red List status of Near Threatened (NT) and above (Table 2).

Table 1: List of the some endangered and economically important medicinal plants of India

Sl.No.	Plant species	Family	Explants	References
1.	*Aegle marmelos*	Rutaceae		Yadav and shoot tip Singh (2011a)
2.	*Acorus calamus*	Araceae	Rhizome segments	Yadav *et al.*(2011)
3.	*Celastrus paniculatus*	Celastraceae	Seeds, Lal and Singh (2010)	Lal *et al.* (2010)
4.	*Commiphora mukul*	Burseraceae	& shoot tip apical	Singh *et al.* (2010b) and nodal
segments				
5.	*Peganum harmala*	Nitrariaceae	Seeds	Goel *et al.,* (2009)
6.	*Prosopis cineraria*	Fabaceae	Seeds	Kumar and Singh (2009)
7.	*Simmondsia chinensis*	Simmondsiaceae	Nodal segments	Kumar *et al.* (2010)
8.	*Spilanthes acmella*	Asteraceae	Nodal and intermodal segments	Yadav and Singh (2010) Yadav and Singh (2011b)
9.	*Stevia rebaudiana*	Asteraceae	Apical buds	Kumar and Singh (2009) Singh *et al.* (2011)
10.	*Sapindus mukorossi*	Sapindaceae	Leaf segments, apical and nodal segments	Singh *et al.* (2010a)
11.	*Bacopa monnieri*	Scrophulariaceae	Leaf explants and Mohapatra and nodal segments	Rath (2005)
12.	*Ginkgo biloba*	Ginkgoaceae	Apical and nodal segments	Tommasi &Scaramuzzi (2004)
13.	*Glycyrrhiza glabra*	Papilionaceae	Nodal segments	Vadodaria *et al.*, (2007)
14.	*Gymnema sylvestre*	Asclepiadaceae	Seeds	Komalavalli & Rao (2000)
15.	*Holostemma ada-kodien*	Asclepiadadeae	Nodal segments	Martin (2002)
16.	*Oroxylum indicum*	Bignoniaceae	Nodal segments	Dalal & Rai (2004)
17.	*Nardastchy jatamansi*	Valerinaceae	Shoot tip	Nautiyal (1997)
18.	*Picrorhiza kurroa*	Scrophulariacae	Nodal segments	Martin *et al.* (2006)
19.	*Saussurea lappa*	Compositae	Shoot tip	Johnson *et al.* (2007)
20.	*Swertia chirata*	Gentianaceae	Shoot tip	Balaraju *et al.* (2009)
21.	*Tinospora cordifolia*	Meninspermaceae	Nodal segments	Gururaj *et al.* (2007)
22.	*Taxus baccata*	Taxaceae Shoot tip	Bhojwani (1995)	

Table 2: Major Medicinal plant species of conservation concerns

Sl.No.	Botanical Name	Status	Sl.No.	Botanical Name	Status
1.	*Panax pseudoginseng* Wall.	Critically	23.	*Ampelocissus barbata*	Endangered
Endangered		(Wall.) Planch.			
2.	*Persea glaucescens*	Critically	24.	*Asparagus racemosus* Willd.	
Endangered(Nees) Long		Endangered			
3.	*Picrorhiza kurroa*	Critically	25.	*Celastrus paniculatus* Willd.	
EndangeredRoyle ex Benth.		Endangered			
4.	*Podophyllum*	Critically	26.	*Cinnamomum*	Endangered*hexandrum*
Royle	Endangered			*cecidodaphne* Meissn.	
5.	*Swertia chirayita*	Critically	27.	*Dioscorea prazeri*	Endangered(Roxb. ex Flem.)
Karst.	Endangered	Prain & Burkill			
6.	*Taxus wallichiana* Zucc	Critically Endangered	28.	*Drosera burmannii* Vahl	Endangered
7.	*Aconitum bisma*	Endangered	29.	*Gynocardia odorata* R.Br.	Endangered(Buch.-Ham.)
Rapaics					
8.	*Aconitum ferox* Wall.	Endangered	30.	*Helminthostac hys*	Endangeredex Seringe
	zeylanica (L.) Hook.				
9.	*Aconitum spicatum*	Endangered	31.	*Lycopodiella cernua* (L.)	Endangered(Bruhl) Stapf
	Pichi- Sermolli				
10.	*Alpinia calcarata*	Endangered	32.	*Mesua ferrea* L.	EndangeredRoscoe
11.	*Mucuna pruriens*	Endangered	33.	*Gymnema sylvestre* R.Br.	Endangered(L.) DC. 12.
Ophioglossum		Endangered	34.	*Lumnitzera racemosa* Willd.	Vulnerable*reticulatum* L.13.
Pterocarpus marsupium Roxb.		Endangered	35.	*Morinda citrifolia* L.	Vulnerable
14.	*Rauvolfia serpentina* (L.)	Endangered	36.	*Nypa fruticans* (Thunb.) Wurmb.	VulnerableBenth. ex Kurz
15.	*Sonneratia caseolaris*	Endangered	37.	*Olax nana* Wall.	Vulnerable(L.) Engl.
16.	*Aristolochia indica* L.	Endangered	38.	*Pericampylus glaucus* (Lam.) Merr.	Vulnerable
17.	*Berberis aristata* DC.	Vulnerable	39.	*Stereospermu m colais*	Vulnerable(Dillwyn) Mabb.
18.	*Cinnamomum bejolghota*	Vulnerable	40.	*Thalictrum foliolosum* DC.	Vulnerable(Buch.-Ham.) Sweet
19.	*Desmodium motorium*	Vulnerable	41.	*Toona ciliata* M.J.Roem.	Vulnerable(Houtt.) Merr.
20. *Gloriosa superba* L.		Vulnerable	42.	*Xylocarpus granatum* Koenig	Vulnerable
21.	*Abelmoschus*	Near	43.	*Tylophora indica* (Burm.f.) Merr.	Near *moschatus* Medik.
Threatened		Threatened			
22.	*Ipomoea mauritiana* Jacq.	Near Threatened			

A general overview of beginning of micropropagation of medicinal plants

In vitro culture is one of the key tools of plant biotechnology that exploits the totipotency nature of plant cells (Haberlandt, 1902) and unequivocally demonstrated for the first time in plants by Steward *et al.* (1964). Beyond the discovery of kinetin (Miller *et al.,* 1955), the major work on *in vitro* regeneration has been cantered around tobacco (*Nicotiana tabacum* L.) tissue culture, culminating in the first convincing demonstration of the control of differentiation of shoots or roots or both by the kinetin-auxin ratio (Skoog and Miller, 1957) followed by carrot (*Daucus carota* L.) tissue culture and birth of the concept of totipotency of plant cell with the regeneration of complete flowering plants of carrot from its phloem cells (Steward *et al.,* 1964). Thus, the micropropagation of medicinal plants remained neglected till complete plants of *Rauvolfia serpentine* (L.) Benth., were produced from its somatic callus tissue (Mitra and Chaturvedi,1970). Plant tissue culture refers to growing and multiplication of cells, tissues and organs of plants on defined solid or liquid media under aseptic and controlled environment. The commercial technology is primarily based on micropropagation, in which rapid proliferation is achieved from tiny stem cuttings, axillary buds, and to a limited extent from somatic embryos.

The effects of auxins and cytokinins on shoot multiplication of various medicinal plants have been reported by Skirvin *et al.* (1990). Lal and Ahuja (1996) observed a rapid proliferation rate in *Picrorhiza kurroa* using kinetin at 1.0–5.0 mg/l. Barna and Wakhlu (1998) has indicated that the production of multiple shoots is higher in *Plantago ovata* on a medium having kinetin along with NAA. Faria and Illg (1995) have also shown that the number of shoots per explant depends on concentrations of the growth regulators and the particular genotypes. The nature and condition of explants has also been shown to have a significant influence on the multiplication rate. Mao *et al.* (1995) reported that the actively growing materials were more responsive to shoot induction than dormant buds in *Clerodendrum colebrookianum*. Also, BAP was proved superior to 6- purine (2ip) and TDZ for multiple shoot induction. The cultured cells and tissue can take several pathways to produce a complete plant. Among these, the pathways that lead to the production of true- to-type plants in large numbers are the popular and preferred ones for commercial multiplication (Bhojwani and Razdan, 1983; Pierik, 1989).

In clonal propagation techniques using shoot tip and nodal segments are must for mass-scale multiplication and conservation of an endangered or threatened and medicinally important species within short period and limited space. The plants produced from this method are true to type. There is a need to conserve plants with medicinal values. Due to ever growing demand, the availability of medicinal plants to the pharmaceutical companies is not enough to manufacture herbal medicines. The powerful techniques of plant cell and tissue culture, recombinant DNA and bio-processing technologies have offered mankind a great opportunity to exploit the medicinal plants under *in vitro* conditions. Micropropagation: In clonal propagation, plants are multiplied using nodal segments and shoot meristems as explants. For rapid *in vitro* clonal propagation of plants, normally dormant axillary buds are induced to grow into multiple shoots by judicious use of growth regulators cytokinins and or auxin and cytokinin combinations. Shoot number increases logarithmically with each subculture to give greatly enhanced multiplication rates. As this method involves only organized meristems, hence it allows recovery of genetically stable and true to type progenies (Murashige, 1974; Hu and Wang, 1983).

Regeneration and organogenesis

For the regeneration of a whole plant from a cell or from a callus mass cyto-diffrentiation is not enough and there should be differentiation leading to organogenesis. This may occur through shoot bud differentiation (organogenesis) or through somatic embryogenesis. In the former, shoot buds (monopolar structures) are formed while in the later, somatic embryos (bipolar structures) are formed both leading to regeneration of whole plant. Callus mediated organogenesis depends on various factors. The type of callus, growth regulators used for induction of callus and also callus developed from the type of explant. The cells, although undifferentiated, contain all the genetic information present in parent plant. By suitable manipulation of growth regulators and contents of the medium, it is possible to initiate the development of roots, shoots and complete plant from callus cultures. In this pathway, groups of cells of the apical meristem in the shoot apex, axillary buds, root tips, and floral buds are stimulated to differentiate and grow into shoots and ultimately into complete plants. The explants cultured on relatively high amounts of auxin form an unorganized mass of cells, called callus. The induction of callus growth and subsequent differentiation and organogenesis is accomplished by the differential application of growth regulators and the control of conditions in the culture medium. With the stimulus of endogenous growth substances or by addition of exogenous growth regulators to the nutrient medium, cell division, cell growth and tissue differentiation are induced. There are many reports on the regeneration of various medicinal plants via callus culture. Pande *et al.* (2002) have reported the successful in-vitro regeneration of *Lepidium sativum* from various explants on MS medium supplemented with 4.0 mg/l BAP and NAA. The role of auxins and cytokinins in callus induction was also advocated by Kumar and Singh (2009) in *Steviarebaudiana,* Goel and Singh (2009) in *Peganum harmala*, Kumar and Singh (2009) in *Prosopis cineraria*, Lal and Singh (2010) in *Celastrus paniculatus*, Yadav and Singh in *Spilanthes acmella* (2010) and *Aegle marmelos* (2011). Out of various cytokinins tested, BAP was the most effective for inducing bud break. Effectiveness of BAP was also observed in *Leucaena leucocephala* (Singh and Lal, 2007), *Prosopis cineraria* (Kumar and Singh, 2009), *Splianthes acmella* (Yadav and Singh, 2010), Taxus baccta (Bhojwani, S.S. and Razdan,1983), N. jatamansi and *Acorus calamus* (Yadav *et al.,* 2011).

Somatic embryogenesis

Somatic embryogenesis is the process of formation of embryo like structure from somatic tissue. The somatic embryo may be produced either directly on the explant or indirectly from callus or cell suspension culture. For the first time, Haccius

(1978) defined somatic embryogenesis as a non-sexual developmental process, which produces a bipolar embryo from somatic tissue. The first report of plantlet regeneration via*in vitro* somatic embryogenesis was in *Daucus carota* (Reinert, 1958; Steward *et al.,* 1958). This pathway has offered a great potential for the production of plantlets and its biotechnological manipulation. In addition to the development of somatic embryos from sporophytic cells, embryos have been induced from generative cells such as in the classic work of Guha and Maheshwari (1964) with *Datura innoxia* microspores. In this pathway, groups of somatic cells/tissues lead to the formation of somatic embryos which resemble the zygotic embryos of intact seeds and can grow into seedlings on suitable medium. The primary somatic embryos are also capable of producing more embryos through secondary somatic embryogenesis. Plant regeneration via somatic embryogenesis from single cells, that can be induced to produce an embryo and then a complete plant, has been demonstrated in many medicinal plant species (Tripathi and Tripathi, 2003). Arumugam and Bhojwani (1990) noted the development of somatic embryos from zygotic embryos of *Podophyllum hexandrum* on MS medium containing BAP and IAA. Efficient development and germination of somatic embryos are prerequisites for commercial plantlet production. Chand and Sahrawat (2002) reported the somatic embryogenesis of *Psoralea corylifolia* L. from root explants on medium supplemented with NAA and BAP. Rooting of shoots was best achieved using different concentrations of auxins. In *A.maemelos*, MS half strength medium supplemented with IAA proved better (Yadav and Singh, 2011). In P. cineraria, rooting was achieved on half strength MS medium supplemented with 3.0 mg/l IBA (Kumar and Singh, 2009), while in *L. leucocephala*, NAA resulted in better root formation (Singh and Lal, 2007).

Acclimatization

Complete regenerated plantlets with sufficient roots were selected, gradually pulled out from the medium and immersed in water to remove the remains of agar-agar particles sticking to the root system by using a fine brush. These plantlets were transferred to pots containing mixture of sterilized soil and sand (3:1). The potted plantlets were covered with a transparent polythene bag to ensure high humidity around the plants. The pots were supplied with MS (half strength) salt solution on alternate days. After about two weeks the polythene bags were removed for 3-4 hours daily to expose the plants to the conditions of natural humidity for acclimatization. These plants were shifted to bigger pots after one month of its transfer and maintained under green house conditions. Successful acclimatization and field transfer of the *in vitro* regenerated plantlets have also been reported in *Leucaenaleucocephala* (Singh and Lal, 2007), *Peganum harmala* (Goel *et al.,* 2009), *Celastruspaniculatus* (Lal and Singh, 2010).

Exvitro field evaluation of acclimated plants

These recent advances in plant tissue culture have resulted in the development of protocols for micropropagation of many important medicinal plants, but the process of transplantation and acclimatization of micropropagated plants to soil environment continues to be a major bottleneck in the micropropagation of medicinal plants.

Acclimatization of a micropropagated plant to a green house or field environment is essential because anatomical and physiological characteristics of *in vitro* plantlets necessitate that they should be gradually acclimatized to the field environment (Hazarika, 2003). Successful acclimatization minimizes the percentage of dead or damaged plants, enhances the plant growth and establishment (Sha Valli Khan, 2003). Dynamics of the process are related to the acclimatized plant species and both *in vitro* and ex vitro culture conditions (Pospisilova *et al.,* 1999). Now days, mycorrhizal technology can be applied to reduce transplantation shock during acclimatization, thus increasing plant survival and establishment rates of micropropagated medicinal plant species (Sharma *et al.,* 2008; Yadav *et al.,* 2011).

Medicinal herbs as potential source of therapeutics aids have attained a significant role in health system all over the world for both humans and animals not only in the diseased condition but also as potential material for maintaining proper health. Fresh strategies of afforestation management and restoration of depleting natural resources blending with modern technologies are also required. Medicinal plants are under the threat of overexploitation and biodiversity depletion. There is urgent need of their *ex situ* conservation. Study of collection and *in vitro* conservation of important plants in the present study opens fresh avenues towards the conservation and resource management of the overexploited medicinal plants. Biotechnology is a motor of technological advancement in both the developed and developing countries though at different levels in scope and content. In recent years, tissue culture has emerged as a promising technique to obtain genetically pure elite populations under *in vitro* conditions rather than have indifferent populations.

Thus *in vitro* cell and tissue culture methodology is envisaged as a mean for germplasm conservation to ensure the survival of endangered plant species, rapid mass propagation for large scale re-vegetation and for genetic manipulation studies. Tissue culture protocols have been developed for several plants but there are many other species, which are over exploited in pharmaceutical industries and need conservation.

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Approaches for Climate Resilient and Sustainable Development of Horticulture in Gujarat

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Introduction

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. It also refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. Significant variation in the mean state of the climate, persisting for decades or longer is referred to as climate change. Climate change is the negative creation of global warming. The alteration of different meteorological parameters or drastically changes in the system of different climatic parameters like temperature, light, humidity, rainfall, sunshine, wind velocity etc are known as "climate change". The intensity of meteorological parameters increased or decreased or become more fluctuate due to climate change.

Horticulture is the back bone of agriculture contributes about 28% of agricultural GDP. It is the broad spectrum which involves many diversified crops like fruits, vegetables, ornamental plants, spices, medicinal &aromatic and plantation crops, has become a key driver for economic development in our country. The area under horticultural crops is increasing day by day more than 25 million hectares. The horticulture production is also achieving new heights exceeding 328(2019-20) million tonnes which has surpassed food grain production in the country. India's vegetable productivity at 17.01 t/ ha. compares poorly with productivity of Spain, US, Japan and Turkey. Likewise, India's fruit productivity at 14.33 t/ha is only half of that in the US. However, we are world's second-highest in fruits and vegetables production. Banana, mango and citrus are the main fruits; potato, onion, tomato, brinjal and tapioca are major vegetables. Maharashtra is the leading state followed by Andhra Pradesh in area & production of fruit, respectively. West Bengal continues to be the leading state in terms of cultivated area and production of vegetables. India has the potential to be a leading world exporter in this sector. Horticulture is also key sector to provide three securities to mankind viz., food security, nutritional security & health security. The horticulture has also a great role to become even more enhanced in bringing many farmers of country out of poverty. In Gujarat Horticulture crop is grown in an area of 18.31 lakh hectare area with production of 237.83 lakh metric ton. Mango, banana, pomegranate, papaya, sapota, datepalm as main fruit crops while onion, potato, okra as vegetables and cumin, fennel, isabgul & chillies are main spices horticultural crops of Gujarat.

Impact of climate change

The climate change has deteriorating impact on all living organisms of earth and creates a question of existence. Because availability of suitable weather condition is the prime requirement for their survival. The earth is experiencing following change:

1. Atmospheric changes
2. Melting of glaciers
3. Changes in rainfall pattern
4. Changes in biodiversity
5. Changes in agricultural production

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1. Impact on agricultural activities

Agriculture provides food security to the world. Adverse climatic parameters are the limiting factors for most of the agricultural activities and crop production. Increase in extreme weather events such as floods, droughts, cyclones, heat waves, etc. adversely affects the agricultural productivity. Quality and yield of any of the crops is only possible through its optimum climatic requirements. Hence, old idiom in gujarati language for farmers is " Khed, Khatar ane Pani, pak ne lave Tani". But now it is time to modify it to " Khed, Khatar, Pani ane Vatavarn ni vani, Pak ne lave Tani". Means farmers must know the effect and impact of climate change on their crop.

The changed climatic parameters affect the crop physiology, biochemistry, floral biology, biotic stresses like disease-pest incidence, etc., and ultimately results in to the reduction of yield and quality of agricultural produces. So, it is big challenge to the scientists of the world. The arid regions are already vulnerable to drought and causing crop failure. The impact of climate change was found from various studies are given here.

1. Physiological effects of carbon dioxide on the crops and different adaptive responses viz.,
   a. Higher daily evapotranspiration rates.
   b. Shortening of crop growth duration i.e. rise in temperatures shorter the picking seasons in various fruit crops. Heat unit requirement will be in much less time.
   c. Alter photosynthate partitioning to economic products
   d. Increase crop respiration rates
   e. The ambient CO_2 concentration is increasing in atmosphere which is beneficial since leads to increased photosynthesis in several crops, especially those with C_3 mechanism of photosynthesis such as wheat and rice, and decreased evaporative losses.
2. Demand for irrigation water would increase with rise in temperature and evapotranspiration rate. It may result in lowering of groundwater table at some places.
3. Change in precipitation pattern and water use efficiency.
4. The glaciers in the Himalayas region will melted resulted in more water availability in main rivers of the country like Ganges, Bhramaputra, etc. and their tributaries in the short-run, but in the long run, the availability of water will decrease considerably.
5. The water balance and water budgeting of the country will be disturbed and similarly, the water quality of groundwater along the coastal track will be affected more due to intrusion of sea waters.
6. The rainfall pattern of many region of country is changing which also resulted for reduction in yields.
7. Soil degradation and nutrient mineralization in soils.
8. Soil temperature affects the rates of organic matter decomposition and release of nutrients. At high temperatures, nutrient availability will increase in the short-term, but in the long-run organic matter content will diminish, resulting in a decline in soil fertility. The N mineralization will also increase, but its availability may decrease due to increased gaseous losses through processes such as volatilization and de nitrification.

   The residues of crops under the elevated CO_2 concentrations will have higher C:N ratio, and this may reduce their rate of decomposition and nutrient supply. Likewise, there is also possibility to rise in sea level may lead to saline water ingression in the coastal lands.
9. Coastal regions can expect much faster percolation of sea water in inland water tables causing more salinity which are resulted to decrease the fertilizer use efficiency.
10. Agricultural biodiversity will also be threatened due to the decrease in rainfall and increase in temperature, sea level rise, and increased frequency and severity of droughts, cyclones and floods.
11. Rise in the mean temperature above a threshold level will cause a reduction in yields. A change in the minimum temperature is more crucial than maximum temperature. e. g. Rice yield declined by 10% for each 1 °C increase in minimum temperature above 32 °C.

Temperature increases of 1 °C, 2 °C and 3 °C, would reduce the grain yield of rice by 5.4%, 7.4% and 25.1%, respectively.

12. Affect the survival and distribution of pest populations.
13. Incidence of pest and diseases of crops to be altered because of more enhanced pathogen and vector development, rapid pathogen transmission and increased host susceptibility. It likely to alter the balance between insect pests, their natural enemies and their hosts. The disease outbreaks prediction is more difficult during rapidly changing climatic parameters and or unstable weather. The effectiveness of pesticides is also reduced.
14. Pest–Disease incidence like mealy bug in cotton, thrips in many horticultural and oilseeds crops, fruit borer in ber and infestation of white grubs in kharif groundnut are the havoc in Saurashtra region of Gujarat.

Impact on horticultural crops

To quantify the impacts of climate change on horticultural crops, we need detailed information on physiological responses of the crops, effects on growth and development, quality and productivity. The rise in temperature would lead to higher respiration rate, alter photosynthesis rate and partitioning of photosynthates to economic parts. It could also alter the phenology, shorten the crop duration, days to flowering and fruiting, hasten fruit maturity, ripening and senescence. The sensitivity of individual crop to temperature depends on inherent tolerance and growing habits. Indeterminate crops are less sensitive to heat stress conditions due to extended flowering compared to determinate crops. The temperature rise may not be evenly distributed between day and night and between different seasons (Srinivas Rao et al. 2010). In tropical regions even moderate warming may lead to decline in yield. In high latitudes, crop yields may improve as a result of a small increase in temperatures. In developing countries, which are predominantly located in lower latitudes, temperatures are already closer to or beyond thresholds and further warming would reduce productivity. The impact of climate change is likely to differ with region and type of the crop and is described here for different crop subsector of horticulture. Horticultural crops are more vulnerable against climate change. Hence, quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants may be affected.

Fruit crops

The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many fruit crops. In perennial crops like mango and guava, temperature is reported to have influence on flowering.

1. Mango is the main fruit crop and pride of Gujarat. It is highly vulnerable against climate change. Currently mango is suffering from the many issues related to climate change like late flowering, poor pollination & fruit setting, development of nubbins, fruit dropping etc. Mango has vegetative bias, and this becomes stronger with increase in temperature, thus influencing the flowering phenology. The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures (Singh et al. 1966, Ramaswamy and Vijay Kumar 1992, Balogoun et al. 2016). During peak bloom period, high temperature (35ºC) accompanied by low relative humidity (49%) and long sunshine hours resulted in excessive transpiration and dehydration injury to panicles. The findings on impact of climate change are as under -
    i. The survey on impact of climate change on mango was carried out by Department of Horticulture, JAU, Junagadh every year. During 2008, the temperature was very low during flowering season resulted in three reproductive flushes instead of one. Initially it was in time, but very poor may be due to adverse effect on buds, anthesis, pollination and fruit setting. However, flowering was started further in March when temperature became optimum. But it was very late flowering reduced yield.
    ii. Similarly, during the year 2009, the real devastating effect was observed in Junagadh region. The temperature was remained detrimental to flowering to fruit setting stage. It was 33 to 36 ^{0}C during

flowering stage. The flowering was reduced up to 65-70% in Saurashtra and 85-90% in South Gujarat. The quality of fruit was also deteriorate in taste and size. The intensity of relative humidity was also found higher resulted to higher infestation of mango hopper and powdery mildew. The state average productivity was reduced up to 2.59 t/ha as compared to 7.0 t/ha.

iii. During the year 2015, the climatic parameters were favourable during flowering but dew formation was started suddenly and became highly detrimental to pollination & fruit setting process. Pollen grains heavily erased due to dew drops. Nearly 75-85% flowering was destroyed. Only 15-20% flowers were settled and reached to pea stage. During this stage, due to off season rain, majority of settled fruits were dropped.

iv. From the last two years, heavy rain extended up to September-October resulted in late flowering coupled with new vegetative flush which results into nutrient scarcity in bearing shoots. Similarly, cold wave followed by higher day night fluctuation in temperature also adversely affecting to poor pollination with nubbins development. At the end of crop, high wind velocity or cyclone also heating the crop with economic fruit drop e.g. Tauktaecyclone of last year. The fruit yield in mango is predicted to reduce 30-40% this year.

v. Air pollution also significantly reduced the yield of several horticultural crops and increase the intensity of certain physiological disorders like black tip of mango which is induced by coal fume gases, sulphur dioxide, ethylene, carbon monoxide and fluoride.

2. Banana cultivation may suffer from high temperature, soil moisture stress or flooding / water logging. The temperature below 10^0C leads to impedance of inflorescence and malformations of bunches. Chilling symptoms on leaves are not seen immediately but it may take 2 to 4 days to appear. Temperature has a big influence on the rate of fruit growth, thus use of bunch covers, which are though, to warm the fruit, increased the growth rate. Higher temperature (31-32^0C), in general increase the rate of plant maturity in banana, thus shortening the bunch development period. Higher temprature also causing chocking or rosseting of plant. Higher air temperature (>38 ^{0}C) and brighter sunshine cause sunburn damage on exposed fruits. Bananas subjected to flooding for more than 48 h are severely stunted for further development and after 72-96 h, there are no recovery of mature shoots and often die. Banana can be affected by low temperature resulted to stunting of growth with yellowing of leaves. Sigatoka disease intensity increased.

3. The experiment on climate was conducted on different custard apple selections during 2007-2008 at JAU, Junagadh. Temperature was recorded very similar during both the years, but humidity (21.72%) and total rainfall (35.99%) decreased in 2nd year (2008) as compared to 1st year (2007). First and second reproductive flush was earlier with higher number of flowers per shoot in 2nd year due to off seasonal rains which resulted in reduced fruit yield. Percentage of mealy bug infestation was also noted very less due to heavy rains during the crawling time of nymphs & adults. Similarly, black spot was also observed higher may be due to higher wind velocity.

4. It was also observed in on going experiment in black jamun at JAU, Junagadh that flowering was very late (30 days) with poor fruit setting during the year 2009 due to high temperature.

5. High and extended rain during 2019-20 also heating the acid lime and pomegranate with disturbing the hasta bahar resulted in poor yield. Summer yield in acid lime is also reduced drastically.

6. In guava, there is severe increase in pests and diseases due to hot and humid conditions. Fruit fly in guava is becoming alarming due to hot and humid conditions.

7. Delay in monsoon, dry spells of rains, hailstorms and supra-optimal temperatures

during flowering and fruit growth are some of the most commonly encountered climatic conditions experienced by the citrus growers over the past decade or so.

8. Papaya cultivation in Saurashtra region also suffered from heavy rains due to water logged conditions.

9. Maturity indices and harvesting of horticultural crops changed due to rise in temperature. Photoperiods may not show much variation. As a result, photosensitive crop will mature faster. For example, Citrus, grapes, melons etc. will mature earlier by about 15 days. Higher temperature (31-32ºC), in general, increases the rate of plant maturity in annual fruit species, thus shortening the growth stages, during which developing fruits and suckers absorb photosynthetic products.

Plantation crops

1. Coconut is another important crop of coastal belts of Gujarat and Saurashtra region. It becoming highly remunerative due to improving its consumption pattern because of its antioxidant property. Peoples have used more during Covid19 situation. Coconut is also affected by climate change. Button shading is going the very serious in coconut particularly Lotan variety might be due to increased temperature in coastal region adversely effects on pollination and fruit setting which drastically reduced the nut yield. Similarly white fly is also with devastating effect on coconut orchards in Saurashtra region.

2. Natural calamities like tauktae cyclone during the year 2021 have impacted the heavy loss of nut production and productivity due to uprooting of destroying the numbers of coconut palms in the coastal region of Gujarat.

Vegetable and spice crops

1. Higher temperature reduced tuber initiation process in potato, reduced quality in tomato and pollination in many crops. High temperature causes burning or scorching effect on blossoms, high transpiration losses limits settings.

2. High temperatures during pre-anthesis can cause significant losses in tomato productivity due to reduced fruit set, smaller and lower quality fruits.

3. In case of crucifers, it may lead to bolting; anthocyanin production is affected in capsicum. Tip burn and blossom end rot will be the common phenomenon in tomatoes.

4. In pepper, high temperature exposure at the pre-anthesis stage did not affect pistil or stamen viability, but high post-pollination temperature inhibited fruit set, suggesting that fertilization is sensitive to high temperature stress.

5. Tomato plants under flooding conditions accumulate endogenous ethylene, leading to rapid epinastic leaf response. Onion is also sensitive to flooding during bulb development with yield loss up to 30-40%. Under climate change scenario the impact of these stresses would be compounded.

6. In onion temperature increase above 40°C reduced the bulb size and increase of about 3.5°C above 38ºC reduced yield

7. In potato, reduction in marketable grade tuber yield to the extent of 10-20% is observed due to high temperature and frost damage reduced tuber yield by 10-50%, depending upon intensity and stage of occurrence.

8. Advancement in appearance of aphids by two weeks with increase in 1ºC and also the reduced growing period of potato seed crop. Plants may respond accordingly to avoid one or more stresses through morphological or biochemical mechanisms

9. Many vegetable crops namely, tomato, water melon, potato, squash, soyabeans, peas, carrot, beet, turnip, etc are more susceptible to air pollution damage. Yield of vegetable can be reduced by 5-15 percent when daily ozone concentrations reach to greater than 50 ppb.

10. Seed Spices are winter season crops and commonly grown in arid and semi-arid tract of Rajasthan and Gujarat requiring certain period of low temperature for optimum vegetative growth.

11. Heavy losses have been observed due to combined effect of chilling as well as high humidity in Saurashtra region during 2020-21.

12. Cumin, coriander, nigella, ajwan are the crops which are very sensitive to frost. Incidence of frost causing serious loss in yield almost reaches up to zero.
13. Fennel and fenugreek are also affected by frost but growth stage plays an important role. So far, no efforts have been made to identify the source of resistance against low temperature injury in available germplasm of seed spices crops.
14. Heavy losses have been observed due to combined effect of chilling and frost injury in cumin, coriander, nigella, ajowan are the crops which are very sensitive to frost.

Flower crops

1. Commercial production of flowers particularly grown under open field conditions will be severely affected leading to poor flowering, improper floral development and colour.
2. Chrysanthemum is a short-day plant. So, flowering round the year in open field condition is not possible.
3. Low temperatures shut down flowering in Jasmine (<19 ^{0}C) and lead to reduction in flower size.
4. Winter season flower crops are normally sown during September-October. But due to heavy and extended rain up to October in Gujarat, the rabi season flower crops were sown late during November. The temperature was drasticallly reduced during November adversely affected on the growth and flowering of the crops like marigold, gaillardia, gladiolus, etc.

Climate Resilient and Sustainable Horticulture: Sustainability conveys the idea of a balance between human needs and environmental concerns. It means that sustainable agricultural systems remain productive over time. They should provide for the needs of current, as well as future generations, while conserving natural resources. Hence, there is urgent need to find out the appropriate mitigation and adaptation measures against climate change.

Mitigation and Adaptation

Mitigation

Mitigation is the steps to reduce or stop the emission of greenhouse gases with help of conscious practices. The various ways to mitigate these abiotic stresses are as under:

1. The strategies for mitigating methane emission from rice cultivation could be management to reduce CH_4 emissions
    a. Alteration in water management, particularly promoting mid-season aeration by proper drainage. .
    b. Improving organic matter management by promoting aerobic degradation through composting or incorporating it into soil during off-season.
    c. Application of fermented manures like biogas slurry in place of unfermented farm yard manure.
2. In case of animal, methane emission from ruminants can be reduced by changing the feed composition to improve the milk and meat yield.
3. The nitrous oxide emission could also be reduced by nitrification inhibitors such as nitrapyrin and dicyandiamide (DCD). There are some plant-derived organics, such as neem oil, neem cake and karanja seed extract which can also act as nitrification inhibitors.
4. Improvement in nitrogen fertilizer application techniques to reduce N_2O emissions
5. The CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil through manipulation of soil moisture and temperature and restoration of soil carbon on degraded lands.
6. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro aggregation, and mulching can play important roles in sequestering carbon in soil.
7. Improved crop and grazing land management to increase soil carbon storage
8. Some technologies such as intermittent drying, site-specific N management, etc. can be easily adopted by the farmers.

9. Dedicated energy crops to replace fossil fuel use.

Adaptation strategies

Potential impacts of climate change depend on the system's ability to adapt to change. The potential depends on how well the crops adapt to the concomitant environmental stresses due to climate change.

Adaptation is nothing but to include the actions of adjusting practices, processes, and capital in response to the actuality or threat of climate change, as well as responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realized.

There is an immense diversity of agricultural practices because of the range of climate and other environmental variables; cultural, institutional, and economic factors; and their interactions. This means there is a correspondingly large array of possible adaptation options.

A crucial component of this approach is the implementation of adaptation assessment frameworks that are relevant, robust, and easily operated by all stakeholders, practitioners, policymakers, and scientists.

Adaptation strategies can be realized relatively fast using a wide range of cultivars and species, changing planting dates or season, planting and rearrangement of orchards requires a consideration of the more long-term aspects of climate change. Breeding work should be intensified to develop new varieties suitable to different agro-ecological regions under changing climatic conditions. The physiological and morphological differences between varieties (genotypes) enable production over a relatively large range of climates and depending upon the suitability to different growing areas the cultivars may be adopted. If there is a strong consumer preference for a particular cultivar and also the suitable varieties are not available, the option of using rootstocks for better performance of the scion cultivars could be explored.

There are several adaptation measures that the agricultural sector can undertake to cope with future climate change.

1. Crop based adaptation
   - **b.** Adapting climate-ready crops
   - c. Use of energy crop e. g. Silver maple, poplar, etc.
2. Based on cropping pattern
   - a. Cropping system
   - b. Intercropping
   - c. Alternative crops
   - d. Crop diversification
   - c. Relocation of crops in alternative areas
3. Adaptation based on cultivars/varieties
   - a. Development of tolerant cultivars/varieties against climate change
   - b. Development of resistant cultivars/varieties against climate change
   - c. Planting different varieties or crop species
4. Modifying crop management practices
   - a. Date of planting or date of sowing
   - b. Adjusting cropping season
   - c. Off seasonal production & marketing of horticultural crops. Use of shed nets
   - d. Using sustainable, customized or liquid fertilizer
   - e. Tillage practices to improve soil drainage, zero tillage, etc.
   - f. Implementing new or improving existing irrigation systems
   - g. Water management through drip irrigation system
   - h. Use of water harvesting technology
   - i. Improvement in crop residue and weed management
   - j. Changes in land use management practices
   - k. Efficient use of resources
   - l. Adopting new farm techniques, resource conserving technologies (RCTs)
   - m. Improved pest management

5. Wind breaks or shelter belts
6. Weather forecasting and crop insurance schemes
7. Use of GIS
8. More use of agroforestry practices
9. Natural disasters (droughts, floods, tropical cyclones, etc.)

Production system management

The emphasis should be on use of recommended production systems for improved water-use efficiency and to adapt to the hot and dry conditions. Strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season should be adopted. Modifying fertilizer application to enhance nutrient availability and use of soil amendments to improve soil fertility and enhance nutrient uptake.

Management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. Production of vegetables could be taken up using clear plastic rain shelters, which can reduce the direct impact on developing fruits and also reduce the field water logging during rainy season. Planting of vegetables on raised beds during rainy season will increase the yield due to improved drainage and reduced anoxic stress to the root system. Grafting of vegetables on tolerant rootstocks would provide the scion cultivars with tolerance to soil related environmental stresses such as drought, salinity, low soil temperature and flooding

Efforts should be intensified to develop new varieties suitable to different agro-ecological regions under changing climatic conditions. Changing planting dates or season, the planting and rearrangement of orchards requires a consideration of the more long-term aspects of climate change. Therefore, before resorting to any adaptation option, a detailed investigation on the impact of climate change on perennial crops is necessary.

With global warming effect, production areas for specific crops and/or timing of sowing/planting could be changed, but for many horticultural crops, market windows and infrastructure, such as availability of local packing and distribution facilities are critical components should be of prime importance.

Water logging

Water logging is a serious problem to many horticultural crops like papaya, banana, mango, etc. The reduction of oxygen below optimum level, termed hypoxia, is the most common stress in wet soils and occur during short term flooding. Under flooding, transpiration is reduced due closure of stomata resulting in decreased water absorption by roots. The strategy against water logging is use of tolerant root stock like trifoliate orange, rough lemon, cleopatra mandarin, sweet orange, sour orange and rangpur lime in citrus. Ridges & furrow in papaya, mango is more useful.

Vegetable grafting

Use of egg plant as root stock for tomato at higher temperature is more promising. Although it was noted that egg plant root stock enhanced vegetative growth at 28 ^{0}C. Similarlly for Parwal (Pointed gourd) and other vegetable crops root stock is available.

Plant growth regulator

Application of certain growth regulators can alleviate the harmful effect of high temperature. Fruit set in tomato under high temperature can be achieved by spraying of sodium salt of PCPA @ 50 ppm or NAA @ 10 ppm at flowering. Similarly, foliar spray of tricontanol @ 1-2 ppm in chilli improves the fruit set. Seed germination in lettuce at higher temperature can be enhanced by soaking the seed in ABA @ 0.1 to 1.0 ppm.

Shading net

The harmful effect of temperature/heat and light intensities can be minimized by using shade net. Generally, 50% shading net is common. It reduces temperature, increase humidity and improves the appearance of fruits. Different filter films such as flourescent films, photochromic films and UV blocking films are also used to reduce the light intensity in commercial green house.

Popular innovations recommended for the farmers of Gujarat

Sr.No.	Innovations	Impact
1	Soft Wood grafting in mango, guava, sapota etc.	Grafts which are most useful in High Density Planting(HDP) in mango. National Horticulture Board(NHB) accredited nurseries are providing the quality grafts to the farmers. Presently each university provides about 25000 grafts of mango and other fruit crops.
2	Cultar (Packlobutrazole) in mango	Nearly 15 days early flowering in mango. Farmer can get the higher price of mango due to early in market
3	HDP and rejuvenation in mango	The innovative technologies are highly adopted by farmers of region for establishment of new orchard and senile orchards, respectively.
4	Adoption of coconut crop with hybrid D x T	Area is increasing in coastal belts due to more remuneration. In order to make availability of hybrid, elite farm in 12 ha. has been developed at Fruit Research Station, Mahuva with 3:1 (female:male) ratio.
5	Adoption of custard apple with HDP 3 x 4 m.	The area is increasing under cultivation due to hardy nature, low cost of production with higher remuneration to the farmers.
6	Pomegranate and banana with adoption of tissue culture and advanced production technologies.	New crops becoming contender crop of region due to its adaptability, market preferability and higher remuneration. All advanced technologies are being adopted by the farmers. Export quality is also practiced
7	Papaya with advanced production technologies	Papaya is also introduced as new innovative crops with highly adoption of newly released variety GJP-1 as well as private sector varieties like Red lady, 786, etc.
8	New crops like dragon fruit, date palm, VNR variety of guava, etc.	Farmers of region are speedily adopting. The acreage of dragon fruit is increasing in Kutch and Saurashtra region.
9	Spice crops particularly coriander and cumin	The area is increasing very fast due to less water requirement of the crops, higher productivity and higher market price and good remuneration to farmers. The innovative adoption of these crops resulted to reduce the acreage of main rabi and semi rabi crops like wheat, mustard, bajra, etc.
10	Green house technology	Many farmers of region widely cultivating high valued vegetable and flower crop viz., tomato, cucumber and gerbera in net house in which the cost of production is reduced as compared to high tech green house. Junagadh Agriculture University is helping the farmers through transfer of technology by three training programme in a year.
11	Organic farming	Adopted by many farmers in region. Similarly, some farmers are following Natural farming using cow based formulations like Jivamrut, panchgavya, amrutpani, etc.Organic farming products fetches good market price.
12	Mechanized farming	Mechanized farming is only tool to overcome the shortage of labour. Horticulture farmers of region also using some tools and implements for various operation like coconut shredder, mango & sapota harvester etc. The project on artificial intelligence is being sanctioned to Junagadh Agril University for innovation in mechanized horticulture.
13	Nurseries	Quality planting materials through small scale, high tech, plug nurseries
14.	Trellis system	Adoption of trellis system in cucurbitaceous & vegetables
15.	Mulching & fertigation	Faster adoption of mulching and fertigation in water melon, musk melon, papaya, etc.
16.	Honey bee keeping	Honey bee keeping to enhance the pollination in horticultural crops with additional income
17.	Wasteland development	Chief Minister Horticulture Development Mission • Policy on Conversion of Government wasteland under horticultural and medicinal plant cultivation • Provision of Rs. 100 Crores • To increase in the area and production of horticultural and medicinal crops, set up export oriented and processing clusters to develop post-harvest management, climate resilience • Reserve of about 20,000 ha. (50,000 Acre) of land in Kutch, Surendranagar, Patan, Sabarkantha and Banaskantha dist, • The land will be leased at a nominal rate for lease of Maximum 30 years. • Government will provide assistance in MIS, Solar Panel, Borewell, Farm Mechanization etc

• Research recommendation of the SAUs of Gujarat

- The farmers of middle Gujarat growing capsicum under naturally ventilated poly house are advised to transplant capsicum at 45 × 30 cm spacing in raised beds for getting higher yield and net return. The beds should be prepared 40 cm apart with 90 cm base width, 75 cm top width and 45 cm height.

- Farmers cultivating tomato in naturally ventilated polyhouse (1000 m^2) are recommended to fertigate the crop with 25: 12.50: 12.50 kg NPK (As per the schedule given in table below) through water soluble fertilizers along with application of 0.5 kg Trichoderma viride and Pseudomonas fluorescens each, 0.5 L Phosphorous Solubilizing Bacteria (Bacillus megaterium) & potash mobilizer- Frateuria aurantia each, 2 t FYM and 5.0 kg micro-nutrients (Grade V) at the time of transplanting for higher yield as well as net returns.
- The tomato growers of South Gujarat are recommended to adopt interspecific grafting of tomato with Solanum torvum during rainy season for getting higher yield and net return.
- The farmers and nursery men raising brinjal seedling in plug tray nursery are recommended to use media of Vermicompost: Cocopeat as 1:1 or 2:1 ratio for maximum germination percentage, good seedling vigour, higher return and maximum survival of seedling in plug tray as well as in main field.
- Farmers of Gujarat are cultivating cucumber under protected condition are recommended to grow cucumber in 50 % white shade net instead of polyhouse to get higher yield and net return.
- The farmers of Saurashtra who are interested in organic cultivation of coconut cv. West Coast Tall (WCT) are recommended to apply FYM @ 60 kg per plant or FYM at 15 kg + Castor cake at 2.25kg +Vermicompost at 8kg + Neem cake at 2.25 kg per plant to get higher nut yield and improved organic carbon and microbial status insoil under saline irrigation condition (EC 10-14 dSm^{-1}).
- The farmers of South Gujarat recommended to cultivate gynodioecious varieties of papaya under insect proof net house (40 mesh) for getting good quality fruits, higher yield and net return without incidence of papaya ring spot virus (PRSV).
- Farmers cultivating tomato in naturally ventilated polyhouse are recommended to vibrate tomato truss with electric pollinator on every 3rd day starting from the day of first flowering for 10 seconds during morning hours between 7.30 am to 9.00 am for better fruit set, higher yield and net returns.
- Farmers and nurserymen of Gujarat are interested in multiplication of desi rose are recommended to raise the cuttings treated with 500 ppm IBA solution (500 mg/l of water) by quick dip method under fan-pad polyhouse for obtaining maximum number of rooted cuttings.

Availability of quality planting material in Gujarat

S.N.	Organization	No. of Unit	Planting Material (Graft & Seedling)	Production (No.in Lakh)	Requirement (No.in Lakh)	Short Fall (No.in Lakh)	Remarks
1	Departmental	23	All fruit crop	2.00	41.50	6.00	-
2	SAUs	15	All fruit crop	1.50			-
3	NHB Accredited	105	All fruit crop	12.00			
4	Private	300	All fruit crop	20.00			Produce not Assured Quality Planting Material
			Papaya	600.00	600.00	0.00	Seeds produced by Private Company
5	Tissue Culture Lab	30	Banana	1230.00	1790.00	540.00	Shortfall procured from other states i.e MH, AP & Karnataka
			Pomegranate	9.00	18.50	9.50	

Horticulture Infrastructure in Gujarat

Infrastructures	Status
Cold Storage	435
Pack House	2300
Integrated Pack Houses	15
Sorting Grading Unit	317
Primary cooling unit	18
Refrigerated Van	19
High-tech Nurseries	28
Ripening Chambers	75
Bio Control Lab	18
Primary Minimal Processing Unit	32

Horticulture achievements

1. **Area expansion:** Diversification towards Fruits, Vegetables, Spices, Flowers and Aromatic crops
2. **Horticulture extension and Technological support:** Adoption of Technologies, Skill development, Training & Capacity Building, Centers of Excellence
3. **Support for infrastructure assets:** Planting material production, Productivity enhancement, Precision farming, Farm mechanization, Post harvest handling, Cold chain, Value addition
4. **Women empowerment:** Canning - Preservation of Fruits and Vegetables, Kitchen gardening

SWOT of Horticulture sector of Gujarat

Strengths

- Government support for integrated development
- Diverse agro –climate
- Production in Clusters
- Technological support Centers of Excellence
- Tissue cultured laboratories and Model nurseries
- Area expansion linked with Micro irrigation
- Higher productivity and quality of produce
- Enterprising and Adoptive farmers

Weakness

- Longer gestation period and technology driven
- High cost of Inputs
- Inadequate value chain
- Shortage of extension manpower for programme implementation
- Gluts and shortage
- Inadequate facilities at market place

Opportunities

- Scope in area expansion of fruits and dry land horticulture
- Potential for processing and export of horticulture crops.
- Establishment of value chain
- Skill development.

Threats

- High cost of production and unstable prices to farmers
- Natural calamities

Issues of Horticulture in Gujarat

- Higher initial investment for plantation of horticultural crops
- Development in rainfed area and problematic soils
- Perishable nature of horticulture crops; Lack of PHM infrastructure at production level
- Limited know how and crop production skill of farmers
- Shortage of skilled labours
- Limited market support for Fruits and Vegetables

Challenges

- Risk management against natural calamities
- Small scale cultivation and limited farmers institution
- Lacking of quality control mechanism of nursery plants

- Fragile value chain, unorganized retailing
- Limited investment for processing and export infrastructure
- Lack of manpower for horticulture extension and technology adoption
- Development of export and processing clusters
- Development of floriculture and aromatic industries
- Assured supply of fruits and vegetables
- Promotion of fruits and vegetable based food habits
- Residue free production

Strategies

- Introduction of New Crops and Varieties
- Utilization of nonconventional area and diversification of cropping pattern:
- Infrastructure support for Good Planting Material production / Quality seeds
- Support to Technologies: Adoption of Micro-Irrigation, Mulching, Fertigation, use of Tissue culture plants, High density plantation, Rejuvenation of old orchards,
- Focus on Skill development of farmers and farm labours
- Support FPOs for Post Harvest Management
- Increasing area under high yielding and high value crops
- Strengthening of Horticulture Extension system
- PPP on creation of Farm advisory services.
- Development of Export and Processing clusters
- Promotion of floriculture Industries

Policy suggestions

- Medium termed production loan for perennial Fruit crops as per interest rate of Crop loan
- Encourage cultivation of fruit crops at public institutions, Green zone and afforestation
- Support farmers for large scale cultivation of horticultural crops
- Lease Land can be provided to FPOs for Post Harvest management Infrastructure at production clusters
- "Khedut Grahak Bazaar" in urban and semi urban areas
- Establishment of Fruit and Vegetable supply chain on AMUL model
- Dedicated space in Urban planning for retailing of Fruits & Vegetable
- Introduction of Nursery Act

Future Thrust

1. To study and analysis on impact of climate change on Agricultural/Horticultural crops and its production.
2. To develop climatic models with software which should furnish the information of unfavorable climatic conditions in advance stage or before season.
3. To develop crop modules as per climatic situation.
4. To develop genetically modified varieties/ cultivars against climatic abiotic stress.
5. To develop the specific agro techniques for the crops suitable during adverse climatic conditions.
6. The agro techniques should be
   - Use of plastics for crop production
   - Use of greenhouse technology
   - Use of green biomass for improving micro climate during hot weather.
7. Stress physiology research identifies mechanisms of stress tolerance and provides approach, method, and traits for screening stress-resistant genotypes
8. Identification of drought and salinity tolerant root-stocks in fruit crops like mango, grapes, guava, fig, annola would be useful and work has already been initiated in these lines.

9. It has been demonstrated that the crops are less affected by frost if grown under the canopy of other cops. In view of this, suitable cropping models are required to be developed using either khejri or date palm based cropping models.

11. QTL mapping and MAS to tag genes for various abiotic stress parameters.

12. There is a need to identify varieties which are photo insensitive. This will help to grow chrysanthemum round the year in open condition.

13. Mathematical models can be worked out to schedule the pruning time to suit the weather conditions prevailing in places where commercial cultivation of Jasminum sambac is done.

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Strategic Development of Horticulture in Telangana for Resilience to Climate Change

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Introduction

Climate change presents one of the greatest challenges to the productivity and sustainable growth of the agricultural sector in India due to extreme events such as droughts and floods as well as changes in temperature. Horticultural crops are particularly sensitive to climate change because of their high water demand and strict temperature requirements. Lack of water for irrigation, flooding due to high rainfall, extreme temperatures (too high or too low) and pests and diseases epidemic can affect the suitability of areas for growing horticultural crops thereby affecting both the yield and quality of produce. Climate change is acknowledged as a threat to different sectors, but use of hi-tech horticulture practices will have to be implemented to meet the ever-changing dynamic challenges emerged due to climate change.

National Importance of Horticulture

Horticulture sector has exhibited a spectacular performance in terms of expansion of area and production of fruits, vegetables, plantations and other horticultural crops since last decade. This sector has also witnessed enhanced crop productivity, diversification, innovative technologies in production, post-harvest and forward linkages alongthe value chain including marketing of horticulture produce (NHB, 2017). Despite huge challenges faced in terms of uncertain weather, cyclones, pandemic drought, ever increasing population, heavy industrialization and indiscriminate use of pesticides, horticulture sector has created history by surpassing the production of food grain crops. This sector is instrumental in leading agricultural growth in the country during the last decade. Apart from its contribution to the economic development, this sector also alleviates malnourishment and improves health conditions.

Total Horticulture production in 2020-21 is estimated to be 326.58 milliontonne, an increase of about 5.81 million tonne (increase of 1.81%) over 2019-20. Increase in production of Fruits, Vegetables, Aromatics and Medicinal Plants and Plantation Crops, while decrease in Spices and Flowers over previous year, is envisaged.

Horticulture Sector in Telangana

Telangana, the newly formed landlocked state is endowed with bountiful resources, fertile soils and diversified cropping patterns. Horticulture sector has been identified as one of the focus sector for development of Telangana State**.** Horticulture in Telangana covers 16.5 % of net sown area and contributes 40.5 % to Agriculture GSDP. The total area under horticulture is 12.40 lakh acres with an annual production of 71.52 lakh MTs. Fruits and vegetables constitute 74% of the total horticulture cropped area. Telangana stands **3rd in area and 8th** in production of fruits while 15th in area, 14th in production and 7th in productivity in Vegetables in the country and ranks 1st in area and production of Turmeric.

Major fruit crops in the state are mango, citrus, banana, guava and papaya while vegetables like tomato, brinjal, bhendi and various varieties of gourds are predominant. Chillies, turmeric and coriander are important spice crops and Oil palm is gaining importance among the plantation crops in recent time. The area under fruits is 4.42 lakh acres with a production of 25.69 MTs and productivity of 5.82 MTs/acre. The area under vegetables is 3.52 lakh

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acres with a production of 30.77 lakh MTs and productivity of 8.73 MTs/acre. The spices are is 3.90 lakh acres with a production of 8.03 lakh MTs and productivity of 2.06 MT/acre (NHB, 2020).

The soil and climatic conditions of the **Telangana** state are mostly favourable for the cultivation of **Horticulture** crops. There is a huge potential for horticulture sector growth which remains untapped.

Ecology of Telangana state

Telangana is situated on the southern part of India. Telangana lies between 15° 46' and 19° 47' N latitude and 77° 16' and 81° 43' E longitude. Telangana is a semi-arid zone and has a predominantly hot and dry climate and is characterized by hot summers with relatively mild winters. The State experiences tropical climate with slight variations depending on the elevation and varies according to the rainfall, type of soils and cropping pattern. The rainfall is received from both the South-West and North- East monsoons, predominantly the former, but precipitation varies across the State. The average annual rainfall is about 906 mm, 80% of which is received from the South-west monsoon.

Agro Climatic Zones of Telangana

The districts of the State can be divided into 3 agro-climatic zones *i.e*. Northern Telangana Zone, Central Telangana Zone and Southern Telangana Zone.

Impact of climate change on horticulture crops

National Level

Climate change has become an important area of concern for India to ensure food and nutritional security for growing population. The impacts of climate change are global, but countries like India are more vulnerable in view of high population depending on Agriculture (Rao *et al*., 2020).

In India, significant negative impacts have been implied with medium term (2010-2039) climate change, predicted to reduce yield by 4.5 to 9 percent, depending on the magnitude and distribution of warming. Since agriculture makes up roughly 16 percent of India's GDP, a 4.5 to 9 % negative impact on production implies a cost of climate change to be roughly up to 1.5 percent of GDP per year (http://www.nicra-icar.in/nicra).

However, the rise in temperature, uneven rainfall distribution and delayed onset of monsoon have led to drought or floods across different parts of the country. This phenomenon is threatening food security globally and imposed barriers on the performance of horticulture sector.

Horticulture crops are exceedingly prone to climate change owing to long economic life of the plant which requires hugeinitial investment and cultivating these crops has made farmers more vulnerabletoclimatechange. Climate change manifests in different ways. Price rise of fruits andvegetable crops is one of the majorand most prominent impacts of climate change. Horticulture sector has also experienced incidences of new pests (eg: *Tuta absoluta* on tomato). Climate change is a confounding factor to the spread and establishment of these pests.

State Level

Rainfed farming systems, representing 54% of the net sown area in Telangana State in India, have become increasingly affected by recurring drought and high climatic variability, adversely affecting the livelihoods of millions of small holder farm families.

Government of India has identified certain Crops & Districts for Telangana State both (Agriculture & Horticulture) and accordingly proposed certain crops and districts for inclusion under One District One Product scheme. Five (5) crops were identified under ODOFP pertaining to Horticulture and they are Mango, Chilies, Turmeric, Sweet Orange & Vegetables.

Biotic and abiotic constraints of horticultural crops due to climate change in Telangana

Crop	Impact of climate change on Production	
	Biotic	Abiotic
Mango	Vegetative Phase Incidence of Webber and stem borer. Flowering Phase Incidence of powdery mildew and hopper during flowering.Incidence of fruit fly	Climatic factors • Unseasonal rains during flowering phase (December-January) • Hail storm • Temperature variation during flowering resulting in erratic and recurrent flowering. Nutrient Deficiencies • Boron and Zinc deficiencies
Sweet Orange	1. Citrus Mite 2. Fruit sucking Moth 3. Leaf Miner 4. Dry Root rot	1. Erratic soil moisture conditions. 2. Presence of subsurface calcareous pans in the root zone in some areas.
Turmeric	1. Leaf spot 2. Leaf blotch 3. Rhizome rot 4. Rhizome fly 5.Shoot borer	Unseasonal Rains Low and excessive rainfall results in poor yields
Vegetables		
Tomato	Sucking pests Borers and virus	High temperature, low yields in Summer, Phytopthora Blight due to high rainfall in October.
Bhendi (okra)	Sucking pests and YVMV	
Brinjal	Fruit and Shoot Borer and brinjal little leaf	
Chilli	1. Spurious seed 2. Development of resistance in pests against the insecticides. 3. Sucking pests and Leaf curl Virus 4. Increased incidence of Midge fly, root rot, wilt, fruit rot, leaf curl virus.	Unseasonal RainsHeavy rains followed by dry spells.Sudden and unexpected / unseasonal rains during winter season spoiling the quality of the fruit.
Cabbage and Cauliflower	Diamond Back Moth	Grown only in winter
Carrot and Beetroot	Rustfly, Anthracnose	Grown only in winter
Onion	Thrips and Purple Blotch	Kharif yield are low
Bittergourd, Ridgegourd, Bottlegourd,Cucumber	Fruit fly and viral diseases	Less yield in summer due to more male flowers.
Colocasia	Phytopthora Blight	

Impact of climate change on fruit crops:

Mango

The area and production of mango in Telangana 3.07 lakh acres with a production of 13.85 Lakh MTs.Mango occupies 60 per cent of the fruit crop area in Telangana. The temperature variation during flowering results in erratic and recurrent and late flowering.

Major mango varieties grown in Telangana are Banganpalli, Himayath, Kesar and Dashehari and Dashehari-35. The Dashehari comes to maturity by April end in Telangana and has good marketvalue. Average productivity of the mango is 3.5 t/acre. As the climate of Telangana is highly favourable for the cultivation of mango, a potential productivity of 5-6 t/acre is achievable with the interventional technologies of high density technology, integrated nutrient management, rejuvenation technology, drip and water use efficiency, fertigation, mechanized pruning technologies. All these technologies have been developed through AICRP (mango and guava) at Fruit Research Station, Sangareddy.

There are several reasons for poor productivity in mango cv. Banganpalli in Telangana. Among them, poor and erratic flowering coupled with poor or nil fruit set in mango cv. Banganpalli is one of the major reasons for poor productivity. The flowering and fruit set in mango is majorly influenced by the temperature during flowering (Davenport, 2007). A night temperature of less than 15^{o}C for 3-4 weeks is necessary for mango to flower, a night temperature above 14°C is needed for proper fruit set (Davenport, 2003). The climatic changes especially temperature during flowering and fruit set period has been attributed to erratic flowering and poor fruit set in mango cv. Banganpalli (Bhagwan *et al*., 2011).

Mango productivity is largely controlled by climate, which invariably cannot be controlled and hence efforts have to be directed to modulate the mango phenology to suit unfavourable climatic conditions (Rajan *et al*., 2011). Under such circumstance's modulation of vegetative growth, flowering, and fruit set by spraying of plant bio regulators and chemicals is the best alternative to mitigate or reduce the adverse climate effect on mango. Treatment of NAA and spermidine has increased yield up to 48.04 % over control due to prolonged flowering by NAA and increased fruit set by spermidine, thus mitigating the climate effects on flowering. (Vijaya Krishna *et al*., 2020)

Two main factors needed for good flowering in mango trees is long exposure to light and heat"Temperature has a dominant influence on the growth cycle, time and frequency of flowering, fruit growth as well as taste and appearanceof the mango in almost all production areas. Growth requires comparatively higher temperatures while inflorescence emergence starts just after the coldest period of the winter in the region. Flowering progresses as the temperature increases. Apeculiar event has been observed, sprouting of flowers, buds and fruits occurred at once in the mango trees thereby flowering cycle has got disturbed with climate change which has got profound effect on yield and productivity of mango trees.

Sweet orange

The area and production of sweet orange in Telangana is 94,897 acres area with a production of 7.59 Lakh MTs. Sweet orange occupies 30 per cent of the fruit crop area in Telangana. The major sweet orange variety grown in Sathgudi variety. Some of the strength of Telangana in sweet orange cultivation are Favourable soils and climate for sweet orange, Pest and disease attack is relatively less compared to other citrus growing areas due to geographic location in scarce rainfall zone, Farmers are having experience in sweet orange cultivation for the past 50 years, Yield and quality parameters are excellent when compared to other sweet orange growing areas in South India. Telangana has good opportunity for crop expansion on account of high income compared to other horticultural and field crops of Telangana.

Average productivity of sweet orange is 15 t/ha with a potential yield of 17 t/ha in Telangana. There is scope for increase of productivity to 20 percent with improved technologies.Fluctuations in temperatures and water stress at critical phenological stages of citrus results in reduced fruit set, decrease in fruit growth and size, increase in fruit acidity, low tree yield, reduced fruit peel thickness, and pre-harvest fruit drop.

Various manifestations of climate change, such as changing seasonal patterns, flood, heavy rains, frost, hailstorms, high temperatures and drought leads to extremities and are visible in recent times. In addition to these fruit crops, there is wide scope to encourage other fruit crops *viz*. grape, pomegranate, fig, custard apple, guava, jamun, jack fruit, banana, papaya, sapota in Telangana as the climatic condition are highly favourable for cultivation of. There is every need to conduct research on the introduction of new fruit crops like dragon fruit, date palms, avocado to find out the adaptability of these crops in Telangana region.

Vegetable crops

Area and production of vegetables in Telangana is 3.5 lakh acres with a production of 25.69 lakh MTs. The climatic conditions of Telangana are suitable for growing wide range of vegetables. Like any other crops, vegetables are also highly sensitive to changes in climatic variables. Low yields in vegetables are accounted mainly because of higher temperatures which in turn will have multiplier effect due to climate change. Yield of vegetables is also affected by changes in global climate, erratic rainfall patterns with high unpredictable temperature spells.

There is vast scope to increase the area under vegetable crops in Telangana owing to its strengths like good market, easy access for farmers, well connected to other states, good yields per unit area, Polyhouse cultivation has picked up well, Fertigation and drip Irrigation are in practice.

The Telangana state provide good opportunity for cultivation of vegetables owing to more employment generation, scope for establishment of value addition and processing unit at Vikarabad, Rangareddy districts act as peri-urban areas, good market for vegetables as well as post-harvest products.

There is a yield gap of 20-30 % in vegetable which can be achieved by the interventional technologies like development of pest and disease resistant varieties, development of varieties resistant to abiotic factors such as drought, flood, high temperature, rainfall, Development of processing varieties of vegetables since the fresh vegetables are highly perishable.

Adaptation measures such as change in the sowing date, use of efficient technologies such as micro irrigation, soil and moisture conservation measures like use of mulches, fertigation and protected cultivation were found to play a vital role against climate change.

Adaptation Strategies for Climate Change Change and Initiations

To combat the effect of climate change on production, various strategies were proposed.

1. Development and dissemination of new crop varieties resilient to heat, photo and water stress. eg. Heat tolerant varieties in Potato.
2. Increase the efficiency of water use by efficient technologies like micro irrigation (drip and sprinkler) as mentioned below.
   - Drip once in a day at 80% PE treatment recorded highest rhizome yield followed by Drip once in 2 days at 80% PE treatment when compare to surface irrigation in Turmeric.
   - In studies on different treatments of drip irrigation scheduling in broccoli (Var. Green Gold), Drip irrigation daily with 100% PE was found effective and recorded significantly higher average head weight of 322 g with 111.1 q/ha of main flower yield and 66.8 q/ha branch flower yield and maximum total head yield (167.7 q/ha).
   - In studies on enhancing water productivity by drip irrigation and mulching in tomato, it was observed that application of drip irrigation at 0.9 bar + black polythene mulch was found productive and recorded highest number of fruits and average fruit weight with yield of 432.3 q/ha which is 25% higher compared to flood irrigation (349 q/ha).
3. Adopting measures like Change in the sowing date, use of plant growth regulators, protected cultivation which are reported here.
   - September Planting under poly house conditions has recorded maximum yield (77.74 t/ha). The results were communicated to department of Horticulture for further recommendations to the farmers
   - In 3 years studies (2011-2013) on response of Broccoli to micro nutrient applications conducted at Vegetable Research Station, SKLTSHU, the highest yield of Broccoli was recorded (112.54 q/ha) with application of Boric acid + copper sulphate two sprays at 30 days after sowing followed by treatment spray of ammonium molybdate alone which recorded 102.27 q/ha.
   - A Four-year study (2013-2017) on influence of age of transplants on seed yield of Brinjal var. Shyamala was conducted at Vegetable Research Station, SKLTSHU. It was evident that among different age of transplants (15,18, 21, 24, 27, 30, 33, 36 days old), transplanting the Brinjal seedling at the age of 27 and 24 days after sowing was highly productive in recording highest seed yield of 28,8 q/ha and 27.9 q/ha respectively. (Hanuman nayak *et al.,* 2019).
4. Soil health improvement and soil and moisture conservation measures like use of mulching with organic and inorganic mulches.
   - Application of drip irrigation at 0.9 bar + black polythene mulch was found productive and recorded highest yield of 432.3 q/ha which is 25% higher compared to flood irrigation (349 q/ha) in Tomato.
   - In studies on Inter cropping of seed spices with vegetables, it was observed that intercropping of carrot recorded

higher yield than sole crop of carrot but cabbage sole crop recorded higher yield to intercropping situation. Highest B:C ratio of 1:2.91 was recorded in Cabbage + fennel treatment, carrot + fennel treatment recorded highest B:C ratio of 1:1.63.

- In studies on organic farming in tomato, the treatment with application of full dose of RDF recorded significantly higher yield of 479.59 q ha^{-1} than organically grown tomato. Among organic treatments FYM@20 t ha^{-1} + VAM + Pseudomonas + Trichoderma + Azotobactorwas found effective and recordedyield of 371.10 q ha^{-1}

5. Integrated Nutrient Management (INM) by incorporating bio fertilizers and nutrient management through fertigation.
   - Fertigation to okra scheduled with 20% at germination 50% at vegetative stage and 30% at reproductive stage recorded highest yield of 113.31 q $ha^{-1.}$
6. Integrated Farming Systems was popularized as an alternative income to farm families

Introduction of New crop- Oil palm

Oil palm crop first started in four states in south presently cultivated in 16 states in country covering 3.31 lakhs hectare producing about 3.0 lakh tonns of CPO (Crude Palm oil rate). To attain self sufficiency and to cut down the imports, around 70 lakh acres have to be brought under Oil palm cultivation.

Telangana State is one of the potential states for Oil Palm cultivation in India and stands third in area after Andhra Pradesh and Mizoram states. Government of Telangana is encouraging farmers to go for Oil palm cultivation in a big way and accordingly 25 districts are notified for promotion of oil palm crop in recent months and it is contemplated to cover an area of 12 lakh hectares (30 lakh acres) under oil palm cultivation by 2025-26 plantation year. In addition to this, construction of Kaleshwaram Lift Irrigation Project a **multi-purpose irrigation project** on the Godavari River in Kaleshwaram, Telangana, resulted in continuous water supply to the farming community which paved the way for expansion of oil palm area in Telangana state.

Only drawback in oil palm cultivation is availability of quality seedlings. Government of Telangana is taking initiations for production of quality planting material by collaborating with line departments like Agriculture and Horticulture, Universities, Tribal welfare and Forest Departments. Further development of efficient techniques for production of quality planting material of varieties/ hybrids and multiplication and distribution of quality seed and planting material of improved varieties.

Establishment of Centre of Excellence in Telangana

After formation of Telangana State, the Government has given maximum importance to Horticulture Sector by launching different innovative programmes. One among them is establishment of Centres of Excellences (COEs) for Vegetables, Flowers & Fruits to impart training to the Poly House farmers and Production of high quality and disease free seedlings of vegetables and plant material of various fruit crops. For this purpose, Centre of Excellence for Vegetables and flowers at Jeedimetla (V), Medchal (D) and for Fruits at Mulugu (V), Siddipet (D) were established.

Centre of Excellence, Mulugu

The centre of excellence, Mulugu Siddipet district for Fruits was established in the year 2017 in an area of 53.25 acres with an objective to Study new crops or cultivars and suggesting varieties suitable to the local conditions, production and supply of disease free, quality planting material, demonstration on latest technologies in crop management and to impart training to farmers and other stakeholders.

The major activities taken up at COE, Mulugu are Production of high-quality fruit crops planting material for distribution to farmers. To demonstrate production of high quality fruits & varieties aimed for both national and international markets year around.

To make horticulture a profitable, diversified farm activity in increasing income of the farmers by achieving potential productivity through sustained and advanced technologies. To create awareness on new technologies through demonstrations on crops like Mango, Citrus, Guava and Pomegranate *etc*. Introduction of New Crops and Cultivars and suggesting varieties suitable to the local conditions will help in extending fruiting period and niche in domestic and export market, along with solving some of the problems related to root stocks.

- In center of excellence Mulugu, 21 varieties of mango have been planted at a spacing of 3 x 2 meters in 11 acres totaling to 7130 plants. During the third year as first crop a total of 6 tonnes was realized from ll acres with an average productivity of 0.545 tonnes.
- Ten Citrus varieties (2272 no.) in acid lime and sweet orange were planted at a spacing of 5 x 3 meters and 4 x 3 meters.
- Further, in guava, 5 varieties (5572 no.) were planted at a spacing of 3 x 2 meters and 2 x 1 meters in 3 acres. During its 3rd year of planting a total yield of 6 tonnes was realized with an average productivity of 2 tonns per acre.
- Five varieties of Pomegranate were planted at a spacing of 4.5 x 3 meters maintaining a total number of 730 trees. Two varieties of Custard apple (699 no.) were maintained at a spacing of 3 x 2 meters. Six varieties of Date palm (68 no.) were maintained at a spacing of 8 x 8 meters.
- The COE, Mulugu has produced nursery plants like 5 lakhs sandal wood plants, 1 lakh mango grafts, 50,000 guava layers, 20000 pomegrante plants, 20000 acid lime and 1 crore vegetable seeds and generated an annual income of Rs. 2.65 crores.

Centre of Excellence, Jeedimetla

Government of Telangana has established Centre of Excellence for Vegetables and Flowers under MIDH in an area of 10.35 acres at Jeedimetla of Medchal District in 2016, it is the first of its kind in Telangana state. The main objective is standardization of technologies in vegetables and flowers suitable to Telangana State. To showcase the production technologies of high quality seedlings under protected cultivation. Timely supply of quality vegetable seedlings for enhanced production under subsidy programme. Infrastructure development for demonstration and trainings to farmers on precision farming. To promote urban farming for production of fresh and quality vegetables by the urban households. Vertical Farming was established to convert Urban Farming (Vegetables) cultivation into a business mode and to meet the demand of leafy vegetables of the metropolitan consumers. Introducing new technologies as Hydroponics and Aeroponics where plants are grown without soil and roots are feeded with nutrient solutions.

Activities taken up at COE, Jeedimetla

I. Naturally Ventilated Poly House (Area – 2016 Sq.mt)

A) Season: April 1st 2021 to July 2021

Crops- Coriander, Cucumber, Cherry Tomato, Bachali

Season: 30th July 2021 to 31st March 2022

Crops – Bachali, Capsicum (15 beds x 140 plants=2100 plants)

S.no	Name of the Crop	Yield / Expected Yield	Unit price Rs.	Gross Income Rs.	Expenditure Rs.	Net Profit Rs.
1	Bachali	6961+9660=16,621 Bunches	Rs.10	1,66,210	2,62,732	1,77,508
2	Coriander	805 Bunches	Rs.10	8,050		
3	Cucumber	1238 kg	Rs.60	74,280		
4	Cherry Tomato	790 p@250gm	Rs.30	23,700		
5	Capsicum	4200 kg	Rs.40	1,68,000		
	Total	4,40,240/-				

B) Season: April 1st 2021 to September 15th 2021 (Carnation 1008 sq mt area)
Season: April 1st 2021 to August 2021 (Gerbera 2000 plants)
Season: 15th Sep 2021 to 31st March 2022
Crop : Hybrid Marigold

S.No.	Name of the Crop	Yield / Expected Yield	Income Rs.	Expenditure Rs.	Net Profit Rs.
1	Hydroponics		Rs.36,690	1,27,851/-	19,681/-
2	Carnation	114.5 bunches	Rs.8,860		
3	Gerbera	2132 bunches	Rs.32,620		
4	Hybrid Marigold	1000 kg	Rs.30,000		
		Total	Rs.1,08,70		

Isl.Red Shade Net
Season: April 1st 2021 to Aug 2021
Crop - Palak, Bhendi
Season: Aug 2021 to 31st March 2022
Crop - Colacasia (1000 nos) & Leafy Vegetables

S.no	Name of the Crop	Yield / Expected Yield	Unit price Rs.	Gross Income Rs.	Expenditure Rs.	Net Profit Rs.
1	Palak	184 bunches	Rs.10/-	1840/-	Rs.1,21,951/-	Rs.12,879/-
2	Bhendi	751.5 kg	Rs.60/-	44,490/-		
3	Colocasia	950 kg	Rs.30/-	28,500/-		
4	Leafy Vegetables	6000 bunches	Rs.10/-	60,000/-		
		Total	1,34,830/-			

B) Season: April 1st 2021 to Aug 2021
Crops- Cherry Tomato, Marigold, Palak,
Season: Aug 2021 to 31st March 2022
Crops- Brinjal (750 nos), Tomato (2000 nos).

S.no	Name of the Crop	Yield / Expected Yield	Unit price Rs.	Income Rs	Expenditure Rs.	Net Profit Rs.
1	Cherry Tomato	1031 kg	Rs.30/-	30,930/-	1,50,451	86,069
2	Palak	509 bunches	Rs.10/-	5,090/-		
3	Marigold	10 kg	Rs.50/-	500/-		
4	Brinjal	1000 pl /4000 kg	Rs.20/-	80,000/-		
5	Tomato	2000pl/6000 kg	Rs. 20/-	1,20,000/		
		Total	2,36,520/			

III.Walk in Tunnel
Season: April 1st 2021 to Aug 2021
Crop - Palak
Season: Aug 2021 to 31st March 2022
Crop - Broccoli, Cauliflower, Bhendi

S.no	Name of the Crop	Yield / Expected Yield	Unit price Rs.	Income Rs	Expenditure Rs.	Net Profit Rs.
1	Palak	3,833 bunches	Rs.10/-	38,330/-	Rs.90,618/-	Rs.26,012/-
2	Broccoli	405 curds	Rs.40/-	16,200/-		
3	Cauliflower	270 curds	Rs.30/-	8,100/-		
4	Bhendi	(700 Plants) 1350 kg	Rs.40/-	54,000		
		Total	1,16,630/-			

IV. Polynet House Area – 2000 Sq.mts
Season: Aug 2021 to 31st March 2022
Crop - Coccinia (500 nos)

S.no	Name of the Crop	Yield / Expected Yield	Unit price Rs.	Income Rs	Expenditure Rs.	Net Profit Rs.
S.No.	Name of Crop	Yield / Expected Yield	Unit price Rs.	Income Rs.	Expenditure Rs.	Net Profit Rs.
1	Coccinia	3,000 kgs	Rs.20	60,000/-	30,000	30,000/-
2	Ornamental Cuttings	25,000	Rs.20	5,00,000/-	2,50,000/-	2,50,000/-
	& Seasonals		Total	5,60,000/-	2,80,000/-	2,80,000/-

Conclusion

Climate change reflects long term changes in temperature, relative humidity, rainfall and other climatic variables. The horticulture crops are exceedingly prone to climate change owing to long economic life of the plant which requires huge initial investment and cultivating these crops has made farmers more vulnerable to climate change. There is a demand for climate smart horticultural practices or interventions which are customized to suit local needs. Strategies like conservation agriculture, natural resources conservation, reforestation, checks on population growth and pollution, reduction of greenhouse gas emissions, breeding drought resistant crops, tolerant to pests and diseases, early maturity, etc. are the need of the hour

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Post-harvest Management of Sub-tropical Fruits: Considerations and Recommendations

NEERU DUBEY

Introduction

Horticulture is the backbone for nutritional security of the country and serves as an important source of micronutrients. Even after a record production of 313 million metric tonnes (2018-19)[1] losses at each step of supply chain is recorded. In a recent survey conducted by AICPHT&CCM, in Uttar Pradesh it was found thatpost-harvest lossesin most of the horticultural crop sarehuge. Ingeneral, postharvest losses are variable from 12-20 % in Mango, 18-27% in Guava, 15-23 % in Litchi and 24-35 % in Sapota[3]. The wasted horticulture produce also leads to CO_2 emissions. As per FAO reports, worldwide food lost & wasted equals one third of the total food produced. This means about 1.3 billion tons food is discarded every year, due to postproduction spoilage, lack of farm-to- market connectivity, in transit losses, and some that is thrown and wasted in the hands of end-users. This quantum of food loss & waste (FLW) is alsoassociated with about 500 million tons of CO_2 equivalent greenhouse gases, which adds to globalwarming.[4]

Currently, India has installed *capacity* of 30.11 million metric tons *cold storage* facilities unevenly spread across the country. These are mostly focused on single commodity i.e., potatoes and chilies. However, the market is gradually getting organized and focus on multi-purpose cold storages is rising. More than 50 percent of the cold storage facilities in India are currently concentrated in Uttar Pradesh and West Bengal, while other states still face a challenge with investments from the government and private operators. Organized players contribute only 8–10 percent of the cold chain industry market, 36 percent of these cold storages in India have capacity below 1,000 MT, and most of the equipment used is outdated.

Current Cold storage (Hub) infrastructure requirement is 0.94 MT (All India)[2]which will act as a distribution point for various commodities reaching to consumption centers. Once the commodity arrives at the consumption hub, it will be stored there for a few days till it gets distributed among the distributers and retailers operating within the vicinity of the hub. Cold storage (Bulk) infrastructure requirement is-34.16 million MT (All India) which will be established near to production center for commodities that can be stored for longerperiod. The major commodities considered are apple, kiwi, carrot, cabbage, potato, drychilly.

In India there was a gap of 70,080 pack houses in 2014-2015[2]. This gap in the last five years might have been reduced by 100-200 pack houses in the country as all the state governments have put major emphasis on the construction of post-harvest infrastructure along with implementation of the proper PHM infrastructure and scientific management of the produce the post-harvest losses can be reduced to half as also increase in economic benefits, employment generation and better income to the farmers.

General activities in Post-harvest management

There are some activities common for post-harvest management in all the crops. These activities are covered in the section below:

Maturity identification: The fruits should be harvested at correct stage of maturity depending on their type and distance from the market. Climacteric fruits which produce ethylene can be harvested at

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physiological mature stage and ripened later whereas non-climacteric fruits should be allowed to ripen on the tree itself.

Harvesting: Temperaturem anagement of perishable commodities begins with proper handling at harvest. Generally, produce should be harvested in the morning so that it will be at the coolest possible temperature during the delay between harvest and initial cooling. Exceptions to this recommendation are produce, like some citrus fruit, that are damaged if they are handled when they are turgid in the morning, peas and beans (dried surface is necessary as otherwise it will attract fungus) or situations where the produce is harvested in the late afternoon so that it can be transported to a local market during the cool night hours. The produceshouldbe protected from solar heat through shading and the time difference should be least between picking and initial cooling a seven a small increase in temperature leads to high deterioration rate. Harvesting should becarried out as carefully as possible to minimize mechanical injury such as scratches, punctures, and bruises to the crop. All instruments should be properly washed before harvesting and hands should be clean. Every care should be taken to avoid solar exposure by placing them in some shaded place. Mechanical injury provides sites for pest attack and increases physiological losses. ion of produce, sorting, grading, packing etc. can be undertaken under this shed instead of open sky. Shade can greatly reduce the temperature of any fresh produce that is being handled outdoors. By this way the shelf life can be increased, and quality can be maintained.

Washing: Cleaning pertains with removal of dirt and chemical residues, reducing the microbial load, insects, and aphids. Clean commodity is appealing to the consumers and easily marketable. Moreover, soil clinging to produce will cause abrasion damage and acts as a source of contamination. Physical damage must be minimized during the cleaning process. The method of cleaning is determined by thenature of the commodity and the dem and of the consumer. Leafy vegetables such as lettuce and muskmelons have rough surfaces that favour theattachment/ infection with microorganisms, hence it requires proper washing. Bulb crops such as onion and garlic, on the other hand, need not be washed. However, the dried outer scales need to be removed carefully as they carry dirt.

Sorting: Sorting is done at the farm to assort the produce into target lots basis qualitative criteria-as non-edible, as reject or dump, by quality, by shelf-life or by market value. Essentially this is the first stage categorization of received produce and separates them into differentiated value-based flow towards as ascertained and useful end-use. Field sorting can help to reduce the volume of produce to be handled at a packing facility. It also lessens the chances of introducing contaminants into the packing facility. Tents or mobile packing sheds can be used as working areas for preliminary sorting of freshly harvested produce**.**

Grading: Gradingistheprocess of classifying producein to groups according to set criteria of quality and size recognized or accepted by governments and the industry. Each group of produce bears an accepted name and size grouping, such as Extra Class, Class Ior Class IIinthecase of the Codex Alimentarius Commission (CAC) standards for freshproduce. Grading can be done on size, appearance, stage of maturity, texture etc.

Pre-cooling: Pre-cooling is removal of field heat at suitable humidity levels to suppress respirat or yactivityandenzymaticdegradation (softening). Removaloffieldheat lowers the core temperature of the commodity and helps to slow down moisture loss and inhibits decay producing micro-organisms. Pre-cooling also helps to minimize production of ethylene and minimize the commodity's reaction to ethylene.

The method for removal of field heat depends on several factors as-

- Temperature of the harvestedcrop.
- Natureof the commoditye.g. (leafy, flowers, fruits), itsrespirationrate
- (s) cooling needs, lowest safe temperature, tolerance to water exposure.
- Product packaging: Box bin, or bag, packaging materials and design configurations affect method and rate ofcooling.
- Product throughput capacity, volume/mass to be handled per unit time will determine the cooling method andscale.
- Mix of commodities; compatibility depends on their nature about sensitivity to odours and

volatiles such asethylene**.**

Storage: Orderly marketing of perishable commodities requires storage to balance day- to-day fluctuation between product harvest and sales for long-term storage to extend the market period. Proper storage of the horticultural commodities is essential to ensure regular and planned marketing. The major factors which affect the storage quality are- moisture loss, loss of carbohydrates, minerals and vitamins, sprouting, physiological disorders, attack of pests and microbiological diseases. The objectives of storage are to slow down biological activity of the commodity at low temperature with controlled atmosphere that will not cause chilling and freezing injury. Storage also helps in slowing the growth of microorganisms and reduces produce drying by reducing the difference between product and air temperature and maintaining high humidity in the storageroom.

Basic storage practices require

- Regular cleaning of the storagestructures.
- Screen to protect fromrodents.
- Periodic inspection to remove any in fectedproduce.
- Properventilation.

Some of the commodities like Apricot, Limes, Peaches, Plum, Sweet Potato, Lemon, Lettuce are susceptible to chilling injury. These products can be injured by one light freezing.

Packaging: Packaging is essential activity to maintain the freshness and shelf life of commodities by providing appropriate environment, protection, and convenience. Packaging should be designed to prevent premature deterioration in product quality, inaddition to serving as a handling unit. In the old traditional methods of packaging, situation of packaging was pathetic in many regions of production. Wooden crates and boxes prepared from local materials such as pigeon pea stems and those made from bamboo or even sacks without any cushioning materials had been inuse. The package protects the produce from tampering, transport hazards, microbial and insect damage, minimizing biochemical and physiological changes. The packaging performs the function of protection, containment, convenience and communication. Agood package should be environment friendly, should have sufficient strength in compression and against impact and vibrations, be stable during the entire distribution chain, compatible with the automatic packing/filling, handling machines, should facilitate special treatments like pre-cooling and be easily printable.

Cushioning materials: *Cushioning material used for packaging fruits and vegetables are dry grass, paddy straw, and leaves, saw dust, paper shreds etc. Cushioning materials help to absorb a proportion of kinetic energy when the package suffers impact or is dropped from a certain height. A cushioning material performs its fundamental role i.e., to reduce the forces created when one surface comes abruptly into contact with another, which prevents compression or deforming damages and minimizes damaging impact forces***.** *Various types of cushioning materials are used along with distribution packages to reduce damage and loss due to mechanical injury during handling and transportation. Sheets of newspaper or shredded newsprint are commonly used as alining material in bamboo and plastic crates, and in corrugated boxes. Leaves are also used as a lining material inside bulk containers. Plastic foam netting is commonly used for wrapping individual fruits before filling in corrugated boxes and partitions and pads made of corrugated board are used to accommodate fruits inlayers.*

Transport: The current situation of transport of perishable is deplorable in many regions. Commodities are loaded loosely and transported with any mode of transportation locally available in remote production places during hot part of day. Sometimes, even field labour sits on these commodities during transportation. These cause heavy damage to commodities. These practices need to be curbed**.**

Careful transport is essential activity to minimizing losses during transport necessitates special attention to vehicles, equipment, infrastructure, and handling. Load and unload transport vehicles carefully.

- Use clean, well ventilated vehicle covered at the top fortransportation.
- Transport the commodities during the cool part of the day by driving carefully over smooth roads to minimize damage toproduce.

- Fresh produce must not be watered prior to loading, as this will lead to decay, rotting, and extensive losses.
- Major causes of losses are improper handling during loading and unloading.
- The transportation is done through road, railways, ships and airways.
- During transportation the major damage is reported through vibration which can be prevented through stacking.

Stacking: Stacking can be defined as the staking of racks, bins and pallets for holding unitized cargo in storage and transport. These can be constructed with metal, wood or plastics suitable for temperature-controlled conditions. When staking containers care shouldbe taken to align them properly. Whenever possible, stacking should be done so that corner matches on both the cartons and the pallet. Most of the strength of CFB boxes comes from the corners so an overhang of even 1 inch will decreases tacking strength by15-34 percent.

Post-harvest management of sub-tropical fruits

Sub topical fruits consisting of Guava, Litchi, Pomegranate, Mango are very high value fruits and require special care and some very specific treatments for better returns and best quality to the consumers. In the subsequent paragraphs post-harvest handling procedure of specific crop is described:

Post-harvest management of Citrus fruit: Citrus spps. is short duration crop suitable for long distance domestic and export market particularly to middle east countries. If required infrastructure for Citrus spps.is develop for primary processing it can develop into a very profitable venture. For primary processing the required infrastructure is clippers, crates and bags for harvesting and transportation to the packhouse followed by sorting, TBZ laden waxing, followed by electronic colour grader and packaging in CFB boxes. If citrus spp is kept in cold storage and transported at 5-7^{o}C and 90-95% RH for enhancing the marketing period (Storage period-2 months). Below 5^{o}C it will be subjected to chilling injury. Small sized fruits can be utilized for juice purpose. The major equipment needed for juice processing are washer, peeler, citrus juice extracting machine, aseptic packaging machine and debittering plant.

Harvesting and Post-harvest Management

Harvesting: The horticulture crop, including citrus fruit are characterized by peculiar problem of being highly seasonal, perishable and Bulky in nature. Due to this citrus fruit need high degree of care at harvest and post-harvest phase. Citrus fruit do not ripen after picking. They must be fully ripened when harvest early harvesting produce poor quality fruit and erratic ripening whereas delayed harvesting results in decay of fruit and reduce juice content. Harvesting should be done when fruit attain full colour and TSS range between 12 to 14^{o} bricks.

Precautions during harvesting

Harvesting in late morning hours when surface moisture evaporates

- Harvesting by clippers/secateurs
- Do not pull or snip
- Harvesting ladder should not lean on tree
- Cut it with clean sharp clippers
- Close to the peel of the fruits retaining shortest stalk and green button
- Put the fruits gently in crates
- No overfilling (20 kgs-optimum)
- Fruits should be placed in solid bins gently

Storage and post-harvest management

- **Grading and Sorting:** For getting good prices and assuring quality for consumer fruit need to be graded in different sizes and variation grading and sizing of fruits is both mechanical and manual. A mechanical citrus packing line called the primary processing center equipped with washing, sorting, size grading, fungicidal treatment for orange and then packing into corrugated fibre boxes
- **Storage** Citrus spp can be stored at 5-7^{0}C with 85-90 % Relative Humidity for four to eight weeks.
- **Transit preparation:** The ideal transit temperature is 10^{0}C. Forced air systems are

used for pre-cooling. The fruits may be packed in well ventilated Corrugated Fiber board Boxes (CFB) boxes (30 cm x 30 cm x 30 cm).

Precautions during transport

- Crates should be loaded carefully in the transport vehicle
- Care should be done that there is no overloading
- Don't transport in heap
- Drive carefully, prefer smooth roads
- Do not delay transport
- Fruit inspection and weighing at the arrival

Pack house operations

- Washing done with chlorinated water
- After washing surface drying
- Waxing with fruit grade wax (Shellac, Carnauba and bees wax)
- Wax coating helps in checking the water loss from fruit surface and imparts fresh glossy appearance
- The waxing of fruits can be done either mechanically (spray brush or spray nozzle type application) or manually (with foam pad, mist spray or dip method
- After waxing, the fruits are again dried at temperature of 30-35°C

Packaging

- The fruits should be packed in corrugated fibre board boxes, having 10 kg capacity.
- Usually two pieces, telescopic, CFB boxes of five ply with waterproof coating to tolerate high humidity during shipment are preferred.
- Normally, a box of size 45 cm x 24 cm x 18 cm having 10 kg capacity is very common and acceptable for export marketing.
- The box must have 5% area punched as holes for ventilation.
- A divider/liner having ventilation holes is inserted in between layers, which will act as cushioning material.
- Overfilling should never be practiced

Pre-cooling/storage and transportation

- Pre-cooling of the produce as soon as possible to remove the field heat
- Forced air pre-cooling (4-6 hrs)
- The distance between the rows should be 1.5 ft apart
- The temperature to be brought down to 7°C
- Storage in crates in cold storage (7-10°C& 90-95 % RH)
- Storage for 1-2 months for off season marketing
- For storage distance between pallets should be between 4-6 inches
- Below 1000 km transport can be done in covered trucks
- Above 1000 km fruits should be transported from packhouse to market in refrigerated maintained at 7-10°C
- Temperature should not fall below 5°C to prevent chilling injury
- At no point the temp control to be switched off

Post-harvest management of Guava

Guava

Bagging

- Sunscald, uneven colour development of fruits and aril paleness during summer are some of the problems reducing the marketability of fruits.
- Bagging the developing fruits 3 months before harvest helps to overcome these problems.
- Butter paper, white color cellulose based bags or zipped polyethylene bag (15x15cm) are suitable for bagging.
- Bagging is done on a bright sunny day when there is no moisture deposition around the fruits.
- White colour bags reflect sunlight and reduce the temperature around developing

fruits.

- The optimal temperature helps in biosynthesis of anthocyanin pigments and prevents their denaturation during hot months.
- About 10-12% higher anthocyanin is available in the arils of bagged fruits, compared to unbagged fruits.

Guava is a relatively hardy fruit grown in tropical and sub-tropical areas of India. Judging the harvest maturity and harvesting at optimum maturity is very critical to reduce losses and maintain marketable quality. The harvest maturity is judged based upon the size and peel colour. The crop records very high postharvest losses pertaining to improper handling practices and inadequate post-harvest infrastructure. The common practice of guava fruit harvest is by pulling the fruit from the plant, but this practice ruptures the soft skin and further harbours as a source of entry for pathogens. The fruits should be harvested using sharp secateurs and collected in a cloth bag or plastic buckets to avoid bruising and injuries on the fruit surface. The fruit is then transferred to ventilated plastic crates and kept in shade. The bruised and diseased fruit are sorted out in the packhouses and then graded based upon the fruit size and weight. CFB boxes and vented plastic crates lined with cushioning materials reduce the occurrence of bruises and losses during the handling, transportation, storage and marketing. The guava fruit can be stored for up to 2-3 weeks at 6-8°C and 95% relative humidity. Like other tropical and sub-tropical fruit, guava develops chilling injury symptoms at temperatures less than 5°C which includes pitting, browning and decay.

Quality Characteristics and Criteria

The major quality characteristics of Guava which can be taken into consideration are:

- Skin colour is used to measure maturity and ripeness.
- Size and shape are other important quality criteria.
- Fruit should be free of defects, decay, and insect damage.

Maturity Indices

- For long distance transportation, fruit should be harvested at the mature, firm stage without any signs of ripening.
- For short distance marketing, fruits should be harvested when they show some sign of color change from green to yellow, as well as initial softening.
- Later harvesting, when fruit are riper, can lead to a high number of fruit fly stings and later larvae in the flesh.

Harvesting

Manual Harvesting of the fruits is done by pulling and twisting the stem which causes development of white patch on the stem and bruising injury on the fruits. It is recommended that fruits are harvested by clippers and usage of net bags to prevent any mechanical damage. Further harvested fruits should be kept in crates.

Sorting and grading

Sorting and grading is absolutely necessary for maintenance of the quality of the produce

Pre-Cooling, Storage, and transport

Pre-cooling facilities to be provided if the fruits are to be shipped long distance to about 10°C.Mature green and partially ripe fruit can be held for 2 to 3 weeks at 8 to 10°C whereas ripe, soft fruit can be held about 1 week at 5 to 8°C with RH of 90 to 95%.

Packaging

In the current situation, farmers do package them in crates but don't use cushioning material which results in damage to the skin. The packaging of guava should be done invariably in crates with cushioning material or CFB boxes.

Post harvestmanagement of Litchi fruits

Litchi is a highly relished subtropical evergreen fruit crop available in few Indian states from late April to mid-July, while the peak season is in May. It is a non-climacteric fruit and the fruit harvest is done only at the fully mature stage, usually determined by the colour development, shape changes and total

Fig. 1: Net bags and clippers for harvesting

soluble solids (TSS) in the juice. Colour charts, hand refractometer and sharp secateurs will be required to judge the maturity and proper harvest. Vented plastic crates will be used to collect the fruit and facilitate efficient pre-cooling through forced-air cooling. Precooling can also be performed with evaporative cooling and hydrocooling equipment. After sorting, the fruits are graded based upon the fruit diameter or weight Postharvest temperature management and proper packaging are critical to reduce losses and ensure the marketable quality for a relatively longer duration. 3-5 ply corrugated fibreboard (CFB) boxes or plastic crates when used as packaging material reduce losses during transport and marketing. The cold storage at 2-5°C and 95% relative humidity can maintain the quality for 1-2 weeks, but there are chances of pericarp browning caused by chilling injury when stored for a longer duration.

Harvest and Post-harvest

- Fruit is harvested when it turns red that is full ripe stage. Once harvested, there is no further ripening of fruits. The fruits are harvested in bunches along with a portion of the branch and a few leaves. At the time of harvesting care is taken to harvest the selected bunch which has attained the desirable maturity as determined by colour development.
- The harvesting tool is a contraption in which hook is tied at the top of a long pole.
- Produce is harvested by farmers' family and hired labour in early morning and afternoon.
- Plastic crates and baskets with liner of jute cloth, litchi leaves and old newspaper are commonly used for packaging on farm.

Care to be taken during harvesting

- In case, harvesting is being carried out from the ground, harvested bunches should be placed in plastic field crates.
- In case ladders are used the picker places harvested bunches into a cotton bag which is regularly lowered to ground and transferred to field crates.
- When picking tools are used to cut the panicles, a bag should be attached to the pole so the fruits do not fall on the ground.

Fig. 2: Packaging with crate liner and foam net

- To avoid breaking of fruits skin, the fruit should not be pulled from the bunch.
- The ideal time for harvesting the fruit is when temperature and humidity are congenial which gives longer shelf life to the fruit.

Sorting and Grading

- Fruits should be cleanly clipped from bunches using secateurs, with 0.5 cm of the stem left attached. Fruits that are brown or not uniform in colour or undersized or showing any damage or disease or have cracked skin should be rejected at this point.
- Fruit infested with fruit borer or litchi moth should also be sorted out because these fruits after fermentation results secondary fungal infection in the packed cartons.
- The remaining fruits should be graded into various classes as per the shape, size and colour of the fruits according to the fixed standard.

Cleaning and Washing

- Washing with water is not preferred
- Cleaning of fruit is recommended by dry brushing

Other treatment: Sulphitation and acidification:

- Anthocyanin content of litchi fruits is lost immediately after harvest if not treated properly. This spoils the market appearance of the fruit.
- Bleaching of the colour by sulphur fumigation and regaining it through acidification has been found more convenient and effective practice in case of litchi.
- At the time of fumigation sulphur: air ratio of 1:5 should be maintained. Immediately after this process, the fruits turn yellow which regain the bright red colour after 20-25 days of storage at 4°C. No change in sulphur or acid content of the aril and its eating quality after sulphuring and acidification has been observed.

Pre-cooling

- The fruit should be pre-cooled to remove the heat which extends shelf life.
- Further the fruits should be brought to the cold storage within two-three hours.
- *Note: Pre-cooled litchi fruits, stored at 0-1°C can be kept fresh for approximately 30 days and transported to distant places markets of the country.*

  Litchi fruits are harvested at the peak summer period and hence require immediate removal of field heat through pre-cooling to retard the different enzymatic activity continuously taking place in the fruit.
- The air-cooling method is quite prevalent method for pre-cooling litchi which is done by maintaining 4-6°C temperature in a room. The well-ventilated containers with fruits are kept for 3-4 hours which facilitate air exchange and thereby induce effective cooling to the fruits.
- Forced air cooling can also be used for pre-cooling if vertical column palletization is available and carton ventilation is appropriate.

Cold Storage

Unlike other tropical and sub-tropical fruits litchis are not chilling sensitive and should be stored at temperature of 0°C to 1°C with 90- 95 percent relative humidity. Fungal growth at this temperature is minimized and the fruits retain their colour texture and flavour.

The probability of browning increases when fruits are stored at low humidity. If normal cold – room cooling is used, cartons should be stacked to enable air movement around each carton. Cooling in this manner takes 8-12 hours.

Packaging

- Packing should be done at low temperature.
- Fruit should be completely dry before packing because moisture content increases the chance of developing disease on the fruits.
- Litchi should be packed in lined containers.

- Pack them in large bins or crates lined with plastic sheets with suitable holes so that air circulation can take place.
- The packages should be well ventilated

For short distance, transportation (200 km or less) tractors with trailers are used. For long distance the most common vehicle is the truck.

Transport and marketing

- Transport facility from packing facility to the market should be in reefer trucks if the fruits have already cooled.
- In all cases, trucks should be covered to prevent contact with wind, rain, direct sun light and heat.
- The post-harvest disease of litchi is predominantly secondary infection that develops because of mechanical damage.
- Use crates for packaging and transport for better ventilation and palletization which will also prevent shaking and bruising
- Transport during cooler part of the day as heated litchi will lose their quality and dehydrate more quickly
- Careful handling, prevention of mechanical damage, and rapid cooling minimize secondary infection

Post-harvest management of Pomegranate

Pomegranate is widely cultivated in Maharashtra and the cultivation is expanding in other states. The fruit has to be harvested when fully mature. The maturity is judged by fruit size and peel colour and harvesting is to be done using sharp secateurs and harvesting bags. The secateurs should be sanitised (using formalin/ bleach) to prevent the spread of bacterial blight disease. The harvested fruit is collected in plastic crates and transferred to the packhouse. The packhouse operations include sorting, washing the fruit in detergent water and grading based on fruit size. 3-ply CFB boxes and plastic crates are used with cushioning materials viz., shredded paper and straw, while transportation and marketing. Individual fruits can also be packed with foam nets before packing in CFB boxes. Waxing of the fruit is not commonly practised in India but it has been reported to significantly increase the shelf-life. The fruit can be stored for up to 6 weeks at 5-7°C and 90-95% relative humidity.

Maturity Indices

- The fruits should be harvested before they become overripe and crack (split) open
- The arils attain deep intensity of colour
- Red colour of juice

Harvesting

The fruit is generally clipped from the tree when ripe, and its quality improves on storing. Pomegranate tree sometimes tends to split open the fully ripe fruits as it is the natural means of seed release and dispersal.

Late harvesting of fruits results in a physiological disorder known as internal breakdown. ie. the discoloration of affected arils from that of rest of the arils. Hence, harvesting should be done at appropriate time. The fruits of pomegranate fruits are harvested only after attaining maturity. Harvest only the mature fruits (ie. semi ripe- ripe stage) as it is not possible to ripen the fruits once they are plucked immature even with ethylene treatment.

Harvesting time: Early morning or evening hours is the most suitable time for harvesting to avoid accumulation of field heat.

Precaution during harvesting

- The fruits should not be pulled from branches to prevent damage.
- Make use of sterile scissors/ clippers for picking (clean with wet cloth & dip in 1%sodiumhypochloriteforsterilization).
- Cut the stem close to the base of the fruits to overcome the damage of other fruits.
- Exercise care not to inflict any injury to the rind during harvest.
- Pay attention to harvest the fruits intact with crown
- Climb the ladders/tripod stands to harvest the fruits from upright branches.
- Collect the fruits in plastic crates of 20kg

capacity washed with detergent

- Don't heap too many layers of fruits in crates.
- Place the cushioning material at the bottom of the crates viz., dries grass, paddy straw or paper.

Sorting: Cracked, split, diseased and infested fruits are removed which is done manually by trained sorter.

Grading: Presently, manual grading is done by the farmers in orchard. It is suggested to install mechanical grading line in pack house to undertake grading in below mentioned four grades.

Table 35: Pomegranate Grades

S.No.	Grade	Characters
1	Super	Attractive red colour fruits, > 750g / fruit, free from spot in the rind
2	King	Attractive red colour fruits, 500-750g/ fruit
3	Queen	Bright red colour fruits, 400-500g/fruit, free from spot
4	Prince	Red colour fruits, fully ripe fruits, 300-400g/ fruit

The white coloured boxes having 5 plies are generally used for export purpose, whereas red-coloured ones having 3 plies are used for domestic markets. The red coloured boxes are cheaper than white coloured ones.

Pre- cooling: The pre- cooling of pomegranate is normally done to 6^{o}C with 90-95% RH as soon as possible after harvest which will help the produce to maintain the best quality till market and consumer.

Packaging for storage: In bulk storage, fruits are packed in layers, in wooden crates each containing about 16-18 kg of fruits. Dry grass, rice straws, or paper are used as cushioning material.

Retail Packaging: The fruits are then packed in corrugated fibre board (CFB) boxes. In a single box, 4-5 fruits of Super size, 6 fruits of King size, 9 fruits of Queen size and 12 fruits of prince size are generally packed

Shrink Film Wrapping

- Fruits having large surface to volume ratio are particularly more susceptible to water loss.
- Individualshrin kwrappac kagingextendsshelf life by preventingmoistureloss, maintaining the firmness and reducing the respiration rate (10-20%)
- Protection against abrasion, maintains attractive appearance, avoids condensation of water droplets within the package, prevents secondary infection
- Heat shrinkable polymeric film of 20ì thickness used for packaging is low in thickness with high tensile strength, low in permeability to oxygen and water, high in permeability, glossy and transparent, ability to shrink at low$_2$ temperature.

Storage: Pomegranate can be best stored at low temperature and high humidity. Fruits stored at 4-5^{o} C and 80-85 % relative humidity did not undergo any shrinkage or spoilage in a few months. CA storage with 5% Oxygen and 15% Carbon dioxide has been shown to extend pomegranate postharvest life for up to 5 months at 7^{O}C.

Post-harvest management of Mango

Fig. 3: Handling, packaging and transport of Pomegranate

Mango is a tropical fruit but is being widely grown even in the sub-tropical areas of the world. India produces the majority of the world's mango with more than 1000 commercial varieties grown in different locations of the country. The availability of the fruit starts from March in South Indian states while in North India the fruit is ready for harvest from late May. The maturity of the fruit is judged by size, peel colour, total soluble solids (TSS) and firmness. The colour charts, penetrometer and hand refractometer will be required to judge the maturity stage, while the sharp secateurs and harvesting bags will avoid bruises and ensure the proper harvesting. Specially designed mango harvesting poles can also be used. After the harvest, desapping of the fruits should be done by keeping the fruit in an inverted position on wooden/metallic frames to prevent sap burn marks on the peel. Hydrocooling is a popular method of pre-cooling, while forced-air cooling can also be used for quick results. Packhouse operations include sorting of damaged fruit, followed by grading based on size and colour. Ripening chambers installed with ethylene cylinders are used to induce safe artificial ripening and uniform peel colour in the fruit. The mature green mangoes can be stored in cold storage at 10-13°C and 85-95% relative humidity, while ripe mangoes can be stored at 7-10°C and 90-95% relative humidity. Controlled atmosphere (CA) storage with 3-5% Oxygen and 5-8% Carbon dioxide can maintain the fruit quality for up to 6-8 weeks. Hot water treatment of 45-55°C for 5-10 min is widely accepted disinfection treatment by several importing countries and it significantly reduces pathogen load on the fruit for up to 13-15 days. Impact bruises and mechanical injuries during the handling, transportation, storage and marketing can be reduced by using CFB boxes and vented plastic crates lined with cushioning materials.

Pre-harvest management

- Bagging of fruits for controlling the post-harvest diseases and bruises with newspaper or brown paper bags one month prior to harvest.
- Harvested fruits ripe uniformly without any disease and fruit fly infestation.
- The problem of blackening upon ripening occurs.
- The shelf life of such fruits is also increased by two to three days.
- Checks jelly seed formation (softening of pulp near stone).
- This technique is eco-friendly and job oriented. (Bags are not suited for coloured mango varieties)

Harvest maturity

- The harvest maturity takes 12 – 15 weeks after fruit set.
- At the time of maturity, stone becomes hard and pulp colour changes from white to cream.

Sorting and grading

- Separate mature unripe fruits from immature and ripe fruits.
- Grade fruits according to size and weight
- Sort out defected, deformed, bruised and diseased fruits.
- Desapping of the fruits is necessary for improving quality.

Desapping

The sap from the fruit is removed by cutting the stalk of the fruits at a length of 5-10 mm from the base of the fruit with the help of a sharp edged scissors.

At the time of stalk cutting, the fruit should be held upside down so as to avoid the flow of sap on the skin of fruit.

It is advisable that whole sap from the fruit should come out during the de-sapping process. However, if intending to reduce this process time, fruits should be placed upside down in a desapping rack for at least for 45 minutes.

Pest management

- Bagging of fruits check development of post-harvest diseases and fruit fly infestation.
- If bagging has not been done, pre-treatment of fruits is required for controlling post-harvest diseases.
- Harvested fruits should be dipped in 0.025 per cent Carbendazim in hot water (52±10^{o}C) for

10 minutes.

- Fixing of wooden block methyl eugenol traps @ 10 traps per hectare commencing from first week of May to manage fruit fly

Ripening

- Do not use calcium carbide, a banned chemical, for ripening of fruits.
- Such fruits do not ripe uniformly and quality of fruits is inferior.
- Calcium carbide is hazardous to health.
- Ripe fruits with ethylene gas (100 ppm or 0.1 %) in airtight room by exposing them for 24 – 48 hrs under controlled conditions of temperature and humidity

  Alternatively, ripe the fruits with dip treatment of ethrel / ethephon solution (250–750 ppm) in hot water (52±20^{o}C) for 5 minutes.

- The same solution could be used four times.
- Premature fruits (fruits harvested up to 2 weeks prior to maturity) could be ripened to an acceptance quality by dipping the fruits in 750 ppm ethrel solution.
- Less mature and mature fruits are ripened by dipping the fruits in 500 and 250 ppm ethrel solution, respectively.

Fruits ripen uniformly with attractive colour

- Fruits ripen within 4 - 8 days depending upon the maturity.
- This technique is also useful for processing industries.
- Sorting of ripe fruits is not required due to uniform ripening of fruits.

Packaging

- The filled boxes / packages should be kept under shade.
- Package should meet the handling and shipping requirements of international standard.
- The pack should be labelled with name of variety, grade, class and brand, if any.

Storage

Fruits could be stored for 6 – 12 days under ambient conditions, according to variety.

- For increasing the shelf life, fruits are stored at low temperature and high humidity.
- Precool the fruits to required temperature before storing at low temperature.
- The shelf life of fruits at low temperature is 2 –3 weeks.
- Use rigid containers that can withstand stacking without getting deformed.
- Do not store other fruits with mango under low temperature conditions.
- Store fruits until they are marketable and profitable.
- Transfer cold store fruits gradually to room temperature to minimize sweating.

Transport

- Do not throw the packages during loading or unloading.
- Stack 4 – 8 containers, as per their strength, in pallets.
- Arrange the boxes in the truck to allow proper air circulation
- Transport the produce during the cooler part of the day, i.e., during night.
- Cover the truck with tarpoline leaving proper ventilation.
- Avoid using large containers for packaging and transport of fruits.

- Transport cold stored fruits in a refer van.

Post-harvest management of Peach

Maturity Indices

- For harvesting peach at the right time, the proper color development in fruits and pit browning should be considered as reliable guides. In yellow fleshed cultivars, deep orange color development on fruits is associated with proper maturity.
- At least 5% of the pit area also should be brown if the fruit is to develop good flavor at ripening.

Harvesting Methodology

These are harvested by twisting with hand. The peak harvesting period for different peach cultivars in hills is mid-May to mid-July. Peaches must be harvested after attainment of harvest maturity. Hand picking is the standard method for harvesting fruits. Use of iron ladder is recommended for easy harvesting.

Peaches must be picked at a stage of development that is advanced enough to allow the fruit to ripen to high culinary quality, yet early enough to minimize bruising and premature softening during storage and transport.

Harvest peaches when they are fully ripe, meaning that there is no green left on the fruit. They should come off the tree with only a slight twist. The fruits found on the top and outside of the tree usually ripen first. The whole inner surface of the hand should contact the peach in the picking operation. Picking with fingertips only may result in bruises which in a few hours become discoloured, thereby reducing the attractiveness of the peach.

Care to be taken during harvesting

- Pickers must be careful not to drop fruit either when placing it in picking baskets, bags or transferring it to field containers.
- Fruit should be treated as gently as possible at every stage of harvest process. When emptying harvesting bags into crates or big baskets care should be taken to ensure that the fruits are not dumped from the high height.
- After harvesting fruit should be hauled to a cooling facility as quickly as possible.

Sorting and grading

- Sorting is done at the farm level under the shade of the tree and small portable tent.
- All disease and damaged fruits are separated
- Fruits are graded into 3 different categories as Grade A, B and C.

Cleaning and Washing

- Remove any stems and leaves still present on the peaches.
- Peaches should be gently wet brushed to remove the any visible dirt or residue by hand.
- Don't use a vegetable scrub brush to wash peaches. The delicate fruit can bruise, or skin can peel off because of the abrasiveness of the brush.
- Because many of the nutrients in peaches and other stone fruits are in the skin, consuming the fruit with the peel adds to its nutritional value.

Pre-cooling

Pre-cooling peaches has been found effective in increasing the keeping quality. Vacuum cooling and hydro cooling have been found suitable for peaches. Rapid cooling reduces metabolic activity at lower temperature. Hydro cooled fruits develop more yellow ground colour than uncooled fruits.

Cold storage

- Peaches are stored under cold conditions at temperature between -0.6°C to 0°C and 90 % RH.
- Even under the most favourable conditions, freestone peaches cannot usually be stored longer than two to three weeks.

Controlled Atmosphere Storage

- The storage life of peaches by storing them in controlled atmosphere has been extended in recent years, because facilities of CA storage are more common.

- In Controlled atmosphere storage containing 5 % CO_2 +1-2 % O_2 at 0°C, peaches can be stored up to 42 days. Peaches and nectarines ripened after 6 and 9 weeks, CA storage showed better internal appearance, flavor, and less decay than stored in air.
- At some pack houses peaches are diffused by machine at the time of grading and before they are packed, defuzzed peaches are susceptible to brown rot than those which have not been treated, since the process involves removal of the protective hairs and Sulphur residue.
- The major benefits of CA during storage/ shipment are retention of fruit firmness and ground color. Decay incidence has not been reduced by using CA 1-2% O_2 + 3-5 % CO_2. CA conditions of 6% O_2 + 17% CO_2 are suggested for reduction of internal breakdown during shipments, but the efficacy is related to cultivar, pre harvest factors, market life and shipping time period.

Packaging

- Each box of peaches is lined inside with old newspaper sheets, keeping in margin for overlapping flaps. Fruits are initially padded with wood wool/ pine needles at the bottom.
- Fruits are arranged in each layer and top layer is covered with paper by bringing together overhanging flaps. Top is nailed. Box is further reinforced externally with a strap. Extra padding may be given for tight packing, generally wooden boxes or fiber boxes are used for peaches.
- Fruits are packed in cardboard boxes of 10-12 kg capacity with rice straw as padding material.
- The produce after harvesting to be packed in wooden containers and transported to the urban areas for sale. Wooden boxes prevent damage of ripened fruits and fetch better price in urban areas.
- The fruits packed in polyethylene line CFB cartons have better shelf life and marketability with higher organoleptic values.
- Protection against abrasion damage involves procedures to reduce vibrations during transport and handling by immobilizing the fruit. These procedures include: mould tray packing to avoiding abrasion on the packing line, and using packing procedures that immobilize the fruit within the container before they are transported to market.

Transport

- Use crates for packaging and transport for better ventilation and palletization which will also prevent shaking and bruising
- Transport during cooler part of the day as heated peach will lose their quality and dehydrate more quickly
- Careful handling, prevention of mechanical damage, and rapid cooling minimize secondary infection

Post-harvest management of Pear

Maturity indices

- Maturity is calculated on days after full bloom.
- In pears, fruit firmness is probably the most reliable indicator of maturity. Fruit to be sold immediately or held only for a short period of time can be harvested at a much softer stage than fruit to be held longer in storage.
- Fruit finish and fruit colour are also reliable indicator of maturity
- Maturity is at fully ripe yellowish stage as immature fruits are prone to shrivel and will also not develop full colour and will be hard making it unfit for consumption.

Harvesting Methodology

- Gently pick the fruit upward, give a little twist and thumb press the pedicel at the point of attachment with the spur.
- Spurs should not be injured during fruit harvesting. A spur can bear fruit for 10-15 years. The broken spurs do not bear fruit for 3-4 years.
- Fruit pedicels also should not break from the centre. Either there should be full stalk or there should be no stalk with the fruit. Harvesting should be done with the help of ladders. Trees

should not be shaken for fruit harvesting.

Care to be taken during harvesting

- Pickers must be careful not to drop fruit either when placing it in picking baskets, bags or transferring it to field containers.
- Fruit should be treated as gently as possible at every stage of harvest process. When emptying harvesting bags into crates or big baskets care should be taken to ensure that the fruits are not dumped from height.
- After harvesting fruit should be taken to a cooling facility as quickly as possible.

Sorting and grading at farm

- Sorting is done at the farm level under the shade of the tree and small portable tent.
- All disease and damaged fruits are separated
- Fruits are graded into two different categories A and B and are sold to wholesale in graded form only.
- Sorting should be carried out to eliminate fruit with visual defects, cuts and wounded areas.
- Pears need to be sorted, where a range of fruit colours, sizes and shapes can be encountered. Sizing segregates fruit by either weight or dimension.
- The remaining fruits should be graded into various classes as per the shape, size and colour of the fruits.

Cleaning and Washing

- Remove any stems and leaves still present on the pear.
- Washing with chlorinated water is recommended followed by surface drying.
- Pear should be gently wet-brushed to remove the any visible dirt or residue by hand.

Pre-cooling

Forced-air cooling is the most common method of rapid cooling for pears, especially in areas of large production. This can cool pears five to eight times faster than traditional room cooling. Hydro-cooling is another effective and rapid method of cooling, but it may increase postharvest decay by spreading pathogens.

Exposure of pears to unfavourable atmospheric compositions can induce physiological disorders and failure to ripen upon removal from CA conditions. CA-stressed pears exhibit flesh browning, develop cavities in damaged tissues, and undergo ethanolic fermentation, which results in accumulation of acetaldehyde, ethanol, and ethyl acetate, and development of off-flavours.

Cold Storage

Pear is stored at 1^{o}C. Depending on temperatures during harvest, it can often take 48-72 hours to bring the temperature down to approximately -1 to 0°C and 90-95% RH.

Controlled Atmosphere Storage

Optimum CA 1 to 3% O_2 + 0 to 3% CO_2; for California-grown 'Bartlett' pears, 1.5 to 2% O_2 + 1 to 5% CO_2 are recommended for long-term storage of early- and mid- season harvested fruits. For late-season pears, CO_2 should be kept below 1% because of the fruit's greater sensitivity to CO_2 injury (core and flesh browning).

CA conditions slow the rates of respiration, ethylene production, color change from green to yellow, and softening of pears. Scald development and decay incidence are suppressed under CA. Storage potential of 'Bartlett' pears at -1 to 0°C and 90-95% RH can be as long as 3 months in air and 6 months in CA.

Packaging

- Each box of pear should be lined with cushioning material keeping in margin for overlapping flaps. Fruits are initially padded with wood wool/ pine needles at the bottom.
- The problem can be minimized by immobilizing the pears (such as tight-fill packing) or by packaging them into plastic bags within the shipping containers during transport.
- Protection against abrasion damage involves procedures to reduce vibrations during

transport and handling by immobilizing the fruit. These procedures include: mould tray packing to avoiding abrasion on the packing line, and using packing procedures that immobilize the fruit within the container before they are transported to market.

- Packaging should be such to avoid vibration and impact damage
- Moulded trays can also be used to immobilize the pears and prevent brushing against each other.

Transport and Marketing

- Use moulded trays with for packaging and transport for better ventilation and palletization which will also prevent shaking and bruising
- Transport during cooler part of the day as heated Pear will lose their quality and dehydrate more quickly
- Careful handling, prevention of mechanical damage, and rapid cooling minimize secondary infection

Post-harvest management of Sapota

Maturity indices

Fruits shed brown scaly external material and become smooth when reaching physiological maturity.

Fruit ready for harvest do not show green tissue or latex when scratched with a fingernail.

Fully mature fruit have brown skin and separate easily from the stem without leaking latex.

Extent of scruffiness is also a good indicator of maturity. A fruit with a smooth surface, shining potato color, and rounded stylar end is considered mature

Harvesting Methodology

- The harvesting tool is a contraption in which hook is tied at the top of a long pole.
- Produce is harvested by farmers' family and hired labor in early morning and afternoon.

It is recommended to use net harvestor to avoid any mechanical damage to the fruits

Care to be taken during harvesting

- When picking tools are used to cut the panicles, a net bag should be attached to the pole so the fruits do not fall on the ground.
- To avoid breaking of fruits skin, the fruit should not be pulled from the bunch.
- The ideal time for harvesting the fruit is when temperature and humidity are moderate which gives longer shelf life to the fruit.

Sorting and grading at farm

- Sorting is done at the farm level under the shade of the tree and small portable tent.
- All disease and damaged fruits are separated
- Fruits are graded into three different categories

Fig. 3 : Harvesting of Sapota by contraption

Fig. 4: Harvesting support by net bags

depending on their size viz. large, medium and small.

Pre-cooling

Forced air cooling to 8°C is the recommended method of cooling for Sapota.

Cold storage

Postharvest life is 2 to 3 weeks at 14 °C with 85 to 90% RH. Exposure of fruit to gamma irradiation at 0.1 kGy extended storage life by 3 to 5 days at 27 °C and 15 days at 10 °C without any effect on ascorbate content.

CA storage

Storage life at room temperature increased from 13 days to 18 days in 5% CO2, 21 days in 10% CO2, and 29 days in 20% CO2. However, fruit held in 20% CO2 failed to ripen, and this level of CO2 is deleterious.

Packaging

- Fruits are packed in cardboard boxes of 8-10kg capacity with rice straw as padding material and ethylene absorbents.
- The fruits packed in polyethylene line CFB cartons have better shelf life and marketability with higher organoleptic values.

Transport and marketing

- Use crates for packaging and transport for better ventilation and palletization which will also prevent shaking and bruising
- Transport during cooler part of the day as heated sapota will lose their quality and dehydrate more quickly
- Careful handling, prevention of mechanical damage, and rapid cooling minimize secondary infection

Ripening

Sapota being a climacteric fruit can be ripened artificially:

- Unripe fruits can be ripened by applying ethephon (1000 ppm.) at 20 – 25° C and can be stored at 2 – 3° C and 90 – 95 per cent RH for a period of six weeks.
- The ripening period of sapota depends upon the variety, stage of maturity and the prevailing temperature.
- The storage period of ripe sapota depends on the respiration, relative humidity, temperature, enzymes' activity and carbon dioxide content. The respiratory peak occurs at the same time or one to two days after peak ethylene production

Post-harvest management of Papaya

Maturity indices

- Papayas harvested 1/4 to full yellow have better acceptance than those harvested at mature - green to 1/4 yellow because they do not increase in sweetness after harvest.[3]
- Uniformity of size and color; firmness; freedom from defects such as sunburn, skin abrasions, pitting, insect injury and blotchy colouration; freedom from decay.

Harvesting Methodology

- Depending on the size and age of the tree, the fruits are harvested manually by hand picking.
- When harvesting fruits, the peduncle should be cut from the end closer to the tree.
- When fruits are inaccessible by hand due to tree height, a specialized pole mounted implement can be used for harvesting them. The harvested fruits drop gently into the mesh bag below the ring at the top of the pole causing minimum damage to them.
- A simple cup and pole device can be made using a household plunger in which handle has a long pole

Care to be taken during harvesting

- Fruits should never be thrown or dropped. After harvest fruits should be placed in a single layer into shallow plastic crates, preferably containing a foam layer for cushioning,
- Field crates containing the fruits should be protected from open sun and hot places till

they are transported to the packing facility.

Sorting and grading

- Sorting is done at the farm level under the shade of the tree and small portable tent.
- All disease and damaged fruits are separated
- Fruits are graded into two different categories
- Damaged/diseased papaya during transport is also removed while grading

Cleaning and Washing

- After the harvest fruits should be washed in water to remove latex and debris, and then treated in a 0.05 per cent thiabendazole solution for anthracnose control before packing.

Other treatment

- To reduce post-harvest fruit rot, papayas are commonly heat treated (43-48°C), then rinsed in cool water. Fungicides also may be used, generally in the wax applied during packing.
- Radiation treatments such as “Sure Beam” are used to sterilize fruit fly eggs and larva in fruit intended for export.
- Fruit should be packed into single-layer boxes, often with tissue or foam padding to avoid bruising. Fruits can be cured at 29°C and 100% humidity for better colour expression prior to transport.
- Standard decay control has been a 20-minute submersion in water at 49°C followed by a cool rinse.
- Dipping in 1,000 ppm of aureofungin has been shown to be effective in controlling postharvest rots. In Philippine trials, thiabendazole reduced fruit rot by 50%.
- Partly ripe papayas stored below 10°C will never fully ripen. This is the lowest temperature at which ripe papayas can be held without chilling injury.

Pre-cooling

Room cooling and forced air cooling are commonly used. Hydrocooling is possible. However, rapid cooling after insect disinfestation treatments can lead to skin scalding. The recommended pre-cooling temperature is 15°C.

Cold Storage

Papaya is stored at 12°C. Below 12°C, papaya experiences chilling injury. Papayas are extremely perishable; shelf life at room temperature ranges from 3 to 8 days, depending on storage atmosphere.

Controlled Atmosphere storage

- Optimum CA: 3-5% O_2 and 5-8% CO_2
- Benefits of CA include delayed ripening and firmness retention
- Postharvest life potential at 13°C: 2-4 weeks in air and 3-5 weeks in CA, depending on cultivar and ripeness stage at harvest
- Exposure to O_2 levels below 2% and CO_2 levels above 8% should be avoided because of the potential for development of off-flavours and uneven ripening

Packaging

Individual fruits should be wrapped in paper, honeycomb structure or other cushioning material to avoid mechanical damages during the transport. They should be packed in a single layer in a fibre board carton with adequate bursting strength. Shredded papers can be used as a cushioning material in the base of the carton. Individual labels can be attached to the fruit for appearance and recognition.

Transport and marketing

Correct atmosphere conditions are required during transport to minimize losses during transport of fruits both for domestic and international markets.

- Most markets require fruit at specific stages of ripeness for optimum sales that varies between 50 to 70 per cent yellow colour depending on the time of year. Thus, stages of ripening indicated by skin colour on departure from the field become important. It may vary from 20 to 50 per cent, ripeness is more crucial during the summer months due to the rapid rates of ripening during the transport.

- Fruits transported too green (less than 20% yellow colour) are likely to fail to ripen adequately when temperature at destination market is low.

Post-harvest management of Plum

Plum is important crop of sub-tropical and temperate region. Plum fruit is very perishable in nature, hence should be handled with care. Packaging also requires a lot of cushioning due to soft skin.

Harvesting and Postharvest Activities

Maturity Indices: In free-stone cultivars of plum, pit browning up to 5% of the pit area is a good index of maturity. The plum fruits are mature when it attained proper size and developed proper colour depending upon the cultivar. The plum fruits are harvested in the month of June-July in Himachal Pradesh. For sale in local markets fruits are harvested when ripe and firm. For distant markets, fruits are picked when firm but have developed 50% colour on the skin.

Harvesting: For local marketing fruits should be harvested when ripe and firm. For distant markets, fruits are picked when firm but have developed 50% colour on the skin. Plum should be harvested along with pedicels avoiding any injury to the fruit. Plums are harvested along with pedicels to avoid any injury to the fruit.

The small baskets should be padded with rice trash or grass at the bottom and sides. Freshly harvested fruits are transferred in these baskets and covered with paper and tied in gunny cloth. The fruits should be graded before packing in basket or wooden boxes. Several pickings are made as the entire fruit on a tree do not ripen at one time. Fruit is borne on spurs also so care should be taken to the save the spurs from breakage, during harvesting. Early morning or evening hours is the most suitable time for harvesting to avoid accumulation of field heat.

Sorting: Cracked, split, diseased and infested fruits are removed which is done manually by trained sorter.

Grading: Presently, manual grading is done by the farmers in orchard.

Plum Grades

S.No.	Grade	Characters
1	Special	4.2 cm and above (diameter)
2	Grade 1	3.6 to 4.2 cm (diameter)
3	Grade 2	Below 3.6 cm

Packaging: For distant markets wooden boxes are preferred over basket. To save fruits from injury each layer of fruit is covered with paper strips and newspaper sheet. Finally, the lid of the box is nailed.

Punnet packaging for retail giving care to the individual fruits will result in protecting the produce and for fetching higher price.

Summary and conclusion

Post-harvest management has the potential for saving a lot of produce from loss and decay and helping the produce reach the consumer is fresh and acceptable form. This will also help to achieve the goal for food and nutritional security. The technologies should focus on type of produce, distance from the market, focused consumer group and requirements of the market but basic procedures are similar for all the crops.

The aim of the post-harvest technology is that food produced must reach point of consumption; whole food is the preferred mode of nutrition; productivity is best measured at end-point or point of delivery; food delivery systems directly impact climate change; when all delivery options fail, non-marketable food can be retrieved and optimized upon through processing technologies.

It is apparent that post-harvest losses can be reduced through efficient cold chain system from the point of harvest to the point of consumption. Even if the country is able to reduce 50 % of the losses or wastage from the current levels, the

Fig. 5: Punnet packaging

farmer's income will be sustainably enhanced and many rural employment opportunities will be created.

With the opening of new avenues in FDI investment scenario will have positive impact and can help boost country's economy facilitating faster movement of produce from production to consumption center and create employment opportunities in produce management of horticulture sector, pack houses, transportation and marketing along with ancillary industries.

The way forward for the development of sector includes:

- Training module for farmers with facilities for harvesting, collecting, safeguarding the produce from the sun and transport to the pack house.
- Centralized pack-houses in all the states with basic facilities of washing, sorting, grading, waxing, pre-cooling, storage and packaging with modifications for different categories of fruits and vegetables depending on the catchment area and training modules for pack-house operators.
- End to end maintenance of the supply chain to reach out to markets in different cities for better price realizations.
- Ripening facilities for climacteric fruits at market area.

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Innovations in Pest Management System for Resilient and Sustainable Development in Horticulture

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Abstract

Horticulture sector is recognised to have the potential to raise the farm income, provide livelihood security and earn foreign exchange. Horticultural crops viz., fruits, vegetables, ornamental plants, spices, medicinal & aromatic and plantation crops, have vast scope of value addition which provides additional employment to farm family. It is the back bone of Indian agriculture which contributes about 30% of agricultural gross domestic product (GDP). The fruits and vegetables, which are extremely nutritious horticultural produce with tremendous human health benefits, are attacked by various insect, pests and diseases resulting in standing crop and post-harvest losses as well as highly perishable and are readily prone to spoilage during storage, resulting in a decrease in quality attributes and induced food loss. Significant amounts of fruits and vegetables produced globally go to waste owing to improper management of insect & pests and diseases, improper handling, transportation, post-harvest operations and lack of processing, etc. Such losses could be ameliorated by adopting effective management strategies, enhanced post-harvest research, development, management and processing of horticultural produce. Creating and adopting innovative approaches and policies, for reducing global fruit and vegetable losses, that are accessible to small-scale farmers in developing countries could substantially prevent such amount of losses. The reduction of losses can help to achieve sustainability in balancing economic, social and environmental dimensions. Intensive focus must be put on to the development of advanced technologies to boost up global food security by enriching the world's agricultural economy with minimal losses of consumable fruits and vegetables. Some of the new initiatives like focus on planting material production, cluster development programme, credit push, formation and promotion of farmer producer organisations (FPOs) are the right steps in this direction. The new technologies in recent years such as drone camera, remote sensing, aerial Ultra-low volume (ULV) applicators, drone sprayers and aerial unmanned vehicles used in present scenario has been adjusting the ways that farmers treat crops and manage fields. Whereas, advance technologies like nanotechnology, ecological engineering and push pull strategy are cost effective, smart and sustainable. These are thus the necessary steps towards the development of safe, economical and sustainable methods of pest management in horticultural crops, as well as food security, for the future.

Key words: Horticulture, GDP, Insect & Pests, Post-harvest Technologies, FPOs

Introduction

Horticulture, which includes the production of fruits, vegetables, flowers, spices, medicinal and aromatic plants and plantation crops has emerged as a major economic. Fruits and vegetables are very important food commodities not only in developing country but also in all over the world (**Verma, 2018**). In declaring 2021 as the International Year of Fruits and Vegetables, the aim of United Nations (UN) General Assembly was to raise awareness of the nutritional and health benefits of fruit and vegetables and their contribution to a balanced and healthy diet and lifestyle as well as to direct policy attention to

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reducing loss and waste of these highly perishable produce items. India, being a home of wide variety of fruits and vegetables, holds a unique position in production among other countries. The diverse agro climatic conditions in the country make it possible to grow almost all varieties of fruits and vegetables. Recent economic growth and changes in dietary pattern have made both the production and consumption of fruit and vegetables increasingly important **(Jat, 2010).** India is the second largest producer of fruits (98.57 million tonnes) and cultivating in an area of 6.64 million hectares and also produces 185.88 million tons of vegetables annually from an area of 10.09 million hectares. It has become the backbone of many states in the country supporting about 12-15 lakh families and providing employment to the tune of about 50-60 lakh people annually **(Verma, 2018; NHB, 2019).** The area under horticulture crops increased to 25.5 million hectare in 2018-19 as per report of NHB (2020), which is 20% of the total area under food grain, and produced 314 million tonnes. As per the 1st Advance Estimates for 2020-21 the total horticulture production in the country is 326.58 lakh MT from an area of 27.17 lakh ha (**Ministry of Agriculture & Farmers Welfare, 2021**).

According to the FAO (2017), the productivity scenario in India is very low among temperate fruits including apple (7.42 t/ha), pear (7.86 t/ha), peach (7.13 t/ha), plum (8.40 t/ha), apricot (2.80 t/ha), almond (0.58 t/ha) and walnut (1.01 t/ha). However, it is more than double in many advanced countries like USA (apple 39.58 t/ha, pear 36.10 t/ha, peach 17.10 t/ha, plum 16.60 t/ha, apricot 9.92 t/ha, almond 2.54 t/ha and walnut 4.20 t/ha) and China (apple 18.64 t/ ha, pear 17.2 t/ha, peach 18.2 t/ha, almond 3.33 t/ha and walnut 3.90 t/ha). The cause of low productivity is mainly associated with biotic and abiotic stress. Since the green revolution (of the 1960s), farmers have shifted from traditional agricultural practices and adapted the modern techniques which comprise the application of a variety of chemical fertilizers and pesticides, maximum ploughing, mono-cropping, etc. These practices pose significant adverse impacts on the agroecosystems **(Taiwo, 2019).** Crop protection has relied heavily on synthetic chemical pesticides, but their availability is now declining as a result of new legislation and the evolution of resistance in pest populations. India incurs post-harvest fruits and vegetable losses worth over Rs 2 lakh crore each year largely owing to the absence of food processing units, modern cold storage facilities and a callous attitude towards tackling the grave issue of post-harvest losses. Among the states, post-harvest losses are maximum in West Bengal worth over Rs 13,657 crore followed by Gujarat (Rs 11,400 crore), Bihar (Rs 10,700 crore) and (Rs 10,300 crore) in Uttar Pradesh **(Economics Time, 2013).** The new technologies in recent years, specifically drone camera, remote sensing, machine vision, aerial ULV applicators, drone sprayers and aerial unmanned vehicles and robotics will increasingly appear in sustainable agricultural systems. The use of small UAVs retrofitted with spraying systems allows precision aerial applications on small targets. These precision applications can result insignificant cost savings and reductions in risk to operators during treatments.

Attempts to reduce the use of synthetic pesticides, especially broad-spectrum insecticides in plant protection and to use alternatives and novel methods for pest control or (bio rational control) are the challenges of pest control for the twenty-first century. To further promote and for holistic growth of the horticulture sector in the country, the Ministry of Agriculture and Farmers Welfare has provided an enhanced allocation of Rs. 2250 Crore for the year 2021-22 for 'Mission for Integrated Development of Horticulture' (MIDH), a centrally sponsored scheme **(Ministry of Agriculture & Farmers Welfare, 2021).**

Contribution of Innovative Technologies to Horticlture

Sensor Development

More sensors become available to support production management and improve quality. Computer vision will influence Greenhouse Horticulture. Progress in computer vision is made to measure internal and external parameters of plants (Pekkeriet *et al.,* 2015).

Computer Vision of 2D and 3D Geometric Features

To measure geometric features and colour aspects, computer vision in horticulture is used to classify plants, to measure growth, to control machinery, to detect pests and diseases and to track plants (e.g., barcode readers). The use of cameras is ubiquitous. With your smartphone running on IOS or Android the number of apps is increasing, also in agriculture. Even in horticulture, one can use the smartphone and download apps that can register the location of a pest or disease **(Röhrig, 2012)** and it is a matter of time that you can determine the pest or disease based on computer vision software with your smartphone.

Computer Vision Internal Features

X-Ray

With computer vision it is possible to measure internal features, using X-ray or microwave techniques, hyperspectral imaging and fluorescence techniques. Using Y-ray in sorting machines becomes common practice for grading flower bulbs, tulip flowers and Alstroemeria. However, successful research is done using above techniques to detect long-horned beetles (*Anoplophora chinensis*) in small imported trees (Jansen *et al.,* 2012).

Hyper Spectral Imaging

In addition to the visible area, there are also ways to look at flowers and plants with cameras using a wider spectrum of light. This makes it possible to look inside the plant. Besides the black and white or RGB cameras (red green blue), there are the multispectral cameras, containing sensors that are sensitive to wave lengths inside and outside the visible spectrum. This creates even more applications that also provide information about an object's internal properties. A multi-spectral camera can contain 4 to 300 spectral bands from far-infrared to far-UV.

Fluorescence Techniques

In chlorophyll fluorescence, a red laser beam is directed towards the object. Chlorophyll strongly reacts under red light. A camera records the fluorescent image. Recording one image with a red laser and one without, then subtracting these images from each other using software, produces an image of a product's photosynthetic activity. The sensor detects photosynthetic capacity of plants, ripeness, shelf life and quality of fruits, vegetables and flowers and the sensor can detect stress and diseases of plants too. The technique develops from using laser beams to high power LEDs **(Jalink, 2009),** which makes the measurement much more robust, cheaper and faster.

Innovations in Pest Management

Traditional strategies like crop rotation, healthy crop variety, manipulations in sowing dates, integrated pest management (IPM), etc. have been commonly used by farmers for the management of insect pests in horticulture. Among these, integrated pest management is the most popular approach. Integrated Pest Management (IPM) is increasingly perceived as a workable solution to these problems. IPM, is defined as a system based on three main principles: (i) the use and integration of measures that discourage the development of populations of harmful organisms (prevention); (ii) the careful consideration of all available plant protection methods; and (iii) their use to levels that are economically and ecologically justified. Since the introduction of the concept in 1959, many studies have suggested that adoption of IPM principles provides environmental, economic and health benefits **(Stern *et al.,* 1959).**

Research has generated new technologies using naturally occurring enemies of insect pests (parasitoids, predators and pathogens) for use in IPM. Some important commercially available products include *Trichogramma*, *Crysoperlacarnea*, *Crytaemus montrouzieri*, *Bacillus thuringiensis*, *Bacillus sphaericus* and Nuclear polyhedrosis viruses (NPV). In addition, a number of plant products such as azadirachtin (neem), pyrethrum, nicotine, etc. are also valuable as biopesticides. In India, more than 160 natural enemies have been studied for their utilization against insect pests **(Kohli, 1997)**. Technologies have been standardized for multiplication of 26 egg parasitoids, 39 larval/nymphal parasitoids, 26 predators and 7 species of weed **(Birthal and Sharma, 2004).** The modern concept of pest management is based on ecological principles and integration of different control tactics into a pest management system. Considering the fact that pesticides are important to control pests, it is essential to assess their ecotoxicity especially on soil health and non-targeted flora and fauna, which is largely unknown.Throughout modern history, various methods to combat insect pests have been contrived; however, inorganic, botanical and natural pesticides mostly exploited during the nineteenth century.

In the twentieth century, significant progress in the synthesis of new chemicals has resulted in a discovery of structures and biological activities of various compounds.Since the 1990s, an implementation of Integrated Pest Management (IPM) principles resulted in two advances; one is the development of novel insecticides with selective properties acting on biochemical sites or physiological processes present in specific insect groups but differ from other organisms in their properties **(Casida and Quistad, 1998)**. This process has led to the formation of compounds, which affect the hormonal regulation of molting and developmental processes such as the insect growth regulators (IGR) and the neonicotinoids. The second advance is the exploitation of other non-chemical methods such as biological and cultural controls, use of pheromones and biopesticides and the substantial advancement in transgenic crops **(Horowitz and Ishaaya, 2012).**

Monitoring of insects and diseases is necessary over an area to create IPM program. If we assess target pests at the right time with the right product so it can save our money, also makes our pest control program more effective, and helps in preserving natural enemies in an area.

Pre-requisites for pest surveillance

Scientifically-based sampling methodology includes selection of spots/plants in a field and pests to be observed (incidence or the damage) need finalization. There is need to be continuous co-ordination among the stakeholders right from programme formulation to field level implementation in terms of knowing the pests status, recommendation of pest management advisories and their dissemination to farmers.

Precision pest management is twofold: first, reflectance-based crop monitoring (using ground-based, airborne, or orbital remote sensing technologies) can be used to identify pest hotspots. Second, precision control systems, such as distributors of natural enemies and pesticide spray rigs, can provide localized solutions. Both technologies can be mounted on equipment moving through fields (such as irrigation equipment), on manned or unmanned vehicles driving around in fields, or on aerial drones.

Aerial Drones

Drones used for detection of pest hotspots are referred to as sensing drones, while drones used for precision distribution of solutions are referred to as actuation drones. Both types of drones could communicate to establish a closed-loop IPM solution. Importantly, use of drones in precision pest management could be cost-effective and reduce harm to the environment. Sensing drones could reduce the time required to scout for pests, while actuation drones could reduce the area where pesticide applications are necessary, and also reduces the costs of dispensing natural enemies. For pest management purpose, two major types of small drones are used: rotary wing and fixed wing.

Sensing Drones to Monitor Crop Health

Sensing drones present several advantages that make them attractive for use in precision agriculture. Sensing drones potentially allow for coverage of larger areas than ground-based, handheld devices. They can fly at lower altitudes than manned aircraft and orbital systems, increasing images spatial resolution and reducing the number of mixed pixels (pixels representing reflectance of both plant and soil). Also, they cost less to obtain and deploy than manned aircraft and satellites and do not have long revisiting times like satellites, allowing for higher monitoring frequencies **(Filho *et al*., 2020).**

Insect Monitoring Traps

These traps avoid the application of chemical as we monitor the insects and control it before caused economic damage. In the whole world, pesticide problem has been reduced by trap invention. Pest can develop resistance against chemical, which can be reduced by traps invention. Trap application performs much better in the sustainable agriculture practices, as it doesn't give any residual effects on the field because of absence of chemicals. Trapped insects can also be used for studying their interaction with environment and their further physiomorphic characters. Finally, these traps have been accepted to have significant importance in IPM which reduces the use of water which required for spray as well as number of spray to manage the pest population.

Types of Traps

Insect traps vary widely in shape, size, and construction. Some common types of traps are described below.

1. **Light traps:** Light traps are used with or without ultraviolet light (UV) that attracts certain insect pest in a certain time. Light sources may include fluorescent light, light emitting diode, etc. Light traps are widely used to monitor nocturnal insect's (insects which are active at night). Natural and artificial factors which may affect the working of light traps are such as night temperature, humidity and lamp type, etc.

2. **Malaise traps:** Malaise trap is a, tent-like structure used for trapping flying insects, especially for Hymenopterans and Dipterans. The trap is made of a material such as terylene netting and can be of various colours. Insects enter the tent wall and thus funnelled into a collecting vessel.

3. **Adhesive traps:** They are also called sticky traps as they capture the insect with the help of an adhesive substance. They may be simple flat panels or enclosed structures. Sticky traps are widely used in agricultural and indoor pest monitoring program. As insect can get shelter in loose bark, crevices, so shelter traps or other artificial cover traps are used. They are also present in various colours.

4. **Flying insect traps:** The following traps are used to catch flying insects: -

   i. **Flight interception traps:** It is also known as a barrier trap. It is a simple kind of barrier which is used between two points usually between trees. So the flying insects fly and fall in a container filled with preservator. They are used for capturing many small insects that are flying about and tend to fly downward.

   ii. **Pan or bowl trap:** They are also known as bee bowl, used in collecting flying insects such as, bees. Usually such insects are attracted to colours, so traps are found in variety of colours such as white, yellow, blue, or purple.

   iii. **Bucket trap:** Bucket traps and bottle traps, are inexpensive. The bucket is filled with soapy water or anti freezing agent to attract the insect pest. Mostly, moth traps are bucket-type traps. The sampling of wasp and beetle population is done by bottle traps.

5. Terrestrial Arthropod traps

i. **Pitfall traps:** For crawling and flightless arthropods such as carabid beetles and spiders, these types of traps are used. In this type bucket is buried into soil and its lid or outer mouth like section is touching air.

ii. **Soil emergence traps:** It consists of an inverted cone or funnel which is attached to a collecting jar on upper side. It is designed to capture insects with a subterranean pupal stage. Emergence traps have been used to monitor important disease-vectors such as, phlebotomine and sandflies.

iii. **Aquatic arthropod traps:** This trap consists of a mesh funnels or conical structures that lead the insects into jar or bottle which is attached with it. It is used to catch aquatic insects such as caddisflies, mosquitoes and odonatan, depending upon their stage. These traps are present in 2 types: free floating or submerged type.

iv. **Baiting for insects:** Ants and different beetles, like dung beetles, carrion beetles, bark beetles, moths, and other insects are attracted to various baits. These baits can be applied to the ground, on trees, ropes, or elsewhere where insect population is high or where we want trapping, and insects can be collected directly from these places. Several different types of baits that are commonly used are Brown sugar yeast bait, Carrion/dung bait, Turpentine, Beer/ molasses bait and Wine/fermenting fruit bait

v. **Lindgren funnel traps:** Such traps are series of black funnels hanging one on top of the other with the help of rope between two trees. A container with ethanol or ethanol/propylene glycol (or some other preservative) is placed on bottom side of funnel. They apparently mimic standing trees and wood boring beetles are attracted to them. The smell of the ethanol is also an attracting parameter for beetles **(Hafeez *et al.*, 2018).**

vi. **Pheromone traps:** Pheromones are natural compounds that are produced in insect body, and they use these chemicals for communication purposes such as food, mating, etc. We use such chemical to monitor their population over an area, such as methyl eugenol is used for fruit fly capturing. The most commonly used pheromones are sex pheromones and aggregation pheromones. The different traps reduce pest pressure on crop which ultimately reduces the pesticide application.

6. Camera equipped traps:

Considering the high image resolution achievable and the opportunity to exploit data transfer systems through wireless technology, it is possible to have remote control of insect captures, limiting field visits. The availability of real-time and on-line pest monitoring systems from a distant location opens the opportunity for measuring insect population dynamics constantly and simultaneously in a large number of traps with a limited human labor requirement. Typically, an automatic trap equipped with a camera involves two modules: the hardware and the software. The hardware is typically composed of the trap structure containing the bait and retaining the trapped insects, an electronic box including the camera, a data transmission modem, a battery, and eventually an external power supply, such as a solar panel. The software is composed of the online repository in which the capture data pictures are stored and accessed plus optional image analysis algorithms to automatically identify and count the captures. Trap design may vary according to the target pest to be monitored, as detailed in this section. Various papers describe prototypes of camera devices coupled with a sticky trap (sticky liners, where the insect is immobilized in the glue and dies), primarily for the monitoring of adult moths (**Suckling 2016**). This work similarly as traps used in pest managements.

Remote Sensing

Remote sensing is the detection of energy emitted or reflected by various objects, either in the form of acoustical energy or in the form of electromagnetic energy (including ultraviolet light, visible light, and infrared light). For crops, remote sensing equipment generally assesses the spectral range of visible light or photosynthetically active radiation (PAR- 400–700 nm) and near infrared light (NIR- 700–1400 nm), with most studies referring to the 400–1000 nm range. Particular stressors, such as arthropod infestations, induce physiological plant responses, causing changes in the plants' ability to perform photosynthesis, which leads to changes in leaf reflectance in parts of this spectral range. For aerial remote sensing, a drone can be equipped with an RGB (red green blue) sensor, a multispectral sensor with between 3 and 12 broad spectral bands, or a hyper spectral sensor with hundreds of narrow spectral bands. An RGB sensor is low-cost, but results in limited spectral information. A multispectral sensor results in more spectral information, but a hyper spectral sensor is generally much better at differentiating subtle differences in canopy reflectance than a multispectral sensor **(El-Ghany *et al*., 2020).** Through remote sensing record precise pest population data which helps in timely and precise application of pesticides. So, indirectly remote sensing helps in cutting down the water consumption in pesticides spraying.

Banker plant system

Banker plant systems have been developed for the biological control of various pest species in protected culture. In such systems, non-crop plants, i.e. banker plants, are placed in the greenhouse and harbour alternative food and beneficials. The banker plant system is an effective strategy for biological control in greenhouses, with many benefits over the conventional release of beneficials. Moreover, they facilitate the reproduction of beneficial (**Yano, 2019**). The banker plant is the plant component of the banker plant system; alternative food is the prey or host or other alternative food added to or produced by the banker plant, and beneficials are the predators, parasitoids or insect pathogens released on the banker plant (**Pratt and Croft, 2000**). Banker plant systems have been introduced in many countries for the biological control of various pest species in protected cultures (**Pratt and Croft, 2000**; **Frank, 2010**). The usefulness of banker plants as an alternative food source for the reproduction of beneficial. Banker plant systems promote the maintenance of a natural enemy population in a greenhouse, by allowing the rearing of natural enemies through provision of an alternative food source. Such systems also allow the early release of natural enemies on the crop from the banker plants, and reduce the expenses associated with purchasing chemicals. Banker plant systems possess numerous benefits compared to conventional release of beneficial (**Yano, 2019**). These banker plant reduces the pest pressure on plant which reduces pesticide application in crops.

Banker plants

Pest	Banker Plant	Food Source	Natural enemy
Aphid	Oat, Wheat	*Rhopalosiphon padi*	*Aphidius colemani*
Thrips	Castor bean	Pollen	*Iphesius degenerans*
Whitefly	Mullen	Plant sap	*Dicyphus hesperus*
Thrips	Ornamental peppers	Pollen	*Orius insidious*

Push Pull Strategy in Insect Pest Management

Push-pull strategy, which is novel approach of pest management by behavioural manipulation of pests and their natural enemies. First time, Australians coined the term push-pull, as a strategy, for insect-pest management. They used repellent and attractive stimuli, deployed in tandem, to manipulate the distribution of *Heliothis* species in cotton, thereby reducing reliance on insecticides, to which the insects were becoming resistant to insecticides **(Pyke *et al.,* 1987).** Push-pull strategy which uses a repellent intercrop and an attractive trap plants. Insect pests are repelled from the food crop and are simultaneously attracted to a trap crop where they are concentrated, facilitating their elimination **(Cook *et al.,* 2007).** In India, **Duraimurugan and Regupathy, 2005** assessed the effects of push-pull strategy with the conjunctive use of trap crops, restricted application of NSKE on cotton leaving trap crops and restricted application of NPV on trap crops was highly effective in reducing the incidence of *Helicoverpa armigera* and damage to fruiting bodies, boll, locule and inter locule basis over cotton sole crop. The use of drought tolerant repellent crop in push pulls strategy, which repel pest population from main crop and totally avoids pesticide application in crops.

Host plant resistance

Plant resistance to a herbivore results from the expression by the plant of resistance-related traits that interfere with one or more aspects of the herbivore's complex interaction with the plant. As an integrated pest management tactic, host-plant resistance entails the intentional use of resistant crop varieties, alone or in combination with other tactics, to reduce the impact of herbivores on crop yield or quality. The resistant and tolerant variety indirectly helps in water conservation by reducing the number of sprays for the management of pests.

Ecological engineering for pest management

Ecological engineering for pest management has recently emerged as a paradigm for considering pest management approaches that rely on the use of cultural techniques to effect habitat manipulation and to enhance biological control. The cultural practices are informed by ecological knowledge rather than on high technology approaches such as synthetic pesticides and genetically engineered crops **(Gurr *et al.*,2004).**

Above ground

- Raise the flowering plants / compatible cash crops along the orchard border by arranging shorter plants towards main crop and taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population
- Grow flowering plants on the internal bunds inside the orchard
- Not to uproot weed plants those are growing naturally like *Tridax procumbens*, *Ageratum* spp., *Alternanthera* spp. etc. which act as nectar source for natural enemies,
- Not to apply broad spectrum chemical pesticides, when the Prey: Defender ratio is favorable. The plant compensation ability should also be considered before applying chemical pesticides.

Below ground

- Keep soils covered year-round with living vegetation and/or crop residue.
- Add organic matter in the form of farm yard manure (FYM), vermicompost, crop residue

which enhance below ground biodiversity.

- Reduce tillage intensity so that hibernating natural enemies can be saved.
- Apply balanced dose of nutrients using biofertilizers.
- Apply mycorrhiza and plant growth promoting rhizobacteria (PGPR)
- Apply *Trichoderma* spp. and *Pseudomonas fluorescens* as seed/seedling/planting material, nursery treatment and soil application

The ecological engineering helps in conservation of natural enemies and beneficial micro-organisms which reduces carry over pest population to next season.

HIPV (Host Induced Plant Volatiles):

Plants respond to herbivory through different defensive mechanisms. The induction of volatile emission is one of the important and immediate responses of plants to herbivory. Herbivore-induced plant volatiles (HIPVs) are involved in plant communication with natural enemies of the insect herbivores, neighbouring plants, and different parts of the damaged plant. Release of a wide variety of HIPVs in response to herbivore damage and their role in plant-plant, plant-carnivore and intraplant communications represents a new facet of the complex interactions among different trophic levels. HIPVs are released from leaves, flowers and fruits into the atmosphere or into the soil from the roots in response to herbivore attack. Moreover, HIPVs act as feeding and/or oviposition deterrents to insect pests. HIPVs also mediate the interactions between the plants and the microorganisms **(Aartsma *et al.*, 2017).** Some HIPV reduces the pest pressure on plant by deterrent effect which ultimately reduces chemical pesticides consumption.

Innovative Approaches in the Application of Agricultural Chemicals

Chemigation is a term defined as the application of agricultural chemicals, including herbicides, insecticides, fungicides, and fertilizers through a centre pivot system (**Chalfant and Young, 1984**) (i.e., an overhead sprinkler line that rotates continuously around a pivot point at the centre of a field). Successful insectigation trials were reported with entomopathogenic nematodes for the control of spotted cucumber beetles (*Diabrotica undecimpunctata howardi* [Barber]) in 1986 (**Reed et al., 1986**), followed by the effective control of aphid (*Aphididae* spp.) populations by chemigating imidacloprid in vegetables in Arizona in the mid-1990's (**Kerns and Palumbo, 1995; Palumbo, 1997)**, and effective control of spotted cucumber beetles in melons in Virginia with drip-applied imadcloprid and thiamethoxam (**Kuhar *et al*, 2002**). Chlorantraniliprole was shown to be highly effective against the European corn borer in bell pepper when applied through a drip irrigation system (**Ghidiu *et al.*, 2009**). Further, chlorantraniliprole applied through a drip irrigation system significantly reduced armyworms (*Spodoptera* spp.) and fruitworms (*Helicoverpa* zea [Boddie]) in tomatoes in field tests in Virginia (**Kuhar et al., 2010**) and **Ghidiu *et al.*, (2009)** reported that chlorantraniliprole and thiamethoxam injected via a drip irrigation system significantly reduced damage to eggplant foliage caused by flea beetles (*Epitrix* spp.) and leaf miners (*Liriomyza* spp.).

New-chemistry insecticides are especially suited for application through a drip irrigation system because they are highly soluble, they are root systemic and essentially non-phytotoxic to most plants, they are highly effective against specific pests, and they are considered by the USEPA to be reduced-risk pesticides. **Felsot et al. (1998)** examined the distribution of imidacloprid in soil when applied through a drip irrigation system and concluded that it is a good candidate for insect control via drip irrigation systems.

Insecticides of different classes for application through a **drip irrigation system** in fruits and vegetables for the control of a wide variety of insect pests:

Sprinkler irrigation system

Sprinkler irrigation is a method of applying water in a manner similar to rain. It is suited for most row, field and tree crops. Water can be sprayed over or under the crop canopy.

Applying pesticides through centre-pivot irrigation systems

The application of fertilizers was first suggested

Common name	Brand name	Insecticide class
Azadirachtin	Aza-direct	Limonoid insect growth regulator (neem)
Chlorantraniliprole	Coragen	Anthranilic diamide
Clothianidin	Belay	Neonicotinoid
Dimethoate	Dimate	Organic phosphate
Diazinon	Diazinon	Organic phosphate
Dinotefuron	Venom	Neonicotinoid
Imidacloprid	Admire	PRO neonicotinoid
Malathion	Malathion 8, Aquamul	Organic phosphate
Rosemary+Peppermint	Ecotec	Botanical oils
Thiamethoxam	Platinum	Neonicoinoid
Thiamethoxam +Chlorantraniliprole	Durivo	Neonicotinoid

and pesticides were next to receive attention. M. Harrison of Colorado State University and others have studied the application of fungicides through center-pivot irrigation systems for control of such potato diseases as early blight. Disease control with sprinkler application of several potato fungicides was effective as with aerial applications. Among the advantages for center-pivot applications commonly proposed are reduced application costs, uniformity of application, timeliness of application, possible reduced operator hazard, possible reduced chemical requirements and improved canopy penetration **(Peairs and Pilcher, 1984)**.

Micro-sprinklers

Micro-sprinklers are emitters, commonly, known as sprinkler or spray heads. They operate by spreading water through air, usually, in predetermined patterns. The sprinkler heads can be mounted on a support stake of 25–30 cm height, connected to the supply pipe. Micro-sprinkler system requires less energy, and generally, operates at a pressure range of 1–3 kg/cm^2 and a discharge range of 40–75 lph. Micro-sprinklers are desirable because fewer sprinkler heads are required to cover a large area. Application of pesticide through micro sprinkler reduces time, labour and quantity of water as compared to conventional method of pesticide application.

Unmanned aerial vehicle

Commercial application of agrochemicals by using unmanned aerial vehicles (UAVs), often referred to as drones or remotely piloted aircraft (RPA), is rapidly growing in use in East Asia with significant commercial activities in vehicle and spray system development. The UAV application of pesticides at low spray volume and low flight altitude has become popular in rice, corn, and cotton, and is even gaining use in high-value crops such as apple and tea. Hence, UAV application technology, which allows higher operational efficiency combined with comparable pest control results, emerges as a new approach to supplement or displace the traditional ground and aerial spraying practices **(Mogili and Deepak, 2018).**

Application of Nanotechnology in Pest Management

The word "Nano" is developed from the Greek word meaning "dwarf" and in technical terms, the word "nano" means 10^{-9}, or one billionth of something. It may be described as agricultural productivity enhancement by development of slow-release formulation, with efficient dosage insecticides, biopesticides, hormones, and nanosensors for pest detection (**Gogate, 2016**). Nanopesticides are small engineered structures which provide pesticidal properties or formulation of active ingredient of pesticide in nanoform. The formulation of nanopesticides are nanoemulsion, nanosuspension, nanoencapsultion and nanoparticles. Nanoparticles possess distinct physical, biological and chemical properties associated with their atomic strength. These nano structures have shown slow degradation and controlled release of active ingredient for long time. Nanopesticide formulations increase the solubility of poorly soluble active ingredient and helps in releasing the active ingredient slowly (**Kah *et al.*, 2012**). Nanoencapsulation is a process through which a chemical or an insecticide is slowly but efficiently released to a particular system for efficient pest control. Nanoencapsulation with nanoparticles in the form of pesticide allows for proper absorption of the chemical into the plants (**Scrinis and Lyons, 2007**). A nanogel has been prepared from a pheromone, methyl eugenol (ME) using a low-molecular mass gelator. This was very stable at open ambient conditions and slowed down the evaporation of pheromone significantly and last for 30 days for control of *Bactrocera dorsallis* (**Bhagat *et al.*, 2013**). The long term release of pesticides through nano formulation of pesticides reduces the frequency of spray required for pest management.

Management of Fruit Pests by Pheromone Nanogels

Environment-friendly management of fruit flies involving pheromones is useful in reducing the undesirable pest populations responsible for decreasing the yield and the crop quality. A nanogel has been prepared from a pheromone, methyl eugenol (ME) using a low-molecular mass gelator. This has been found very stable at open ambient conditions and slowed down the evaporation of pheromone significantly. This enabled its easy handling and transportation without refrigeration, and reduction in the frequency of pheromone recharging in the orchard. Notably the involvement of the nano-gelled pheromone brought about an effective management of *Bactrocera dorsalis*, a prevalent harmful pest for a number of fruits including guava. Thus a simple, practical and low cost green chemical approach has a significant potential for crop protection, long lasting residual activity, excellent efficacy and favorable safety profiles. This makes the present invention well-suited for pest management in a variety of crops **(Bhagat *et al*., 2013)**

Conclusion

Implementing innovative ways and regulations for minimising global fruit and vegetable losses that are affordable to small-scale farmers in developing nations could significantly reduce such losses. Loss reduction can aid in achieving long-term sustainability by balancing economic, social, and environmental factors. The development of sophisticated technologies must be given top priority in order to improve global food security by enhancing the global agricultural economy while minimising losses of consumable fruits and vegetables. Although, several advanced technologies have been developed, the extent of their diffusion and rate of adoption among farming communities are very slow. Thus, there is a need to strengthen the means of technology transfer and improve the lab to land programme.

In summary, it can be concluded that innovation in India has huge applications across all the dimensions as discussed above not only to accelerate the growth of horticulture but also make it far more profitable and sustainable to the benefit of farmers and consumers. Increasing horticulture production has also enabled diversification in the consumer diet towards more protein, fiber, vitamins, and minerals.

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Effective Management of Insect Pests for Sustainable Development of Horticulture

A.K. CHAKRAVARTHY

Introduction

Large-scale crop monocultures facilitate the proliferation and increasing prevalence of diseases and pest insects. Several studies highlight the impacts of plant diversification upon pathogens, and the population dynamics of insects and beneficial organisms in horticultural ecosystems. Habitat manipulation techniques as intercropping relay cropping and crop rotation can significantly improve disease and pest management. This paper considers the concept of crop diversity, recent insights and mechanisms underlying crop diversity, and discusses its potential for improving sustainable horticultural practices. Recently, the phytobiomes resulting from increased crop diversity are increasingly recognized for their contribution to disease and pest management, understanding the interactions between pathogens or pests with their host phytobiome may lead to novel options for the prevention of pests like (I) a better understanding of the mechanisms of interactions between crop species and genotypes; (ii) ecological progress including a better understanding of the context-dependency of those interactions; and (iii) the role of micro topographic variations in horticultural systems for priming basal resistance to pests and pathogens by intercropped crops. India is a biodiversity- rich country embracing diversified cropping patterns and farming systems. Many of the tropical fruits, vegetables and flowering plants and their wild relatives are found in India. It is also the home for several medicinal and aromatic plants.

Crop diversity

Growing systems currently employed prefer the simplified environment covering large areas of cultivated land, and replace the indigenous plant diversity with other cultivated plants. This not only leads to the loss of cultivated plant resources but also reduces benefits provided by biodiversity agroecosystems. It is essential to recognize the mechanisms of diversification in horticultural systems that favour both disease and pest management and increased yield (Li *et al*. 2009; Yang *et al.* 2014; Ding *et al*. 2015). In parts of south India, cultivation of cotton, chillies, groundnut and onion has proved successful.

Increasing crop diversity through intercropping is a simple and effective practice that offers advantages in reducing disease and pest population densities and severity (Li *et al.* 2009; Ding *et al.* 2015). Intercropping and mixed cropping of different crops or varieties are traditional agricultural practices that have long been used for preventing disease and pest infestations across different regions (Yang *et al.* 2014). The plant components of the intercropping system are not sown at the same time, but the substantial part of their growth periods, play a key role in growth and the ecological environmental target of intercropping (Li *et al.* 2009). Several patterns of crop arrangements in intercropping - such as row intercrop or strip intercropping, mixed planting crops, and relay intercropping have been used for disease management. Refuge or border plants like castor, Adathoda, Glyceridia, Agave, Crotolaria, Tapioca, Zizyphus, etc. has proved useful in certain situations.

Crop rotation

Crop rotation, i.e., growing different crops in different seasons in the same field, is among the most effective ways to control soil-borne plant diseases (Cook and Veseth 1991). The rotation of

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different crops reduces the disease inoculum due to host absence, or other effects of the hosts, and organic residues that can affect the pathogens or antagonistic organisms (Hoitink and Boehm 1999). The inoculum of the pathogen is greatly reduced with the length of the non-host period during the growth of a specific crop (Garret and Cox 2006). The rotation design is important for managing the specific pathogens present (Krupinsky *et al.* 2002). Several researchers have suggested that the application of agro diversity through the growth of multiple crops can have beneficial effects on a given land (Li *et al.* 2009). The microbial communities in the plant and soil are also influenced by crop diversity and diverse crop residues, which further affects the pests, weeds and plant diseases (Hoitink and Boehm 1999; Garbeva *et al.* 2004). Early and late blight diseases wilt, root rot root grubs and cutworms can be avoided by crop rotation. Alternating legumes with non- legumes or solanaeceous with non- solanaceous crops has beneficial effects and helps farmers to sustain their income.

Intercropping

Growing two or more crop species at the same time in the same field is termed intercropping (Ofori and Stern 1987). Different types of intercropping include crops grown in alternating rows (row intercropping), crops grown in alternating strips (strip intercropping), relay intercropping and mixed intercropping. The main purpose of intercropping is to allow for more important biological and crop interactions. The advantages of intercropping include reducing weeds, using the available resources more efficiently, increasing yields, and most importantly, providing biological and economic stability (Brooker *et al.* 2015; Vandermeer 1989). This method has been adopted for more than 100 years in most of the tropical regions of the world (Vandermeer 1989), and to a lesser extent in temperate regions (Li *et al.* 2001). However, monoculture practices introduced in the last century reduced the use of the intercropping systems in temperate regions (Francis 1986) because of mechanization.

Crop cropping

A cover crop is defined as any living ground cover that is planted with or after the main crop, and usually killed before the next crop is planted (Hartwig and Ammon 2002). Introduced before 1945, it includes double cropping into one main crop to increase organic matter and reduce weeds, pests and soil erosion. Moreover, relay cropping, over seeding, and interseeding are also types of cover cropping (Hartwig and Ammon 2002). Vesicular-arbuscular mycorrhizae can also benefit from this type of cropping system, which helps to suppress weeds (Jordan *et al.* 2000). The use of these systems had been greatly reduced with the introduction of herbicides and synthetic fertilizers (Hartwig and Ammon 2002).

Cultivar mixtures

Cultivar mixtures are combinations of cultivars that are agronomical compatible but have no additional breeding for phenotypic uniformity. They are mainly implemented to reduce pathogen populations, and the cultivars' phenotypic variation can also suppress weeds and pests as well. Therefore, in choosing cultivars for the mixture, it is essential to select those which can reduce the pathogens on crops. Crop diversity has been widely adopted in many regions because the above-mentioned patterns of crop diversity can provide multiple services in sustainable horticultural systems.

Organic horticulture

With the development of organic horticulture in the developed countries, crop diversity has been re-evaluated in recent decades, because crop diversity practices can be both sustainable and profitable, and can support a wide range of food needs for different consumers. In organic horticultural practice, only a few (natural) fungicidal products are allowed, so other ways of reducing or suppressing both above- and below-ground pathogens are needed, and crop diversity can be a powerful strategy to fulfil this demand of organic production (Heaton 2001).

This ecological management system is responsible for promoting the soil biological activities, biodiversity, and biological cycles, and for providing human health benefits such as providing nutrition and reducing environmental pollution. This kind of organic horticulture practice can maintain, restore and help in enhancing ecological harmony; hence it is known as the most sustainable form of horticulture (Heaton 2001). The management strategies used recently for organic products are different from conventional methods. The main important difference is the limitation of the chemical fertilizers and pesticides used in the production system. Instead, cultural and biological approaches are used to protect crops from pests and diseases (Letourneau and van Bruggen 2006). A limited number of fungicides, natural products in the form of plant extracts, or biological control are allowed to be used in organic practices but the sustainability of organic fungicides is still doubtful (Van Zwieten *et al.* 2004).

To maintain and increase soil fertility in cases of chemical fertilizer reduction, leguminous crops are widely applied in crop rotations. In addition, soil can be nourished with organic residues in the form of animal manure and cover crops. The management of organic matter is an important practice for maintaining soil fertility and sustainability (Mäder *et al.* 2002).

The benefits of crop diversity

Crop diversity is the most traditional type of agricultural practice observed in many Asian countries and some tropical regions (Vandermeer 1990; Geno and Geno 2001). The mixed crops in the form of coconut-pineapple, maize-potato, maize-sweet potato, sorghum-pigeon pea, and beans-maize are examples of crop diversity. In modern agriculture, much attention is given to grasses and wheat clover, and using multiline of rice and wheat.

Advantages of sustainable horticulture

One main reason for adopting crop diversity is to produce products in a more sustainable and secure way compared to monoculture (Vandermeer 1990). In some regions in the world, this practice is related to its linkage with organic horticulture and it is used only occasionally (Vandermeer 1995). The increase in yield that can be achieved through mixed cropping also has combined effects on the yield observed per unit of land area. The other advantage of crop diversity includes pest reduction, suppression of diseases and weeds without applying chemical pesticide, and, most importantly, reducing the leaching of nutrients. The crop diversity practices have good impacts on the reduction of the airborne pests and pathogens, but only limited attention has been paid to soil borne pathogens (Li *et al.* 2009).

In crop diversity systems, more intensive and prolonged soil coverage can reduce soil erosion (De Bie 2005). This is the most important in erosion-sensitive soils. For example, the run-off coefficient directly increased the yield by 50% in Jordan (Sharaiha and Zaidat 2008) and resulted in the efficient use of water by mixed cropping systems. Reductions in pests have also been recorded with microclimatic changes within the canopy (Hooks and Johnson 2003; Bukovinsky 2004; Pitan and Otalunde 2006) or changes in the environment which can lead to higher parasitoid densities (Ayalew and Ogol 2006).

Disease and pest suppression by introducing crop diversity in intercropping systems is also widely noted, with a 73% disease reduction when compared with mono-cropping (Boudreau 2013). Various factors are responsible for disease suppression, such as a decrease in the availability of host plants, alteration of pathogen dispersal by microclimate changes, interference in the activities of vectors, and enhancement of the resistance of hosts leading to reduced establishment of the pathogens (Boudreau 2013). Furthermore, Letourneau *et al.* (2011) concluded that effects on herbivore suppression, enemy enhancement, and crop damage suppression were significantly stronger in diversified crops than in crops with fewer or no additional associated plant species.

Crop diversity and pest management

Many scientists work on crop diversity and pest control in China, and both extension and mechanistic studies have already made good progress. A prevention strategy was assessed, specifically the intercropping of potato with maize and adjusting planting time and spacing to avoid peak rainfall periods. Research results showed that early or late planting of potato, ensuring peak potato vigorous growth, avoided the period of peak rainfall, along with increasing light and air penetration (Li *et al.* 2009).

They clarified the effects of crop diversity on the management of major pests and diseases in southwest China, and their results showed pest and disease reductions of 16.7–88.3% by intercropping with crops belong to Gramineae and Leguminosae or Gramineae and Solanaceae, in both small- and large-scale experiments. Integrated utilization of a high heterogeneity of crops, along with optimizing the spatial and temporal layout of crops, can lead to the best crop protection results.

They also unravelled mechanisms of crop combinations, spatial and temporal layouts of crops for disease management, and the mechanisms underlying the effects of the intercropping system were analysed in detail. i) Changing the heterogeneity of crops can clarify the interaction between crop heterogeneity and the compatibility of parasites. The higher the heterogeneity of crops, and less compatibility between parasites and crops, the better effect of crop protection (Ding *et al.* 2015). The root effluvium such as benzoxazinoids (BXs), are well known secondary metabolites for defence in grasses, can suppress the pathogens in the soil. Volatiles of crops, such as cis-3- hexen-1-ol and E-2-hexenal, can attract natural enemies of harmful insects in the field. ii) Changing the spatial structures of communication can lead to altering the micro-climate in the field, improving the ventilation and light transmission, and reducing the humidity of crop canopies, which can suppress the parasites (Yang *et al.* 2014; Fang *et al.* 2016). iii) Changing the temporal layout of crops can improve the function of natural enemies, by altering the timing of crops flowering in the same field, and prolong the food chains in rice-fish co-cultural systems (Xie *et al.* 2011; Ren *et al.* 2014). Shifting to an earlier or later date of the sowing time for intercrops can also prevent the susceptible pathogen growing phase from coinciding with the rainfall.

Parameters and standards for crop diversity utilization were designed based on the abovementioned mechanisms. Practical techniques were established, which include a combination of mutually beneficial crops, stripe rotation, roots complementary to each other, ratios and patterns of intercropping, and shifting to an earlier or later date of the sowing time for the two crops to prevent the disease susceptible phase from meeting the rainfall. Such techniques are highly effective for the management of potato late blight, soft-rot of Konjac, northern leaf blight and southern leaf blight of maize, chocolate spot of broad bean, corn borers, leaf miners and aphids. These diseases and pests could be reduced by 33.7 to 62.1%, while pesticides can reduce them by 53.9 to 71.8%, compared with mono-cropping (Li *et al.* 2009). Both economic and ecological benefits can be achieved by using these intercropping techniques. These techniques are applicable on a large scale in many provinces in China, and are widely adopted in many Southeast Asian Countries.

CONCLUSION

The sustainable development goal provides a renewed impetus for focusing on using biodiversity for food and nutrition, and for linking it to the sustainability of future agricultural systems in China. To build a beautiful countryside in China, to reduce environmental pollution, to mitigate health risks and diversity loss caused by the over reliance on chemical pesticides, multi-functional agricultural biodiversity must be explored. It is especially necessary to understand the mechanisms of molecular interactions among the plant-plant-microbiome systems underpinning the increases in yield and quality, and improvements of disease and pest management, for sustainable agricultural development in future. We need to enhance fundamental research for the conservation and utilization of diversity in agricultural systems. Employing biodiversity for a sustainable agricultural product that produces diverse, nutritious foods will contribute to the conservation of these bio resources, and conserving the biodiversity in natural and agricultural systems will make them available for future global climate scenarios as well.

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Bio-intensive Management of Insect Pests in Horticulture Crops

H.S. SINGH AND GUNDAPPA BARADEVANAL

Making the food available to more than 1.35 billion Indian population under diminishing natural resources necessitates the use of high yielding varieties, balanced use of fertilizers, judicious use of quality pesticides along with farmers education to use modern farming techniques. The use of chemical fertilizers and pesticides has played a positive role in increasing agricultural productivity and in making India self-sufficient in food production but this has offered many problems. Around 2 million tons of pesticides (47.5%herbicides, 29.5% insecticides, 17.5% fungicides, and 5.5% others) are used annually across the globe. Around 64% of global agricultural land is at risk of pesticide pollution and about 1000,000 human beings are affected by acute poisoning by contact with pesticides (Mohamed *et al*., 2020). Production workers, formulators, sprayers, mixers, loaders, agricultural farm workers, birds, fish, beneficial insects, and non-target plants, consumers are affected by pesticides. They pollute the ecosystem such as groundwater, sea, air, soil, and non-target vegetation. According to an estimate, approximately 18% of our total crop produce is lost due to pests despite the use of pesticides.

Demand for green agri-produce is increasing

Agriculture sustainability (Pretty J., 1998), soil degradation, biodiversity (CSE, 1998), impact on human health and the environment as a whole are some of the concerns that are raised against the current chemical-based strategy. The search for alternatives with a focus on the long-term sustainability of agriculture has been enhanced in the last decade. In developed countries, the initiatives toward green agriculture have been prompted both by market attractiveness as well as state support activities. Usage of bio-fertilizer and bio-pesticides, organic farming (Bernhard Berger, 2001), Biodynamic farming (Planning Commission, 2001) low input agriculture (http://www.ileia.org/), permaculture (Allan Atkisson, 1991), sustainable agriculture (Pretty, J. 1998), integrated farming practices (integrated pest management and integrated nutrient management) are some of the practices that are being espoused by proponents both in developed and developing countries. All these practices have evolved as alternatives to chemical use in agriculture keeping in view the increasing demand for green agriculture products across the world (Gilk Paul, 2003). Meeting this growing demand for green agriculture products is a constraint as well as a window of opportunity not only for the agriculturists but also for producers, suppliers, and traders of agriculture inputs (fertilizer, pesticide, etc.) and outputs (www.etagriculture.com/).

Practice of bio- intensive pest management is a part of green agriculture

Bio-intensive pest management is a systems approach based on an understanding of pest ecology that ensures ecosystem services. Conceptual frameworks of BIPM-Bio intensive integrated pest management (Singh S.P., 1998) and BIOPM-Bio-intensification of Orchard for pest management (Singh and Srinivas, 2016) have been published in Indian literature. It begins with steps to accurately diagnose the nature and source of pest problems and then relies on a range of preventive tactics and biological controls to keep pest populations within

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acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks (Benbrook, 1996). Bio-intensive IPM emphasizes proactive measures to redesign the agricultural ecosystem to the disadvantage of insect pests and the advantage of its parasite and predator complex but at the same time, shares many of the same components as conventional IPM. The most recent bio-intensive integrated approaches for pest management utilize components such as cultural methods viz., crop rotation, summer ploughing, fallowing, intercropping, pruning, mulching, spacing, planting date, trap cropping, etc, and use of resistant cultivars; bio-agents viz., predators, parasitoids and bio-control agents, mycorrhizal fungi, botanicals including bio-fumigation, oil cakes, FYM, crop residues, green manuring, and other organic amendments, physical methods viz., hot water treatment of planting material, soil solarization and bio-rational chemicals like pheromones.

Key elements of bio-intensive pest management

With the awareness of environmental problems, exploitation of different cultural and mechanical practices has been advocated as a vital approach to curb pest populations. Altering the planting time, increasing the plant diversity, use of trap, barrier, and intercrops, crop sanitation, fertilizer as well as water management and crop rotation, etc., have been advocated. For example, planting marigold as a trap crop for managing fruit borer in tomato (Srinivasan and Krishnamoorthy 1993). To make the environment uncongenial for pests and also to enhance the activity of natural enemies, the new cultural practices may be evolved. Pests of sucking nature can be managed to a greater extent with the adoption of resistant varieties. For fruit fly management, growing of trap crop, setting pheromone traps, protein bait spray with permitted insecticide and good sanitation is required. The single line trellis system yields good results by the way of reducing borer incidence and downy mildew infestation in bitter gourd (Singh et al., 2007). The use of nylon net as a barrier for control of brinjal shoot and fruit borer along with shoot clipping could reduce the borer incidence.

Semiochemicals that control the communication of insects both inter-specific (allelochemicals) and intra-specific (pheromones) and can be used in pest management either alone for pest monitoring and decision-making, for mass trapping, or mating disruption, or in combination with insecticides, sterilants, or insect pathogens. Additionally, semiochemicals released by plants can repel insect pests from the crop ('push') and attract them into trap crops ('pull'). The potential use of semiochemicals for pest management on small-scale farms remains underexploited. Fruit flies in cucurbits and fruit crops are well managed by the use of pheromones. In rice, maize, cotton, and vegetables, the pheromone technology has been in practice, however, still, improvement is needed. There are numerous avenues for use of allelochemicals in IPM programs either directly against the insect pests or through the enhancement of natural enemies. Volatiles from herbivorous insects and their host plants may serve as reliable cues for bio-control agents in search of suitable hosts. (Hilker and Mcneil, 2008). The aphid parasitoid *Diaeretiella rapae*, prefers host insects feeding on *Brassicae* and is attracted by *Isothio cynataes* that are typical for these plants (Baer *et al*., 2004).

Botanical pesticides in general possess low mammalian toxicity and thus constitute least or no health hazards and environmental pollution. A number of compounds found in neem seeds, notably azadirachtin, have proven useful as insecticides. The use of neem and Pongamia cakes in pest management in brinjal, cucurbits, and okra are the new strategies devised. Neem seed kernel extract (NSKE) sprays are recommended on a variety of crops such as crucifers, tomato, and cucurbits against all pests, on tomato and cucurbits against serpentine leaf miner, and beans against stem fly. The use of neem seed cakes is well known for controlling nematodes. These also reduce soil-borne insects like termites, grubs, etc. The use of cakes for the management of many insect pests of brinjal, okra, cucurbits, etc. has been demonstrated at IIHR, Bangalore. Sprays of neem and Pongamia soaps were found to be highly effective in controlling insecticide-resistant DBM in cabbage. The studies conducted at IIHR have shown that soaps were also effective in reducing *Helicoverpa armigera* in tomato and to a limited extent shoot and fruit borer in brinjal (Krishnamoorty and Kumar, 2004). Various neem formulations, insecticides from *Pongamia, Vinca, Melia, Chrysanthemum, Parthenium, Annona,* etc. are a few of them have already shown in-depth promise in pest management. More research is being focused on the development of formulation, standardization, and commercial utilization of these botanicals in pest management.

The new approach to insect pest control is the use of substances that adversely affect insect growth and development. These substances are classified as insect hormone mimics or insect growth regulators (IGRs) owing to their effects on certain physiological regulatory processes essential for the normal development of insects or their progeny. IGRs may belong to this type of (selective) insecticides and can be grouped according to their mode of action, as chitin synthesis inhibitors (i.e. of cuticle formation) and substances that interfere with the action of insect hormones (i.e. JHs, ecdysteroids) are newest of all approaches to operational and commercial insect control. For example, diflubenzuron and its derivatives were effective against insect pests and mites infesting field crops and were relatively harmless to beneficial insect species. On the other hand, buprofezin, a chitin synthesis inhibitor, was used against homopteran pests including nymphs of brown planthoppers, *Nilaparvata lugens* (Stal.), leafhoppers, *Nephotettix cincticeps* (Uhler), whiteflies, *Bemisia tabaci* (Gennadius), and scale insects attacking fruit crops and certain species of Coleoptera and Acarina.

Natural control is highly emphasized in Bio-intensive pest management

It is well established that the lack of natural enemies is one of the main reasons for the build-up of large pest population densities (DeBach and Rosen, 1991). The reasons why natural enemies are not able to catch up with pest population densities are manifold. Bio-control theory predicts that such natural enemies may still be effective control agents, provided the ratio of the number of prey per natural enemy can be lowered (Berryman, 1999). This is usually attempted by conservation measures or augmentative mass releases of reared bio-control agents (Bellows and Fisher, 1999). Some researchers focus on modifying the environment to improve the chances of establishing parasites and predators. Lab cultured parasite predators include a few such *as Trichogramma, Apanteles, Micromus, Chilonis, Crysopids, Telemomus, Bracon, Coccinellids, Orius, Goniozus, Syrphid* and *Anthrocorid* whereas, under mango ecosystem, the naturally occurring natural enemies reported are many such as Mango hoppers (31), Mango mealybug (20), Mango shoot borer (3), Mango leaf webber (6), Rastrococcus (16), Aspidiotus (10), Fruit flies (8), Stone weevil (4) and *Chloropulvinaria polygonata* (10). Hence their conservation becomes more important than applied biocontrol. Due to excessive use of pesticides some of the entomophages have been reported to be endangered namely, *Trichogramma, Rogas aligarhensis, Campoletis chlorideae, Microplitis flaviventris, Bracon gelechiae, Geocoris ochropterus* and *Apanteles plutellae* (Yadav, 2006). Conservation of various natural enemies (NEs) like *Chrysoperla zastrowi Arabica, Trichogramma chilonis, T.Japonica, Cotesia plutelliae, Diadegma semioclausum,* Coccinellids, Syrphids, and anthocorid bugs at farmers' field has been found useful for sustainable agriculture. The research on biological control has generated promising microbial agents like *Bacillus thuringiensis* (Bt.), Nuclear Polyhedrosis Virus (NPV), Entomopathogenic fungi like *Beauveria bassiana, Metarhixium anisopliae,* and *Nomurea rileyi*.

Bio diversity below and above the ground finds priority

Bio intensified system is a more dynamic and ecologically informed approach to pest management that considers the orchard as part of the prevailing agro-ecosystem where flora and fauna are well understood and managed to minimize pest damage. Maintaining and increasing biological diversity in the orchard as a strategy. It is fact that agroecosystems with decreased biodiversity result in an unstable system that is prone to recurrent pest outbreaks (Altieri, 1994). Contrary to this, systems with high biodiversity are more stable where, a variety of organisms provide more checks and balances on each other, which helps prevent one species (i.e., pest species) from overtaking the orchard. There are many ways to manage and increase biodiversity in and around the orchard, both above ground and in the soil. The conservation and enhancement of biodiversity in orchard both above and below ground are part of the foundation of sustainable farming practices. Such measures also lead to improved biodiversity in other parts of the environment which are adjacent to but not directly part of the orchard. In addition to diversity other efforts to conserve and enhance natural enemies are equally important for bio intensification. The process includes:

- Developing healthy and biologically active soils (increasing below/ above ground diversity) includes ground vegetation enrichment and management, rational cultural operations and chemicals, soil organic matter, pH, nutrient balance, and soil moisture, and improving the underground population of microflora, earthworms, and insects.
- Habitat modification for beneficial organisms includes the use of uncultivated land for organism diversity, developing diversity inside the crop such as entomophage park, weed strips, hedgerows, and windbreak as refugia, intercrops, tree banding, and mulching
- Enhancement and conservation of insect biodiversity may be done by developing mass emergence devices for indigenous and laboratory-reared natural enemies and by reducing the direct mortality of natural enemies
- Inoculative/ supplementary/ inundative release of laboratory reared /mass cultured bio-agents.

Host plant resistance

Breeding and production of crop plants with heritable arthropod-resistant traits has been recognized for more than 100 years even though it is not available for all pests. Host plant resistance (HPR) Inhibit pest attack through toxic or repellent compounds or physical factors such as color or toughness. Moreover, it has the advantage of cumulative effect, specificity, eco-friendly, ease of adoption, compatibility with BIPM components, and eliminates or reduces the use of pesticides.

Plant-incorporated protectants (PIPs)

GM crops /Plants have foreign genes causing the plants to produce a pesticide inside their tissues. Genetic manipulation of seed varieties for pest resistance is an important constituent of the plant protection strategy. Examples are virus-resistant varieties producing the virus coat protein, which covers virus particles after infection preventing their replication. Genetically modified varieties of some crops, such as cotton and rapeseed-mustard, have been developed but these are surrounded by controversies regarding their long-term effect on the environment and human beings. All of the genetically engineered insect-resistant crop varieties produced so far use specific genes taken from *Bacillus thuringiensis*, a common soil bacterium, to produce proteins that are toxic to certain groups of insects that feed on them. Regarding insect pest control so far only Bt corn and Bt cotton varieties are being grown. Work in this sector is in progress and it is expected that some directives for field use of such crops in horticulture will come sooner or later.

Perennial orchards are most suited for bio- intensive pest management

Many fruit orchards are the permaculture with certain man-made interventions which can be appropriated for the suppression of insect pests. However, research and model on this aspect are lacking in the Indian context. The primary goal of the bio-intensified orchard is to provide options for the effective management of pests and beneficial organisms in an ecological context. This requires a different set of knowledge from conventional IPM, which in turn requires a shift in research focus and approach.

BIPM may be most useful in situations where potentially effective natural enemies have become ineffective due to biotic or abiotic factors and the pests cannot be satisfactorily (economically and/or environmentally) controlled by other methods. It may be most popular among organic growers and has potential, especially in orchards. This bio-intensive approach needs to build the knowledge/information infrastructure by making changes in research and education priorities to emphasize ecology-based pest management and redesign orchard management programs to promote bio-intensive IPM. If the technology is standardized and practiced in the orchard, there is the possibility that the natural enemies will get food (nectar/pollen/ insect stages) to survive and multiply in number during the shortage of food or under insecticide spray. Some of the natural enemies attracting plants such as lucerne, *Cassia occidentalis*, *Cassia tora,* Indian Senna, cotton, *Vicia angustifolia,* cowpea, maize, many flowering plants, and lantana have been advocated in the orchard ecosystem (Yadav, 2006). The natural enemies will move to the fruit plant when food is present and the plant is safe to settle. The orchard may attract and provide shelter and food for natural enemies in the areas where flood/drought is common or where orchard neighbouring fields are under intensive chemical farming. Thus, the adjoining field crops may be benefited from natural enemies' presence. There may be no need for the application of insecticides against pests like scales and mealybugs, mild foliage feeders, mango fruit borer, etc. The population of hoppers may go down naturally which further may be controlled by using bio-pesticides. A tall tree canopy that normally remains unsprayed for pest control will be taken care of by natural enemies. In addition to the above, the orchard will serve as a focal place for the dispersal of natural enemies in other adjoining orchards.

Elderly trees, located in many areas have a well-developed large canopy area with considerable height where the distribution pattern of different insect pests varies horizontally and vertically within the canopy area. It becomes too difficult to access the top of the canopy to spray with a conventional spray machine. Having power-operated tractor-mounted sprayers by every farmer is not possible. It remains a challenge to provide an efficient low-cost high capacity power sprayer to growers who normally do not spray the top of the canopy for any pest in tall trees. Natural enemies have no limitation to tree size, hence; can get easy access to even huge and tall canopy. There are pests (hard and soft scales, stationary mealy bugs, trunk borer, red-banded mango caterpillar, and psylla) that are not adequately or cost-effectively controlled by other means including pesticides. Conceptually, if human intervention is reduced in the ecosystem and natural enemies are nurtured/applied, the pest population will seldom exceed the threshold level contrary to seasonal /annual ecosystem where pest infestations are high and man intervention is inevitable.

Bio-intensive pest management is poorly appreciated and adopted by farmers

The proposed concept is not new as people have been advocating its relevance and importance across the world. However, in a country like India where pest control through pesticides in the orchard is still not a common practice, application of the said concept is difficult on a larger scale. The concept of organic farming /low input farming is coming up and to keep technology ready, it needs to be standardized for the orchards located in different agroecosystems across the country.

Research needs in bio-intensive pest management

The standardization process requires some research such as i) identification of entomophilic, flowering/ nectar /pollen-producing plants suitable to season and region and appropriate for intercrop, entomophage park, strips inside the orchard, hedge, and windbreak, ii) feasible size of entomophage park and seasonal rotation of plants round the year, iii) soil conditioning process suitable for underground biodiversity iv)identification of potentially effective natural enemies in the agro-ecosystem and study of high priority wild natural enemies to determine their habitat requirements and their limiting factors in the orchard, v) standardization of field cages for mass emergence of natural enemies from orchard infested materials, vi) standardization of structures/devices and methods for field rearing of laboratory-reared natural enemies, vii) natural enemies' establishment, density and their population, viii) pest densities, ix) cost on reduction/appreciation in pest management practices, x) soil fertility/microorganism load and organic matter build up in the orchard xi) crop yield and pest infestation.

The expected dividends

The benefits of implementing BIPM can include reduced chemical input costs, reduced environmental impacts, and more effective and sustainable pest management and such reductions will benefit the grower and in turn the society. Hence, bio-intensive IPM is considered the desirable path for achieving sustainability in agriculture. The challenge before applied entomologists is to develop, validate and disseminate the site-specific bio-intensive IPM technologies to the farmers.

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Remote Sensing Based Irrigation Intelligence with Manna Software

Manna Offers Irrigation Intelligence Solutions to Help Growers Decide when and how Much to Irrigate

SANGITA LADHA

Precision Farming to Smart Farming

Increasing population and abrupt weather fluctuations around the world has put huge pressure on agricultural food products for quality and sustainable food production. In 2050, our planet will need to provide food for an estimated 9 to 10 billion people. In order to produce anything like that figure, we're going to need a lot of water. Achieving food security in the future while using water resources in a sustainable manner is a major challenge for this and for next generations. The big question is: how can we increase water productivity so that we can grow per drop more crops.

Precision Farming is defined as managing variations in the field accurately for higher productivity with fewer resources thereby reducing input and production costs. By increasing water use efficiency, we can increase the amount of crops grown with the same amount of water and can provide food for a larger population. The advent of Micro Irrigation Systems has enabled precision in application of water and fertilizers at the right place and in a right way. Whereas **Smart Farming** is an emerging concept that refers to managing **farms** using modern Information and Communication Technologies to increase the quantity and quality of products while optimizing the resources. Today's growing challenges in agriculture, urges shift from ***precision farming*** to ***smart farming*** in order to maximize food production while reducing the resources invested.

MANNA IRRIGATION: The Concept of Intelligence Software

The challenge facing all humanity: maximizing food production while reducing the resources invested. **Manna** seeks to meet this challenge, by striving to develop a solution that contributes to efficient water usage in field of irrigation.

Irrigation Decision Support from Outer Space -MANNA IRRIGATION, a system in particular is recognized where irrigation is critical to crop development, and water availability is declining due to climate changes.

Manna Irrigation is a leading Israeli company and backed by **Rivulis Irrigation** which is one of world's leading *Micro Irrigation Company*. Manna Irrigation offers **Irrigation Intelligence Software** to Individual farmers using **Remote Sensing Techniques & Agronomy**. Manna offers irrigation intelligence solutions to help growers decide when and how much to irrigate.

Manna Irrigation with its **sensor-free, software-only** approach, leverages high-resolution, frequently updated **satellite data and hyper-local weather information** to deliver highly affordable and accessible **site-specific irrigation recommendations.**

Business Director, Rivulis Irrigation India Pvt Ltd.
Email: Sangita.Ladha@rivulis.com

In other words, it includes software only, without sensors or hardware in the field, and therefore is easily adopted by users. Its goal is to support the farmer's decisions: when and howmuch to irrigate, without the need for physical contact with the soil or the plant.

The system relies on **satellite imagery** analysis combined with precise **meteorological data** and **agronomy model.** Satellite images are received from three different satellite systems every day; Manna system analyzes the satellite data to determine the exact and current crop conditions vegetation vigor, water potential and more.

Weather data is based on a virtual- station, hyper-local weather service that provides historic, current and forecast conditionsat the farm level. The agronomy models are adapted to each crop (currently supporting about 50 crops) and geographic location. The system combines all these factors in parameters of the soil and irrigation system, and provides precise and dynamic irrigation recommendations (daily/ weekly).

The software enables individual farmer, receive recommendations through Web / Mobile includes:

(a) Daily/Weekly Irrigation Recommendation

(b) Real time Crop Monitoring Maps/Images

(c) Daily weatherForecast

Benefits of Software

By using, actionable information by Manna Intelligence Software, farmers are able to effectively manage **Irrigation Scheduling Decisions** with below benefits:

- Real time, daily reliable estimate of water requirement of the crop on helps in applying **accurate amount of water**
- Real time hyper-local weather data (on daily basis) including reference evapotranspiration helps grower/farmer in taking decision like **Irrigation scheduling and Irrigation planning**
- Daily satellite images helps farmer in analyzing different portions of his farm area for **crop uniformity** & take suitable decisions
- Sensor free & easy to use accurate solution helping farmers to access his farm from **anywhere and anytime** i.e. Real time & dynamic

Two major impacts of using such a tool and achieved in major crops of India is:

- Significant amount of water & electricity saved
- Increase in Yield & Water Use Efficiency

Manna's accessibility

Every grower in the world has direct access to personalized and affordable irrigation intelligence on the smart phone which they can use daily for optimized and confident irrigation decisions.

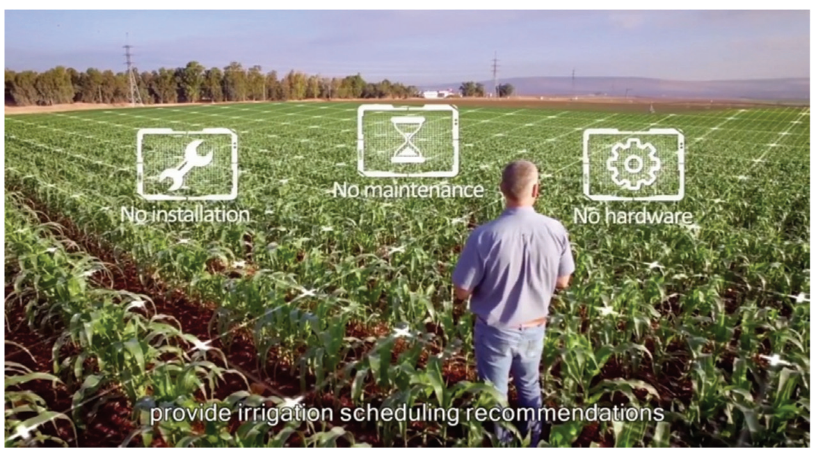
Way Forward

Agriculture production is experiencing a modern revolution and has involved the use of communication and information technology. Use of modern agricultural technologies is must. This can be a powerful tool for farmers for the efûcient use of resources and real-time management.

Manna software computes the amount of water lost to evapotranspiration that should be provided by irrigation systems with input on crop data and planting date information. Using remote sensing satellite data, soil moisture level at the root zone level is estimated, without deploying any physical sensors in the farm. The assimilation of high resolution weather data from meteorological station provides customized precise calculations on water application to every farm. Without any doubt, smart farming is helpful for farming community with real-time alerts thereby assisting the grower in farm management with precise use of agricultural resources for sustainable food production. Such an inexpensive, effective and innovative technology which has outreach anywhere in the country can enable growers *adapt to smart farming even with limited knowledge and skills.*

Manna software is way forward for transformation from Precision farming with Micro Irrigation to Smart and Digital farming.


manna
Irrigation Intelligence
WATER MANAGEMENT
ON FINGER TIPS
WHEN TO IRRIGATE &
HOW MUCH TO IRRIGATE
Measuring Crop Water Demand from Space
NDVI Normalized Difference
Vegetation Index
Measures Vegetation Density
More Vegetation =
More Water Demand
NDVI=0.6
Mid Water Demand
NDVI=0.4
Low Water Demand
NDVI=0.75
High Water Demand

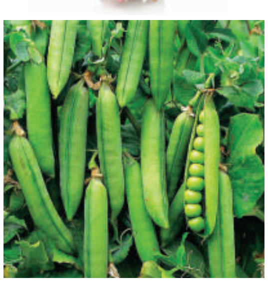

No installation
No maintenance
No hardware
provide irrigation scheduling recommendations


Multi-spectral
satellite data
Hyper-local
weather info
Irrigation
Protocols
Manna Irrigation
Decision Engine









NHRDF
Quality Seeds


NHRDF is a pioneer institute in the country for R&D on onion & garlic and developed many varieties. These varieties have export potential and high yielding. We are providing quality service to farming community of India since 1977.

NATIONAL HORTICULTURAL RESEARCH & DEVELOPMENT FOUNDATION (NHRDF)

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dhanuka
dhanuka
धानुका खेती की नई तकनीक
हर किसान की ख़ुशहाली के लिए
खेती बाड़ी में पूरे विश्व में
भारत दूसरे नंबर पर आता है...
ये लहलहाती सफलता मेरे किसान भाईयों
आपके ही पसीने से सिंची गई है।
लेकिन भारत दूसरे नंबर पर क्यों ?
पहले पर क्यों नहीं ?
धानुका के सेम्प्रा उपयोग से गन्ना और
मक्का की फसल से मोथा नष्ट करके
और उत्पादन में वृद्धि करके अपने देश
को पूरे विश्व में नंबर एक बना सकते हैं।
मुफ्त
1 बाल्टी,
100ग्रा. बूस्टन के 3
पैक (कुल 300ग्रा.) और
1 खरपतवारनाशक
नोज़ल
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अविष्कारक
निसान केमिकल इन्डस्ट्री, लि0, जापान
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