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Proceedings of National webinar on

Challenges and opportunities of vegetable production in warm humid tropics

10-13 November, 2020

Editor:
T. Pradeepkumar

Organised by:
Kerala Agricultural University
Indian Society of Vegetable Science

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Kerala Agricultural University, Thrissur

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Foreword

Warm humid tropics are regions lying along the east and west coast of India including Kerala. The humid tropics are resource-rich lands with adequate water supply, naturally fertile soils, plentiful sunshine and a favourable terrain, which favour the production of diverse varieties of vegetables, fruits and other crops. There are certain challenges in production like abundance of pest and diseases, high soil acidity, high humidity with high temperature, shrinking land resources etc, which need to be addressed in an ecologically sustainable manner. Annual precipitation exceeds or equals the potential return of moisture to the atmosphere through evaporation. Total annual rainfall usually ranges from 1,500 mm to 2,500 mm, but levels of 6,000 mm or more are not uncommon.

Vegetables crops, like other agricultural crops, are sensitive to climate variability. Vegetables are generally sensitive to environmental extremes and the increasing temperature, reduced irrigation water availability, flooding and salinity would be major limiting factors in sustaining and increasing vegetable productivity. Global climate change, especially erratic rainfall pattern and unpredictable high temperature spells reduce the productivity of vegetable crops. Currently, the world agriculture especially the vegetable production is passing through a difficult situation and faced with the challenge of food/nutritional security to meet the requirement for ever growing population.

This publication entitled "Proceedings of national webinar on challenges and opportunities of vegetable production in warm humid tropics' draws the attention of researchers and policy makers on the major recommendations from the webinar organised by the Kerala Agricultural University and Indian Society of Vegetable Science (ISVS) on 11 to 13th of November 2020. The webinar was inaugurated by Dr.R.Chandra Babu Hon. Vice Chancellor of Kerala Agricultural University in the presence of the distinguished chief guest Dr. Anand Kumar Singh, Deputy Director General (Horticulture) Professor (Dr.) K.V. Peter, President, ISVS and Dr. Pradeepkumar, Director (Planning) and Head , Department of Vegetable Science, KAU and Organizing Secretary. The panelists in the webinar included five Vice Chancellors of different agricultural universities and eminent scientists from national institutes (ICAR IARI, ICAR IIHR and ICAR IIVR) and private companies. The online event had more than 630 registered participants, which included PG students, Scientists, Professors, Progressive farmers and selected entrepreneurs from all over the country.

Webinar recommended the popularization of high yielding varieties and hybrids in combination with vegetable grafting technology for combating climate change. Root stock breeding, multiplication of rootstocks and mass production of grafted seedlings should be prioritized by development agencies rather than supplying seed packets to the farmers. Under Kerala conditions rain shelters with 50 mesh insect proof side net is more ideal than the polyhouses. Use of Aluminium strips was recommended to lower the temperature inside the rain shelter and provide adequate shade. An integrated nutrition supplemented with micro nutrients and balanced irrigation is recommended to realize the full potential of the varieties grown under protected structures. The selection of crops and specific varieties suitable for rain shelter and polyhouse is also crucial, as most of the varieties grown under open conditions will not be suitable under protected cultivation. The emphasis should be on development of production systems for improved water use efficiency adoptable to the hot and dry condition.

The webinar also discussed major diseases causing crop losses in crops like cucurbits, tomato, chilli, brinjal, okra and cassava and their management. Breeding varieties for resistance to viruses in these crops should be given emphasis by National Research Agencies and Private companies to reduce pesticide load and ensuring safe to eat vegetable production. The development of Bt brinjal and its significance were discussed. The webinar also recommended to relook at the moratorium against release of Bt Brinjal in India. The role of wild species should be explored as a source of resistance genes and the experts identified different wild species in okra, bitter gourd ,brinjal and tomato which could be used for breeding program against viruses, bacterial wilt and nematodes in the warm humid tropics. The potential of hybrids developed by Kerala Agricultural University- seedless watermelon and cucumber-to be popularized in the humid tropics was highlighted by experts.

The role of vegetables as protective food and scope of Ayurveda in boosting immunity were also highlighted by experts with particular reference to COVID pandemic. The centre of diversity of many of the wild species is in the warm humid tropics, hence the webinar recommended conservation and utilization of under exploited and wild species of vegetables. This webinar initiated preparation of a road map towards achieving self-sufficiency in vegetable production in the warm humid tropics.

Enhancing adaptation of tropical production systems to changing climatic conditions is a huge task. It requires the combined efforts of many national and international institutions and an effective and efficient strategy to deliver technologies that can mitigate the effects of climate change on the diverse crops and production systems. The scientific information and technologies developed through these initiatives must be readily accessible, consolidated and utilized in a strategic way. This can only be achieved through collaboration, complementarity, and coordinated objectives to address the consequences of climate change on the world's crop production. I wish to place on record my appreciation to the organizers, Kerala Agricultural University and Indian Society of Vegetable Science for taking lead in bringing out an online platform and later compiling the important information in a commendable way.

Prof. (Dr). Kirti Singh

03-07-2021

Preface

Kerala Agricultural University and Indian Society of Vegetable Science jointly organized a National level Web Conference on "Challenges and opportunities in vegetable production in the warm humid tropics" during 11, 12 and 13th of November, 2020. More than 500 participants, including PG students, scientists, professors, progressive farmers and selected entrepreneurs from different parts of the country attended the webinar.The panellists in the webinar included five Vice Chancellors of different agricultural universities and eminent scientists from national institutes (IARI New Delhi, IIHRBangaluru, IIVR Varanasi) and private companies. Warm humid tropics extended along the east and west coast of India are resource-rich lands which possess adequate water supply, naturally fertile soils, plentiful sunshine and a favorable terrain. However there are certain challenges in production like abundance of pest and diseases, soil acidity, high humidity with high temperature, shrinking land resources etc, which need to be addressed in an ecologically sustainable manner.Some States of Warm humid tropics have productivity of vegetable crops less than National average, whereas, some can achieve yet higher productivity in view of rich resources and availability of technological options. The existing yield gaps can also be bridged by increasing seed replacement rate/ the area under seeds of improved varieties and especially hybrids, apart from using high-tech vegetable production technologies and by adopting good agronomic practices, that are based on natural resource conservation, and both water and nutrient use efficiency.

Three days national webinar discussed in length about the strategies to be adopted for addressing the challenges of vegetable production in humid tropics and this proceedings included all presentations by the eminent speakers on various aspects discussed in webinar which stretched for three days. In order to meet the increasing demand for nutritious food there is a need to maximise yield per unit area in a sustainable manner. Major recommendations of the webinar includesadoption of alternative cropping techniques like protected cultivation, precision farmingetc along with the increased use of high yielding F1 hybrids. Breeding for yield, quality, biotic and abiotic stress tolerance and diversification of food by use of underutilized crops also should be given importance. National experts stressed the need to harness the benefit of new technologies including transgenics along with the phenomenon such as parthenocarpy, polyploidy and male sterility in tropical vegetables.The role of wild species should be explored as a source of resistance genes and the experts identified different wild species in okra, bitter gourd brinjal and tomato which could be used for breeding program against virus, bacterial wilt and nematode in the warm humid tropics.

The role of vegetables as immunity booster was also highlighted by experts with particular reference to COVID pandemic. In situ conservation of related and wild species of vegetables required utmost attention for future use in breeding programmes. Humid tropical regions covers eight states which are strategically placed for meeting the vegetable requirement of the region and country. Long term integrated approach is required for achieving the sustainable improvement in vegetable production. Policy makers, scientists and extension workers should work in tandem for realizing these goals. The recommendations by the national experts must be readily accessible to all stake holders in the region and this proceedings is an attempt to provide critical information in a comprehensive way. Let me express my sincere gratitude to Hon. Vice Chancellor, Kerala Agricultural University, Prof. (Dr.) R. Chandra Babu, President, Indian Society of Vegetable Science, Prof. (Dr.) K.V. Peter, Doyen of Indian vegetable Science, Prof, (Dr.) Kirti Singh, Past President of ISVS and Former Vice Chancellor of OUAT, Prof. (Dr.) D.P. Ray and all the national experts for extending their cooperation as session chairman, and lead speakers whose support and guidance made this webinar a success. Institutional support extended by Dr.Madhu Subramanian, Director of Research, Dr. Jiju P. Alex, Director of Extension, Dr. Sudheer, K.P., National Fellow, ICAR, Dr. Jyothi, M.L. Dean, College of Agriculture, Vellanikkara and Dr. Helen, Professor, CITI is gratefully acknowledged. Meticulous planning by the organizing committee comprising of faculties and students helped in running the webinar without any technical glitches. I also thank the support of Directorate of Extension in bringing out this proceedings and the Lumiere printing works, Thrissur for the clean documentation.

T. Pradeepkumar

National Webinar
"Challenges and opportunities of vegetable production in warm humid tropics"

Inaugural Session

Dr. R. Chandra Babu
Hon. Vice-Chancellor
Kerala Agricultural University

Dr. A.K. Singh
Dy. Director General (Horti.)
ICAR

Prof. K.V. Peter
President
ISVS

D.P. Ray
Principal Advisor,
Siksha 'O' Anusandhan University

Inaugural Speech

Dr. R. Chandra Babu
Hon. Vice-Chancellor, Kerala Agricultural University, Email: vc@kau.in

Vegetables assume great significance as protective food in the health and nutritive security of the predominantly vegetarian population of India. As such my colleagues have chosen the right topic to discuss and to come out with strategies to address the challenges and opportunities of vegetable industry in the country. Varied agro-climatic conditions has enabled Idian to claim the largest diversity in commercial vegetable crops. It is possible to grow a wide variety, especially of tropical vegetables year round in many of these diversity hotspots. The tropical climate, good rainfall and adequate sunlight facilitate growing of vegetable crops throughout the year in humid tropics of the country. In regions where climatic vagaries exist adoption application of technological advance *viz.* precision farming, rain-shelter, poly-houses etc. has helped to enhance the vegetable production. Advanced research in vegetables could standardise production technologies for the cultivation of cool season vegetables even under humid tropical climates. This has enabled the farming community to grow cool season crops in rabi season, even in unconventional states like Kerala.

Kerala Agricultural University has pioneered the development of hybrids in crops like watermelon and salad cucumber through parthenocarpic methods, which has opened tremendous opportunities for vegetable seed industry. Moreover, vegetables as rich sources of vitamins, minerals and antioxidants have significant role in contributing to the food industry in developing nutraceuticals and other functional foods for meeting the nutrient requirement of a balanced diet. Developments in hydroponics, indoor farming of micro-greens, vertical gardening etc. have opened new vistas for vegetable cultivation and has helped to integrate it into the urban scape. These demand better production packages that provide opportunities for our scientists to develop technology for growing vegetables, even in soil less and less fertile soil conditions.

Recently Government of Kerala has initiated Subhiksha Keralam programme to make the state self-reliant in food production and the programme includes a variety of vegetable crops. This warrant the need to streamline the production practices and related technologies to suit the complex, diverse and risk prone conditions of innumerable small and marginal holdings involved in the program. Micro climate and soil fertility have to be customised to suit the requirements of the selected crops. Also concerted efforts to breed varieties in tune with the consumer preferences need attention. Moreover, the challenges posed by tropical humid environment conducive to pests and diseases need biological and eco-friendly interventions that support safe-to-eat standards. Vegetables grown in protected cultivation also demand development of suitable varieties that are responsive to bio control mechanisms. These become essential prerequisites as the Government of Kerala wants to move towards organic agriculture considering the public health and environmental concerns. Post-harvest loss of vegetables in the value chain from farm gate to consumer is another important aspect that needs scientific interventions especially in the tropics where perishability is high compared to temperate conditions. Mechanisms to improve the shelf life, cold storage and other infra-structure which facilitates the forward supply chain need to be expedited. Value addition is another viable option that hold great scope in vegetable crops top reduce post-harvest losses. Many value added products have been developed from vegetables by Kerala Agricultural University and these protocols are available under transfer of technology scheme for entrepreneurs and other users. But still we need to increase the percentage of value added products from the vegetable crops in the state and across the country so that the farmers are better benefitted. Implementation of minimum support price to vegetables in the state as in cereal grains, cotton and other crops will protect the vegetable farming from vagaries of market instability and encourage more to take up vegetable cultivation.

Government of Kerala has recently come out with basic support price for 16 agricultural commodities for the first time which can be emulated throughout the country.

I hope and wish that this compendium of the proceedings of the three days webinar held from 11/11/2020 to 13/11/2020 under the Department of Vegetable Science, Kerala Agricultural University will provide effective strategies and bring out useful recommendations for the vegetable crop production in the humid tropics of the country.

Key Note Address

Dr. Arun Kumar Singh
Deputy Director General (Horticulture), ICAR, Email: ddghort.icar@gov.in, ddghort@gmail.com

Today we have gathered here to take part in the conference 'Challenges and Opportunities of vegetable production in warm humid tropics'. We have with us dignitaries who provided leadership in the success of vegetable industry in India viz ., respected Dr. K.V. Peter, Dr. Chandra Babu, DR. D.P. Ray, Dr. Brahm Singh, Dr. Jagdish Singh. I thank all of them for being a part of this conference and giving valuable ideas and leadership so that we can take the vegetable industry to the next level. I also appreciate the efforts of Dr. T Pradeepkumar, organizing Secretary who has taken effort to materialize this conference and happy to note that large number of people are taking part in this webinar and hope this will bring good recommendations. ICAR is at the stage of formulating the EFC for the next five years and will be happy to incorporate the ideas coming out of this conference so that we can achieve it based on the objectives in short term, intermediate or long term mechanism.

We have achieved a remarkable progress in horticulture crops including vegetables.Vegetable industry has contributed so significantly in terms of tonnage towards the progress. Whatever vegetable we have produced last year and previous year, more than 66 or 67 percentage of vegetable production is coming only from 5-6 vegetables. We have to develop the management options for the remaining vegetable so that the area under other vegetables can be increased and also there is a concern from the government of India that focus should be given to the indigenous vegetables *ie.*, those vegetables which are having great significance in nutritional aspect and are easy to cultivate.Traditional knowledge is available on these crops and we have to popularize them to achieve a national status and we can create a brand for indigenous vegetable in India and can be exported under the brand name . During the Covid lock down period, the export of many vegetables has risen to 15 - 16 per cent. It is the sign of emergence of this sector and the spice crops are another one contributed to export sector which is lead by one or two commodity and its export raised to the tune of 32 per cent. The vegetable export from the country has surpassed 26,000 crores. Hence we have done a remarkable job and also the analysis from one of the government divisions is that the agriculture is the only sector during the covid period which has shown the growth rate of more than 4 per cent. Official reports are there that more than 50 per cent of the growth has been driven by horticultural sector alone. This shows that there is a possibility to expand the vegetable horizon and we have to come up with the solutions for challenges this industry is going to face in the future. The demand is rising locally as well as globally and at the same time the production conditions are not going to be the same as what we enjoyed in the past. The implications of the climate change is not a myth and it is a reality that is visible in various parts of the country across the commodities. This puts new challenges and in addition to that there is a fresh demand in a new format of the vegetables either as fresh /value added or processed vegetables.

There are few challenges to be highlighted. Although we are producing so much of vegetables, the study conducted by GoI in 2016 revealed that the harvest and post harvest losses in major agricultural commodities was more than 13 billion dollars *ie.*, approx. 95,000 crores every year which is a massive amount. Vegetables are the class of the agricultural product where the post harvest loss is relatively high because of high perishability. This is a major challenge and we have to come up with research protocols or methods to reduce the post harvest losses and to minimize it to a level which is less than threshold value so that the profit out of this should be gone to farmers or fare stake holders in the vegetable industry. Next challenge is that though we are producing a massive amount of vegetables only a small portion is subjected to the value addition or processing. If wewant to increase it to 2-3 per cent every year we need to have a technologies *ie.*, Varieties having processing traits. Production and demand supply should be relooked. Onion production is 26.5 mt and our requirement is only 18-19 mt. and even if there is 20-25 % loss, we have 20 mt at our disposal. Though there is a 2 mt extra production this year, the onion price is increasing with little inflow to the farmer's hand. Most of the production is from rabi season which creates a glut in the market during harvest. Here the challenge is price instability and availability resilience to the market. One of the solutions for this is to go for offseason cultivation by expanding the cultivation in non traditional areas so that we can overcome the price fluctuation. Like onion, many crops are there where interventions are required to stabilize the price and this can be tackled by the development of consistent technologies *viz.*, production technologies for non traditional areas, varieties etc. These technologies will help farmers to go for enhanced production. The government has taken many steps including the programmes like contract farming, PMs Kisan programmes where the technology driven price reduction in the cost of production of vegetables or horticultural crops as whole. Also, the central government has created Rs. 1,00,000 crores as fund for the infrastructure development which is much more applicable to the high value crops like vegetables and fruit crops. These provisions must go along with the complete package of practices of the newer materials in newer areas or in the professionally matured areas of horticultural crops particularly vegetables. Hence multi branched efforts are to be given to address the problems of vegetable industry. Universities and ICAR institutions have to do the best for this in a partnership mode so that we can address these problems and come up with viable reproducible solutions for the farmers. Another challengeassociated with many vegetable crops cultivated in India is the yield variability across the country. Productivity of the same commodity/varieties varies in different places and this has to be looked into. We have to establish a connection between the farmers through KVKs/ SAUs so that we can have a two way communication and can find out the exact reason behind the low yield by analysing the situation and a prescriptive kind of extension services to the farmers can be adopted which is the need of the hour compared to one way communication. The horticultural crops are labour and knowledge intensive, which requires huge working capital. Hence it requires heavy investment which can be considered as a national investment to ensure the income of the farmers in turn to the states or nation.The technologies should be economically viable and environmentally sustainable with a great degree of sturdiness which doesn't spoil water, the soil, the environment and also it should meet the market needs. Hence we have to work on how to fill this gap from field to the laboratory. We have huge amount of genetic resources in almost all vegetable crops. We have to prepare a map where a commodity is being produced in large quantities, and where its consumption centres are and how much far the commodity has to be transported. This analysis helps in developing the production technologies around the mega consumption centres. Also, we have to think of increased production per unit area which can be attained through green house cultivation, vertical farming, aeroponics, hydroponics etc. to ensure the required production for a longer time.We are lacking in these because of lack of skilled manpower for taking up these technologies. We don't have sufficient of genotypes suitable for these technologies.Varieties suitable for hi-tech production technologies will help to expand the area under cultivation in green house conditions. Pollination management in protected structures is important and several options are available for successful production inside protected structures. Skilled manpowers are required for popularizing cultivation in protected structures. It should be generated by increasing the technical knowledge among the students and to make them professionally fit for handling and taking up these type of technologies.

Another issue facing vegetable cultivation is the huge revenue losses due to pest and pathogens. This ranges from 15 to 35 and there are some commodities where the losses are even high. We have to handle this issue biologically as well as chemically. There is a need to develop varieties or lines with resistance or tolerance against these biotic stresses in a manner that the economic losses are below the threshold level. Emphasis should be on engagement of predators or other biological solution which is economical and environmentally viable. Though chemical solutions are viable, many are not ecofriendly and the MRL level of chemicals may hinder the export of commodities. GOI is giving thrust to increase the agri export and the presence of chemicals may pose threat to it. Hence these issues should be addressed scientifically in time and these challenges should be discussed in the webinar and recommendations should be made and can be incorporated into the research area by respective institutions for desirable results. Finally the technologies should reach to the grass root level by dissemination through KVKs/ SAUs/ three tier system of governmentand thereby increasing the revenue of farmers and nation and ensure nutritional security.

Finally, let me congratulate the organizers for conducting the webinar which will be a platform to exchange the ideas and to look into the challenges, success of various institutions and opportunities which benefits the vegetable industry of India in terms of production and export.

Key Note Address

Prof. K.V. Peter

President, ISVS and Former Vice-Chancellor, Kerala Agricultural University, Email: kvptr@yahoo.com

The wide belt of land and water that lies between the tropics of Cancer and Capricorn is home to half of the world's people and some of its most diverse and productive ecosystems.This tropical region is characterized by some unique properties, problems, and tremendous potential. Majority of the people living in this region of the globe are dependent on agriculture for a livelihood. Agricultural production practices in tropical regions are frequently unsustainable because the capacity of land to support crop production is rapidly exhausted. Ensuring food and nutritional security for an ever increasing population is a major challenge, and we agricultural scientists shoulder a huge responsibility in resolving these challenges. While cereals, pulses, fruits, vegetables and other foods complement each other in ensuring balanced nutrition to mankind, but the role played by vegetables in providing diverse nutrients is inevitable.

Vegetables play a crucial role in ensuring nutritional security by way of supplying micro-nutrients like vitamins, minerals over and above the carbohydrates and proteins. They are also abundant sources of phytochemicals which are powerful antioxidants that help alleviate many degenerative diseases in humans. They are a rich source of bioactive compounds and neutraceuticals which are extremely beneficial to human health and well-being. Vegetables are also a source of natural colors or pigments which have wide application in food, textile, pharmaceutical and other industries. The diversified and highly nutritive vegetables are affordable and cost effective solution to hidden hunger and malnutrition. Vegetable cultivation in the warm humid tropics of our country has several unique advantages and at the same time limited by several challenges. The humid tropics are generally resource-rich lands which possess adequate water supply, naturally fertile soils, plentiful sunshine and a favorable terrain, which favor the production of diverse variety of vegetables. However there are certain challenges like abundance of pest and diseases, soil acidity, high humidity, high temperature, shrinking land resources etc.

Vegetables contribute 40% of the area under horticulture crops in India and 59.2 % of the horticulture production in India.The current area production and productivity of vegetables in India is 10.259 million ha, 184.39 million tonnes and 17.97 tonnes/ha respectively. Inspite of this the bitter truth still stands that in the 2020 Global Hunger Index, India ranks 94th out of the 107 countries. There is an ever increasing demand for nutritious food and hence we need to increase the production and productivity of vegetables. The possible way out is by maximizing a sustainable yield per unit area, adopting alternative cropping techniques like protected cultivation, precision farming etc. Encouraging the increased use of high yielding F1 hybrids. Popularizing the use of high yielding innovative production technologies. Breeding for yield, quality, biotic and abiotic stress tolerance and diversification of food by use of underutilized crops.

Protected cultivation of vegetables is an efficient technology for increasing the productivity of vegetables coupled with enhanced quality. These structures ensure efficient utilization of space, water, energy and other resources. There are a range of protected structures which could be adopted by the farmers depending on their requirement. Some of these structures areclimate controlled greenhouses, naturally ventilatedpolyhouses, low cost net houses, rain shelters, nylon net houses, nylon net row cover, simple shade net etc.Some of the most important practices that are follower in protected cultivation of vegetables are Preparation of planting beds, soil sterilization, irrigation, misting before transplanting, planting ,pruning and training, fertigation etc.

Vegetable grafting is an important technique which has to be standardized and adopted in several vegetable crops because of several advantages like imparting tolerance to biotic and abiotic stress, enhancing vigour of seedlings, increasing yield and quality of the produce. Different types of grafting techniques like peg grafting, cleft grafting, approach grafting, splice grafting etc. are followed in vegetables depending on the crop and success rate. Cultivation of solanaceous vegetables which are prone to bacterial wilt is successfully possible by grafting high yielding scions on to wilt resistant root stocks. Cultivation of tomato is challenging under Kerala conditions, this can be overcome successfully by adopting grafted seedling for cultivation.

Soilless cultivation of vegetables is a new approach gaining wide popularity for both seedling production as well as vegetable production under different systems like aeroponics, aquaponics, hydroponics and microgreen production. Protray seedling production using different combinations of soilless media like perlite, vermiculite, coirpith compost etc have revolutionized the vegetable seedling nursery production industry. It offers several advantages like uniform and better germination of seeds, easy transportof seedlings to long distances due to low volume and weight, better establishment of crop in the main field as the crop escapes transplanting shock etc. Besides these the portray raised seedling endure 10-15 days early crop. The spent media used for raising seedlings can be used as a good manure.
Hydroponics is a technology for growing plants in nutrient solutions with or without the use of an artificial medium(gravel, perlite, peat moss etc.). This system is highly productive ensuring 3 to 10 times more yield and also conservative of land and water (90% more efficient). It is protective of the environment and has a relatively short production cycle. In this system crops can be produced even under unfavorable conditions. Several crops like leafy greens (lettuce, spinach) capsicum, cherry tomato etc can be successfully grown under hydroponics. This technology is gaining popularity among the farmers and entrepreneurs of our country.

Aquaponics is a food production system that combines the aquaculture, which is growing fish and other aquatic animals, and hydroponics which is growing plants without soil. It involves production of fish and vegetables with same input resource of water and nutrients. This results in effective utilization of fish pond water and its nutrients for production of vegetables /plants simultaneously with added returns on input resources. Plants act as bio-filter for the recycled water to fish pond.Fish produce ammonia, which is converted to nitrate by nitrifying bacteria present in the system. The water is sent to plants, which absorb nutrients that they need and finally the water is returned to the fish.

Microgreens are seedlings of edible vegetables and herbs, which are rich in flavor and nutrition and hence created quite a buzz among health-conscious eaters. They can be produced from seeds of practically any edible plant. Microgreens can be produced anywhere and anytime, hence very popular among urban households where availability of land is limited.Microgreens are small in size, can provide surprisingly intense flavors, vivid colors, and crisp textures and it can be served as an edible garnish or a new salad ingredient. Commonly grown microgreens include amaranth, basil, beet, cabbage, celery, chervil, chinese kale, cilantro, fennel, mustard, parsley, radish, swiss chard etc. They are rich source of vitamin C, vitamin E, vitamin K and beta- carotene and also minerals like Ca, Mg, Fe, Mn, Se and Mo, besides having nutraceutical properties. They are generally grown on soilless media or hydroponic systems without any external inputs other than water. The quality and intensity of light is a crucial factor in the production of microgreens.

F1 hybrids in vegetable crops offer lot of advantages like high productivity, earliness of the produce, phenotypically uniform produce with good quality, better keeping quality and resistance to biotic and abiotic stresses. Over the past decades several superior hybrids have been developed and released for cultivation, both by the public and private sector enterprises. However the adoption of F1 hybrids, for cultivation is limited due to a number of factors the major one being high cost of hybrid seeds. This limitation has been overcome to a large extent by adoption and exploitation of biological traits like male sterility, self-incompatibility, parthenocarpy and gynoecy. Kerala Agricultural University has developed cucumber hybrids 'Heera' and 'Shubra' by using gynoecious female parent and parthenocarpic cucumber hybrid KPCH-1, which has gained great acceptance among the farmers who grow cucumbers on a commercial scale under protected structures. Superior ridge gourd hybrid KRH-1 was developed using Cytoplasmic genetic male sterile system.

Some of the other superior hybrids are 'Swarna' and 'Shonima', triploid seedless watermelon hybrids, multiple disease resistant hybrids 'ArkaRakshak', 'ArkaAbhed' in tomato, virus tolerant chilli hybrids ArkaMeghana and ArkaKhyati. GMS based okra hybrid Arka Nikita, brinjal hybrids KashiSandesh and KashiKomal etc.

Bio fortification is a process of enhancing the nutritional quality of food crops through plant breeding, molecular approaches or agronomic practices. It is a potent tool to achieve nutritional security and therefore gained lot of importance among the scientific community. The Indian Institute of agricultural research has developed anthocyanin rich radish varieties PusaJamuni and PusaGulabi, beta carotene rich cauliflower variety Pusa Beta Kesari 1. Anthocyanin and beta carotene rich sweet potato varieties BhuSona and Bhu Krishna from Central Tuber Crops Research Institute.

Under exploited vegetables are a group of vegetables which have not received the deserved attention with respect to their popularization, cultivation, research etc. They are an untapped treasure house of nutrients and have tremendous potential to contribute to nutritional security. Moringa, curry leaves, winged bean, cluster bean, chekkurmanis, agathi, mint, velvet bean, chow chow, teasel gourd, spine gourd, vegetable soyabean, ivy gourd, lima bean, ridge gourd pointed gourd etc are some of the under exploited vegetables which are rich source of vitamins, minerals, antioxidants, polyphenols, fibre and micronutrients. They also have numerous neutraceutical properties- anti diabetic, anti-cancer, anti-inflammatory etc.

It gives me immense pleasure to participate in this National web conference on "Challenges and opportunities in vegetable production in the warm humid tropics" organized jointly by the Kerala Agricultural University and Indian Society of Vegetable Science. It is a three day event enriched with deliberations from most eminent scientists from all over the country on various aspects of vegetable production and improvement focusing on the unique characteristics of the warm humid tropical regions. I wish all the organizers, speakers and participants a very fruitful and enlightening experience during the web conference. My best wishes for the smooth and successful conduct of this wonderful event.

Special Address

Dr. D.P. Ray
Principal Advisor, Siksha 'O' Anusandhan University, A Deemed to be University of UGC, Bhubaneswar, Odisha
Former Vice-Chancellor, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha
Former President, Indian Society of Vegetable Science, Varanasi, Uttar Pradesh, Email: dpray1949@gmail.com

Current Scenario

Indeed, it is matter of great pleasure for me to chair the Plenary Session and present plenary session lecture on topic Challenges and Opportunities in Vegetable Production in the Warm humid Tropics in three days Web Conference on November11-13, 2020 jointly organized by Kerala Agricultural University and Indian Society of Vegetable Science. India as a coast line comprising of nine states *viz.,* Kerala, Gujarat, Maharashtra, Goa, Karnataka and in the West coast region and Tamil Nadu, Andhra Pradesh, Odisha and West Bengal in the East coast region of India. The Eastern Coastal Plain is a wide stretch of land lying between the Eastern Ghats and the Bay of Bengal. It stretches from Tamil Nadu in the south to West Bengal in the east.The temperature in the coastal regions often exceeds 30 °C (86 °F), and is coupled with high levels of humidity. The region receives the north-east monsoon and south-west monsoon rains. The south-west monsoon splits into two branches, the Bay of Bengal branch and the Arabian Sea branch. The Bay of Bengal branch moves northwards crossing north-east India in early June. The Arabian Sea branch moves northwards and discharges much of its rain on the windward side of Western Ghats.

Among warm humid tropics**,** The Kerala which is host of the Web Conference out of the total requirment of 8.18 lakh tonnes, the state produces 3.47 lakh tonnes. In mid 90s, the area under cultivation of vegetables was around 70,000 ha only and imports from neighboring states were increasing. Kerala Government noticed this trend and started various developmental projects in very early in the year 1997-98 and was declared as a "Harita Year" and organizing farmers into "Harita Sanghams" started massive programs for commercial cultivation of vegetables in selected areas. The good achievements under the project and the level of area under vegetable cultivation, which has become more than doubled during last 5 years. As a result, the v egetable production in the state has increased from 6.5 lakh tonnes in 2016 to 9.5 lakh tonnes in 2019. A wide variety of vegetables are grown in Kerala.The important vegetables are tapioca, minor tubers (*Amorphophallus, colocasia, diascorea* and *coleus*), drumsticks, bitter gourd, snake gourd, okra, cucumber, pumpkin, ash gourd, green chillies, brinjal etc. Winter season vegetables like cabbage, carrot, cauliflower etc are grown in high altitude regions of the state namely Wayanad, Idukki and Palakkad.

Department of Horticulture in Kerala Agricultural University which was established in 1955 and the Department of Vegetable Science attained its status of individuality in the year 1998 by the division of Horticulture Department. The department has taken much efforts to release many high yielding and disease resistant particularly bacterial wilt and viral diseases in several vegetable crops besides standardization of production and protection technologies. The improved varieties released for coastal districts of Kerala are;

Vegetable crops	Improved varieties released for coastal districts
Tomato	Sakthi*, Mukthi*, Anagha*
Brinjal	Surya*, Swetha*, Haritha*, Neelima* (F1)
Chilli	Ujwala*, Anugraha*
Pumpkin	Ambili, Suvarna, Saras, Sooraj
Bitter gourd	Priya, Preethi
Snake gourd	Baby
Coccinia	Sulabha
Ridge gourd	Deepthi
Ash gourd	KAU local
Oriental pickling melon	Mudicode local, Saubhagya

Okra	Salkeerthi, Aruna, Susthira (MR)**
Amaranth	Mohini
Winged bean	Revathy
Vegetable cowpea	Vyjayanthi, Lola, Bhagyalakshmy, Anaswara, Varun, Kairali(MR)**

* Bacterial wilt resistant, ** Mosaic resistant

- **The Tamil Nadu** is one among the leading Horticulture State contributing 5.8 % towards National Horticulture Production and 5.4 % in respect of total Horticulture crops area at National level. Tamil Nadu accounts for nearly 2.35 % of area under vegetables in the country. In terms of production. the State share is nearly 3.5% in vegetables. Out of the total geographical area of 130.05 lakh hectare, the total area covered under Horticulture crops accounts to 13.76 lakhs hectare . Tapioca, onion, tomato, brinjal & ladies' finger (Okra) are the main vegetables grown in Tamil Nadu which account for over 70% of the total area. The Horticulture Department has taken up the challenge to fulfill the State's policy by achieving higher growth rate in Horticulture by implementing several developmental schemes of Govt. of India and State Govt. The Department of Vegetable Crops in Tamil Nadu Agriculture University was established during 1979 as a component of Horticultural College and Research Institute and since then, intensive research, education and extension activities are pursued to promote vegetable crops cultivation. The department has generated technologies like grafting technology in brinjal, sequential cropping system of cassava with vegetable cowpea for better return, production practices for cultivation of capsicum and tomato in polyhouse, production practices for cultivation of tomato and cucumber under shade net, weed management in onion, application of SOP for high yield and quality in tomato, application of foliar spray for high yield and quality in vegetables production of virus free elite planting materials in cassava through tissue culture, and mass multiplication of virus free cassava planting materials besides development and release of high yielding and disease resistant/ tolerant 45 varieties and 15 hybrids of different vegetable crops.

- **The Andhra Pradesh** is the fifth largest state in the country both in area and population. The State has 17.48 lakhs hectare under Horticultural crops with an annual production of 301.73 lakhs metric tonnes a ccounting for 7.6 % of total horticulture production in the country. The university is working in Horticulture on thrust areas like increasing productivity, sustaining productivity under biotic and abiotic stresses, improving nutritive value and food safety, environment protection, increasing profitability to farmers, export promotion, minimization of post-harvest losses and processing and value addition.The university is known for development of high yielding and resistant/ tolerant to biotic and abiotc stresses in vegetable crops specially in chilli (Bhagyalakshmi, Andhra Jyothi, Sindhur, Bhaskar, Aparna, Prakash etc), brinjal (Bhagyamati, Gulabi, Shyamala), snake gourd (Swetha), coriander (Sindhu, Sadhana, Swathi, Sudha,), elephant foot yam (Gajendra) colocassia (Satamukhi, Bhavapuri) and sweet potato (Samrat, Kiran)

- **The Odisha** is located on the east coast, where the normal rainfall received from June to September from South-West monsoon is immensely suitable for growing spices like ginger, turmeric and chilli, a variety of root and tubers and a whole range of vegetables. The low temperature existing in hilly areas at higher altitude offer ideal conditions for growing off-season vegetables. Brinjal is the major vegetable followed by tomato, cauliflower, cabbage, potato, okra, yams, sweet potato, pumpkins, gourds, melons, cowpea, beans, agasti, knol khol, radish, beet, carrots etc. Apart from production and protection technologies, the department of Horticulture of ***OUAT*** has developed and released several vegetables crop varieties resistant / tolerant to bacterial wilt as this is devastating problem for cultivation of vegetable crops in the State. The outstanding varieties like Suprava, Suruchi and Subrabhi in ginger; Roma, Suroma, Ranga and Rashmi in turmeric; Utkal Tarini, Utkal Madhuri, Utkal Keshrl in brinjal; Utkal Pallavi, Utkal Dipti, Utkal Kumari and Utkal Urvasi in tomato; Utkal Rasmi and Utkal Ava in chilli and Utkal Gaurav in okra have been accepted by the farming community and are in wide adoption in the State of Odisha .

- **The West Bengal** is the highest producer of vegetables in the country. West Bengal accounted for 15.9 per cent of the country's total vegetable production in 2018-19, whereas, UP produced 14.9 %. Madhya Pradesh (9.6%), Bihar (9%) & Gujarat (6.8%). The State is situated in the heart of fertile Gangetic delta and thus comprises of high geographical diversity with six agro climatic zones. There is a wide diversity of horticultural crops grown in West Bengal. Common vegetables (excluding potato) are: tomato, cabbage, cauliflower, radish, carrot, pea, brinjal, onion, garlic, okra, palwal, cucurbits (gourd, cucumber, bitter gourd, bottle gourd, sponge gourd, pointed gourd, squash), French bean, leafy vegetables (spinach, amaranthus, ipomoea), elephant foot yam, taro (arvi), turnip, beet, brussels sprout, tapioca, etc.

- **The Gujarat** occupies the first position in respect of productivity of crops like onion, potato seeds. The total area under horticulture crops and their production are continuously on the rise in Gujarat. The State holds first position in the production of cumin, fennel. More than 90% of the fennel in the country is produced by Gujarat alone. It has the highest productivity in the country for onion (25 MT/ha.), potato (28.81 MT/ha.) and the world's highest productivity of potato (87 MT/ha) has been reported from Deesa of Gujarat's Banaskantha district. A number of good integrated pack houses, air cargo complex and gamma irradiation projects have been established by Gujarat Agro Industries Corporation. In addition, onion dehydration industry of the state is the biggest in the country. The Gujarat Agricultural University which was established in February 1972 with the State wide mandate for the triple function of Agricultural education, research and extension. Apart from standardization of several production and protection technologies in vegetable crops, the department of vegetable has also developed and released several vegetable crop varieties.

- **The Maharashtra** contributes 6% of production of vegetable in the country. The area under vegetable crops is about 4.10 lakh ha. The total production is 50.02 lakh M.T. per year and the productivity is more than 12.50 M.T. per hectare. Maharashtra is the largest producer of onion in the country covering an area about 1, 20,733 ha. with average production of about 14 lakh M.T. Maharashtra is exporting about 3,50,000 to 4,00,000 M.T. onion every year and recently cultivation of white and yellow onions are being promoted by the state. A large number of varieties of vegetable crops have been developed and released for Konkan coast of Maharashtra, among of them Sonali in tomato, Konkan Kirti in Chilli, Konkan Bhushan in Dolichos bean, KonkanWali in yard long bean, Sheetal in cucumber, Konkan Shweta in Snake gourd, Konkan Tara in bitter gourd, Konkan Harita in ridge gourd, Konkan Durangi in Amaranth and Konkan Ruchira in drum stick,

- **The Goa** is well known for the native vegetables *viz.,* brinjal, okra, Chillies cucurbits with distinct qualities and consumer preference. Although, local varieties of vegetables are cultivated in Goa, improved varieties and hybrids are not adopted at a commercial scale in farmers field. The improved high yielding varieties and hybrids developed in the neighboring states are better in their yield performance under Goa condition.

- **The Karnataka** contributes around 15% of the horticultural production in the country. It contributes around 10% of the fruit & vegetable production in India. The climatic conditions of the state favors for cultivation of all types of vegetables and considered as Seed Industry Hubs. The IIHR and different stateAgriculture and Horticulture Universities of the State have developed a large number of varities of different vegetable crops for growing in large areas.

Opportunities:

Organic Vegetable Production

In most of the States of warm humid tropics including Kerala, there is a large potential for organic farming due to the favourable agro climatic conditions. Many vegetables are grown without the application of chemical fertilizers or pesticides. International demand for organic food is increasing day by day. The farmers are using comparatively less fertilizers and vegetables grown out of agrochemicals have great advantage in the international market. There is immense scope for promoting organic farming vegetables. Agencies like Horticultural Board, Vegetable and Fruits Promotion Council, can help much in promoting organic cultivation in the state as vegetables and fruits produced out of organic farming are in high demand inside and outside the state/country. Organic farming includes natural farmings (ecological vegetable farming, rishi farming, angara, amrit pani, panchya gavya, biodynamic etc.), FYM, composting, green manuring, biofertilizers vermicompost and vermi wash in the production and protection process.

Tapping of Underutilized Vegetables

In our country, more than 70 types of vegetables are grown but maximum emphasis has been given on important vegetables like tomato, brinjal, chilli, cauliflower, cabbage, pea and few important cucurbits. Besides, a number of minor vegetables are also grown in different parts of the warm humid tropics. Though presently the area under minor vegetables is very limited, it is expected that in near future there will be more demand of these vegetables. Even today, these vegetables are fetching very high price in multistar hotels and other tourist restaurants. Among all the vegetables in cole family, broccoli is rated as more remunerative. Recently, two improved varieties of broccoli namely, Palam Samridhi (Green headed) and DOG PPB.1 (Purple head) have also been developed for cultivation. Demand for supply of seeds of these vegetables is now coming from various states. Likewise asparagus and broccoli, there are number of other underutilized vegetables such as faba bean, summer bean, lima bean, winged bean, velvet bean, chive, leek, welsh onion, Brussels sprouts, Chinese cabbage, *Momordica cochinchinensis, Coccinia indica, C. cordifolia, Melothria heterophylla,* Curry leaf, drumstick, agathi, waterleaf, Indian spinach, parsnip, celery, lettuce, globe artichoke, sweet corn, baby corn etc. which can be cultivated successfully in warm humid tropics. The importance of these crops, a network project on improvement of underutilized vegetable crops had been sanctioned by ICAR which was implemented at 7 centres of the country *viz.* IIVR, Varanasi; IIHR, Bangalore; IARI, Katrain; ICAR Res. Complex for NEH Region, Barapani; CCSHAU, Hisar; SKUAST(K), Srinagar and KAU, Vellanikkara. The various recommendations from these centers can be taken for strengthening the research on underutilized vegetable crops in all states of of warm humid tropics as per need.

Vertical Vegetable Farming

With the pressure building on farmlands and its increasing cost in the urban areas, terrace gardening is only ideal alternative to grow vegetables domestically with the additional benefits of reducing global warming. The emphasis would be given on identification/development of suitable varieties/hybrids for pot culture, standardization of growing techniques such as growing media, type of containers, nutrient and pest management and selection of vegetables according to availability of space, water and light intensity.

Better avenues for Post- harvest and Value addition of vegetable crops

Most of the state of the warm humid tropic are considered as the *cafeteria of horticulture crops* in view of its sustainability for cultivation of various horticulture crops. Hence there is good avenues for development various value-added products of vegetable crops. Huge post-harvest losses of vegetables due to perishable nature of vegetable and poor postharvest infrastructure. At the same time huge demand for fresh and processed vegetable is being observed both domestic and international market. Setting up of post-harvest facilities both for fresh and processed vegetables can harness this opportunity. Setting up of pack house facilities with strong marketing chain can solve this problem. Similarly setting up processing industry at production catchment area can also solve this problem. Additionally, both fresh and processed vegetable sector at production catchment zone generate huge employment opportunity for rural youth and women.

Vegetable Seed Production Hub

Though, due to diverse agro-climatic conditions and availability of inexpensive farm labour including women, warm humid tropic of India particularly Karnataka and Hyderabad have become vegetable seed production hub in our country, but it can also be strengthened. This will help to cut down the import of vegetable seed and simultaneously create the export potential. Also, this will have a positive influence on Indian economy in terms of employment generation and earning foreign exchange. Through skill development and participatory seeds production, it would be possible to improve the livelihood security of the vegetable farmers.

Emerging Issues

Yield gap

Some States of Warm humid tropics have productivity of vegetable crops less than National average, whereas, some can achieve yet higher productivity in view of rich resources and availability of technological options. The existing yield gaps can also be bridged by increasing seed replacement rate/ the area under seeds of improved varieties and especially hybrids, apart from using high-tech vegetable production technologies and by adopting good agronomic practices, that are based on natural resource conservation, and both water and nutrient use efficiency.

Expensive cost of cultivation and lack of agricultural workers

As per estimates, between 1993- 94 and 2015-16 (almost 20 years), the real farm income had just doubled and farm income per cultivator received slightly higher increase mainly due to a decline in the number of cultivators after 2004-05, since the young generation seemed to have opted out of agriculture and shifted for the employment to urban areas. Further, the low income and increasing disparity between income of the a farmer and non- agriculture worker (almost double) is one of the reasons for agrarian distress. The low and highly fluctuating farm income is detrimental to the farming and farm investments, and forces the cultivators, particularly the youth, to leave farming. Even the labour cost for cultivation has gone up considerably since the implementation of the scheme under Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA).

Emergence New Diseases and Insect- pest

- Introduction of hybrids in vegetable crops has created several new disease problems like Pseudocercospora leaf blight in tomato and brinjal in India. Seed-borne diseases and their inoculum in vegetables increased throughout the country due to OGL and GATT agreement as well as free movement of seed without proper quarantine (Pandey, 2000). Disease intensity of many diseases such as enation leaf curl in okra, chilli leaf curl, gummy stem blight, Didymella leaf blight and viral diseases of cucurbits increased tremendously. Alternaria leaf blight in cole crops and radish increased throughout the country due to transportation of infected seed materials. Tospo virus is now a severe problem in almost all vegetable crops. Intensive and monoculturing of vegetables also increased the disease pressure of soil-borne pathogens. *Sclerotium* , *Sclerotinia* and *Rhizoctonia* are engulfing almost all vegetable crops and becoming serious every year . Collar rot severity and its inoculum in soil increased due to susceptible F 1,s of tomato. Seed-borne diseases like black rot of cole crops and their inoculums in vegetables increased throughout the country including warm humid tropics. Similarly, adoption of high nitrogen responsive F 1 hybrids has changed the disease scenario. In tomato the hybrids are very much susceptible to collar rot, which occurred as major problem in southern parts of the country. The off-season vegetable growing practices have prolonged the survival period of pathogens in the field of most of the soil borne diseases.

- Some of the insects pests of vegetable crops become major and are gradually attaining the major pest status in different regions of the country due to changes in the ecosystem and habitats are *Helicoverpa armigera* in tomato, whitefly *Bemisia tabaci*, serpentine leaf miner *Liriomyza trifolii* on tomato and cucurbitaceous crops, fruit fly on fruits and vegetables, mealy bugs on several horticultural crops, gall midge on brinjal, okra stem fly and bitter gourd leafhopper, red spider mite on okra, brinjal, cowpea, Indian bean and nematodes on several vegetable crops. In recent times there were out break of gall midge, which known to be a minor pest and gradually becoming a regular problem in chilli, capsicum and brinjal in the states of Andhra Pradesh and Karnataka and in brinjal in Chattisgarh. Various species of mealybugs in cotton, vegetables and papaya have intensified their severity of occurrence in different parts of the country and have become indicator insects for the current ecosystems due to slow changes in climate in the last one decade. Several national and international polyphagous pests like termite, white grubs, hairy caterpillars and *Spodoptera litura*

Climate Change

Climate change is threatening to push the number of hungry even higher in the decades to come, due to new challenges in whole agriculture and vegetable production in particular. Temperature across the world could rise up to 6^{O} C by

2050. Climatic changes will influence the severity of environmental stress imposed on vegetable crops. Moreover, increasing temperatures, reduced irrigation water availability, flooding, and salinity will be major limiting factors in sustaining and increasing vegetable productivity. Extreme climatic conditions will also negatively impact soil fertility and increase soil erosion. Thus, additional fertilizer application or improved nutrient-use efficiency of crops will be needed to maintain productivity or harness the potential for enhanced crop growth due to increased atmospheric CO_2.

Heavy Metal in Vegetables

Besides pesticide hazards, in study jointly undertaken by toxic links Imperial College of London and ICAR, vegetables such as spinach, cauliflower and okra were found to contain high levels of lead, zinc and cadmium with 72 per cent of the samples having metal content beyond the prevention of food adulteration norms. Lead is one of those toxins that do not good to the body, but its presence interferes with brain development, reduce intelligence and capacity of the person to absorb calcium and iron. Large doses of zinc can cause cramps and nausea and prolonged exposure can decrease high density lipo protein levels, damage pancreas and lead to loss of appetite. Further due to uninterrupted mono cropping and apathy towards the use of organic matters in the soil over the last sixty years, essential nutrients have been lost from most of our vegetables. According to an estimate in vegetables an average decline of 27 per cent in iron, 46 in calcium and 24 per cent in magnesium have been reported. In coming years we have to concentrate on these challenging issues.

Quality Assurance

Acceptance of the horticultural produce in the high-quality conscious era require the produce to be of high standards free from toxins and other elements of health hazards, which could be achieved through, popularization of improved agro-technique, emphasis on cultivation of specific varieties for table, processing and export, emphasis on harvesting horticultural produce at optimum maturity, grading, packing and transport, setting up of quality control laboratories, wide dissemination of international quality standards for various commodities and, ensuring pesticide residues within permissible limits. With the opening up of the economy and emergence of free trade there shall be increasing competition to capture the markets, which is equally true for horticultural products. The strategies, to overcome the implication on Indian horticulture, would include emphasis on creating awareness about implications of WTO regime among horticultural entrepreneurs, identification of horticultural cropping zones, harmonization of sanitary and phytosanitary standards and strengthening of mechanism to meet the requirement and strengthening of quality assurance.

Human Resource Development

Advanced training in research methodologies and instrumentation, biotechnology, micro-irrigation, fertigation, IPM, INM, biofertilizer, biopesticide residue, PHT and product development need priority attention for increasing research capabilities of the scientists. Skill development for state level development functionaries through in- service training at different R&D institutions will enhance capabilities of extension staff. Technology adoption pattern cannot be uniform through the country and will vary from crop to crop even from region to region. Certain degree of flexibility in research planning and research strategy is therefore obvious. Also, with the opening of global markets removal of quantitative restriction under the WTO export – import scenario is likely to change at much faster place. Market forces will play more dominant role and demands for modern technologies will increase. Research system in horticulture will have to be very alert and should be able to adjust with the changes. Development of both short term and long-term strategies for modernizing Indian horticulture will depend largely on the research support and strength of research system.

Financial distress

Among 8,000 farm suicides in India (2014-15), financial distress alone accounted for 38.7 per cent of farmers' suicides (ICFA, 2016) including states of warm humid tropics. To arrest this scenario of financial distress among farmers, short duration marketing loans may be considered on the lines of self-liquidating production loans. Financial inclusion of the farming community can be improved tremendously by transacting all financial benefits, mainly the subsidies in different forms directly to farmers' account through e-governance. Presently, only 15 per cent of the loan is disbursed as investment credit which has to be significantly increased.

Future Strategies and Way Forward

- Development of vegetable varieties that can grow in such environments and that can prevent entry of heavy metals, other pollutants into food chain is envisaged.

- Grafting is a promising tool to improve the tolerance of vegetables against abiotic stresses like salinity, cold, heat, drought, flooding and nutrient deficiencies grown in warm humid climate. Therefore, breeding of suitable rootstocks resistant and tolerant to different biotic and abiotic stresses is a promising option in solanaceous and cucurbitaceous vegetables. The strategy is to focus on selection of rootstocks that further increase yield potential of scions under diverse growing conditions. The modern breeding tools would be integrated to understand the genetic basis of root stock and scion interaction in vegetables. Understanding the molecular mechanisms that probably underline the graft-induced changes could pave the way to a better knowledge over the rootstock-scion interactions, the role of rootstock in scion performance and eventually the improved quality and fruit harvest from grafted vegetable plants.

- Development of photo and thermo insensitive varieties may break the area and seasonal boundary for the cultivation of several vegetables grown in warm humid climate. Isolation of photo insensitive genotypes in vegetable will also help to grow short day vegetables under long day condition and *vice versa*. Development of high temperature tolerant strains in temperate vegetables can enable their cultivation in intermediate as well as subtropical areas. Conversely cold tolerance in tropical vegetables will be beneficial in evolving genotypes for temperate areas.

- For development of nutrient-rich vegetables **,** *g*eneration of metabolome profile of vegetables with an emphasis on indigenous vegetables would a foundation for achieving enhanced nutrient levels in vegetables. The metabolomics approaches would be employed to decipher ultimate biochemical outcome of changes in the genome, transcriptome and proteome that could be exploited for enhancing the metabolic value of new vegetable varieties.

- The modern breeding strategies should focus on those physiological traits with increased photosynthetic activity, more adaptation to biotic and abiotic stress, minimum energy spend on inputs with maximum dry matter production. Opportunities will be explored to alter the crop duration, timing of crop development, primary growth of plant (form), canopy architecture, branching, shoot and root growth etc. which may help to escape the insect pest attack or abiotic stress.

- The 'Genetically Edited Vegetables (GEV)' with higher amounts of bioactive components may play better role in preventing/fighting chronic noncommunicable diseases in addition to providing basic nutrition. Development of vegetable cultivars that possess higher proportion of bioactive phytochemicals, tolerance to biotic and abiotic stresses through the use of new biotechnology techniques like "Genetic Editing."

- Development of multipurpose vegetable crops will be required to fulfil the increasing demand of vegetables. The same plant producing fruits as well as leafy vegetable will give the multiple yield and income to farmers. Similarly crops with high biomass can be designed to produce biofuel as a by-product. Vegetables crops with high biomass are suitable for this. The metabolic engineering using genes for synthesis of biofuel in model plants is a successful example and the same strategy can be further extended to specific vegetable crops to develop multiproduct crops. Such multiproduct crops will produce vegetables and clean and cheap energy from dry biomass.

- The efficient utilization and management of resources and increasing input use efficiency in vegetable crops are of utmost important to future farming. High-tech interventions involving precision farming micro-irrigation, fertigation, protected/greenhouse cultivation, mechanization, soil and leaf-based fertilizer management and use of modern tools like geo-informatics (Remote sensing, GPS & GIS). Water foot print of vegetable production, crop modeling and decision support systems will facilitate the development of appropriate technologies for improving crop productivity and quality while minimizing the cost of inputs. Besides, with the recent advances in sensor technology, it would be possible to promote smart vegetable farming using the state-of-the-art sensor based automated delivery of inputs like water and nutrients.

- Development of efficient vegetable-based crop rotations/cropping systems to harness synergistic/ positive interactions of companion crops/crops in sequence and to minimize negative allelopathic effects is of paramount significance in achieving the objectives of enhancing productivity, input use efficiency and sustaining environmental quality. This would also help in minimizing the infestations of weeds and recurrence of pests and diseases.

- Contamination of vegetables, fruits and other food commodities with harmful pesticide residues and pollution of the environment due to indiscriminate use of inorganic fertilizers and pesticides is a matter of concern all over the world. Development of suitable organic farming modules in vegetable crops would help in production of safe vegetables, minimizing environmental pollution and improving soil health through enhanced carbon sequestration and biological activity.

- Nanotechnology can be exploited to revolutionize vegetable production through development of efficient and cheaper fertilizers, enhancing the ability of plants to absorb nutrients, more moisture retention by encouraging microbial Polysaccharide production and can improve our understanding of the biology of different crops. Development of slow release nanofertilizers formulations can be used for smart release of nutrients that commensurate with crop requirements and thereby reduce nutrient losses and improve nutrient use efficiency of vegetable crops.

- Remote sensing helps in detecting changes in reflectance from the crop canopy brought about by various crop stress like water, nutrient and insects and diseases and therefore has the potential to detect abiotic and biotic stresses in agricultural crops including vegetables. Remote sensing provides a means for rapid observation and digital recording of hundreds of plant samples within a short time. Coupled with GIS and global positioning systems (GPS), it would aid site specific crop management determination of fruit yield, quantification and scheduling of precise and proper fertilizer, irrigation needs, application of pesticides for pest and disease management and has potential for increasing net returns and optimizing resource.

- Plants live in intimate contact with microorganisms some of which cause disease and while others protect the plant against disease. Extensive investigations are necessary to know the microbial diversity, type of interactions and to rapidly identify microbes for utilizing useful ones or their products for managing the disease and sustainable agricultural production. Development of sensitive *in-situ* diagnostic devices for root exudates and most common beneficial microbes is required to modulate plant microenvironment to get better yield.

- Harnessing social media to build the e-Agriculture community to involve farmers into policy and strategic discussions, development of Internet school for farmers, e- learning modules, creation of Social Media Team (SMT) and e-Choupal model, digitalization of available information in order to complement existing and future agricultural communications efforts. Farmers could register themselves and directly gain knowledge and expertise under Smart Farmer Concept.They can extract information from agri networking sites, participate in events (e-Choupal), develop their own network, comment, share and contribute content.

- In order to enable farmers, participate in progressive high value markets, such as modern retail, value added agri. produce and export markets, the government established the institutional machinery of Farmer Producer Organizations (FPOs). As of March 2016, there are over 2000 FPOs in the country which are trying to shift the farmers from low-margin fresh produce to high-margin value-added products. But their major challenge lies in marketing and selling. Thereby, innovative marketplace / platforms along the lines of e-NAM should be leveraged with good investments to facilitate marketing and intermediary-free selling

- Each organization handling horticultural crop must have their Apps. The term "Apps" is a shortening of the term "application software"."Veg Apps" will be a mobile application developed various technologies by different organizations can be downloaded from their websites and run on smart phones and other mobile devices. The "Veg Apps" will have mobile web site bookmarking utilities such as crop advisory services, decision support, mobile-based instant messaging among the stake holders, GPS based nutrient and pest-disease management and many other applications.

- The newly launched crop insurance scheme of the Central Government has many positives to the farming community and it may be made compulsory for all farmers so that a non-loanee farmer is not pushed to extreme in case of crop-loss. Crop insurance products should be designed with a village as a unit, which represent similar crops or cropping patterns.To increase competition, instead of selecting one Agri-Insurance player through bid system for a district, all the districts should be made open to all the players. In addition, a separate Agriculture Insurance Regulatory Authority needs to be established. If possible, a Toll Free Agri-Insurance number should also be launched to improve the awareness of the scheme and as a portal toward registry and track of claims and disputes. Thanks to the Organizers of the Web Conference for giving me an opportunity for expressing my views on topic Challenges and Opportunities in Vegetable Production in the Warm humid Tropics. Thanks to all of you.

Jai Hind, Jai Bharat

National Webinar
"Challenges and opportunities of vegetable production in warm humid tropics"

Session 1

Challenges and opportunities of protected cultivation in humid tropics-

Chair:
Padma Sree Dr. Brahma Singh
Founder Chairman,
Professor Brahma Singh Horticulture Foundation
Founder President,
Indian Society for Protected Cultivation, Delhi

Dr. Balraj Singh
Project Coordinator
AICRP (HB&P)

Dr. C. Narayanan Kutty
ADR (Vegetable Mision)
Nodal Officer

Dr. Shankara Hebber S
Principal Scientist
IIHR, Bangalore

Dr. Prananb Kumar Hazra
Dean, Post Graduate Studies,
Professor, Dept. of Vegetable Science, Faculty of Horticulture,
Bidhan Chandra Krishi Viswavidyalaya

Session 1

Challenges and opportunities of protected cultivation in humid tropics-
Padma Sree Dr. Brahma Singh, Founder Chairman, Professor, Brahma singh Hort. Foundation, Delhi

1 **Protected cultivation of vegetables in the humid tropics**
- Dr. Balraj Singh, Project Coordinator, AICRP (HB&P)

2 **Recent advances in vegetable grafting and prospects of soilless vegetable cultivation**
- Dr. C. Narayanan Kutty, ADR (Vegetable Mision), Nodal Officer

3 **Recent developments in crop management of important vegetables under poly house and rain shelter**
- Dr. Shankara Hebber S, Principal Scientist, IIHR, Bangalore

4 **Future vegetables and new generation hybrids**
- Dr. Prananb Kumar Hazra, Dean, Post Graduate Studies, Professor, Department of Vegetable Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya

Prospects and Challenges in protected cultivation of vegetables in hot humid topical regions of India

Dr. Balraj Singh, Project Coordinator, AICRP (HB & P) IARI,
Former Vice Chancellor, Jodhpur Agricultural University, Rajasthan, drbsingh2000@yahoo.com

Protected cultivation is being practiced across the country and there is a progressive growth in this sector. The scenario of vegetable cultivation in protected structures shows that around 0.14 mha area is under protected cultivation out of total area of 10.2 mha, under vegetable cultivation in our country. In China, who stands first in vegetable cultivation, the total area under vegetable cultivation is 24.5 mha whereas area under protected structures is 3.5 mha and 95.62% of the protected structures are being used for vegetable cultivation giving more emphasis to hybrid seed production (more than 50%) and the rest for commercial vegetable cultivation.The different protected structures include plastic mulching, low tunnels, high tunnels, walk-in tunnels, rain shelters with insect proof net, solar green houses, net houses and green houses.The dismal growth of protected cultivation in India compared to China is due to poor agreement between the designs of protected structures and prevailing agro climatic conditions of the region. Lot of work has been done in warm humid tropics regarding protected cultivation. The extreme climatic conditions prevailing in North India limits the utility of this technology when compared to mild climatic conditions of places like Pune and Bangalore of Southern India. Hence proper designs suitable to the climatic conditions are needed.

Why protected cultivation?

- Continuous increasing pressure on agricultural land due to urbanization
- Increasing pressure on water available for agricultural sector
- Low productivity and poor quality under open field conditions
- Erratic changes in climatic conditions and climate change
- Increasing thrust of new viruses, diseases and pests
- Fast increasing population and demand of quality fresh food
- Fast change in food habits specifically of urban areas.

The other challenges in open field cultivation that force to adopt protected cultivation are :

- **Biotic stresses**
  - Viruses
  - Insect pests
  - Fungus (air/soil borne)
  - Bacteria (air/soil borne)
  - Nematodes
  - Weeds
- **Abiotic stresses**
  - Temperature
  - Relative Humidity
  - Sunlight
  - Wind velocity
  - Soil salinity/ acidity

Structures used for protected cultivation of Vegetables

Various structures that are suitable for various climatic conditions of our country are,

- **Green houses**

  a) Climate controlled
  b) Semi climate controlled (with pad and fan cool system or heating device)
  c) Naturally ventilated (low cost and can be equipped with solar system and water harvesting structures)
  d) Raised arch
  e) Rain shelters

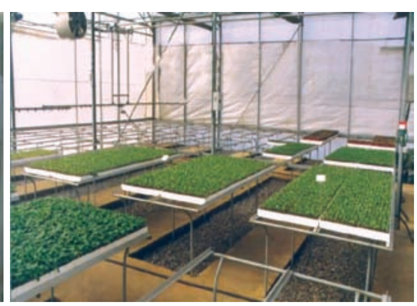
- **Net houses**
  - a) Insect proof net houses
  - b) Shade net houses
  - c) Rain shelters cum insect proof nethouses
- Other temporary structures
  - a) Walk-in tunnels
  - b) Plastic low tunnels
  - c) Plastic mulches (raised bed with drip irrigation system)
  - d) Temporary plastic walls

Protected structures made of glass houses which come under climate controlled green houses are more prevalent in European countries and are not recommended for major vegetable growing tracts of India. The semi climate controlled and naturally ventilated green houses are highly suited for our climatic conditions. They are widely adopted for quality vegetable seedling production. Rain shelters cum insect proof net houses are highly suitable for areas receiving high annual rainfall, where rainfall is the major limiting factor. The temporary structures *viz*., walk-in tunnels and plastic low tunnels are found not suitable for hot and high humid regions. Low pressure drip irrigation system with a head height of 1.5m to 2.0m instead of pressurized drip irrigation system can be employed inside the polyhouse structures which will help reduce the cost of operation. Ventilation is important for protected structures in hot humid climate. Side ventilation of 5m and top ventilation of 1.5m is most ideal for hot humid tropical condition.

Seedling Production in protected structures

Seedling production in protected structures is a lucrative business. Disease free planting material is the first and foremost requirement in crop production. Soilless cultivation can be followed in protected structures for bringing down soil born pest and diseases. Seedling production in plug trays with suitable medium, production of scion

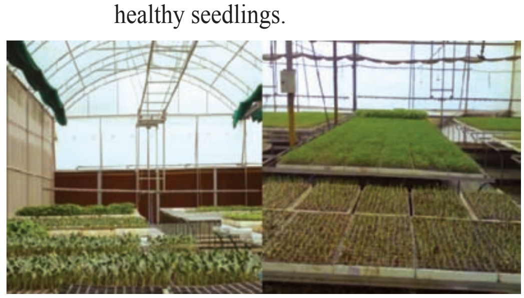
Naturally ventilated greenhouse with brick flooring for raising nursery. Polythene sheet can be spread over the flooring before raising seedling to prevent bacterial wilt and nematodes.



Hi- tech nursery system with raised benches on aluminium belts having semi controlled climate system for virus free healthy seedlings.

Multi celled plug trays for seedling production. These can be of different volume and size depending on the group of vegetables for proper root growth

In hot humid climate, instead of fan and pad cooling system exhaust fans for removing excessive humidity can be used. Ventilation is very important for nursery in hot humid climate.



Green house with fan and pad cooling system is recommended in central, northern and western parts of India where humidity level is very low in summer season.

Cucurbit seedlings ready for transplanting. High root density ensures better establishment in the main field.

and stock for vegetable grafting, maintenance of grafted seedlings are commonly carried out in protected structures. Vegetable grafting is the practice of grafting high yielding disease susceptible varieties on resistant root stocks, mainly followed to combat soil born problems *viz*., bacterial wilt, nematode infection etc. It is a perfect non chemical answer for biotic stress management in vegetable crops. In addition, protected structures are free of insect vectors transmitting viral diseases and ensures climate conducive for seedling growth. Hence these structures help in pest and disease free and healthy seedling production. The utilization of low cost technology for ventilated structures will make the venture economically viable.

Future prospects of protected cultivation in Tropical Region of India

➢ **Challenges for protected cultivation in tropical region**

The future prospects of protected cultivation in tropical region of India can be derived from various challenges that limit the growth. They major limitations are

- Suitable designs of green houses or insect proof net houses having optimum level of ventilation have to be developed.The optimum relative humidity required inside the green house is below 60-70% which helps in reducing pest and diseases incidence. Therefore, ensuring sufficient ventilation is a decisive factor for successful cultivation in protected structures.
- Quality cladding material- deposition of algae on roof top plastic or on the nylon net is a big menace in areas with high rainfall and humidity. Hence it is very important to use good quality cladding material having several characters *viz*., antifungal, antibacterial, antidust, antialgal, UV stabilised etc. Regular cleaning of the cladding material should be practiced, otherwise it adversely affects the production inside the green house.
- Prevailing high humidity is favorable for infestation by major diseases and pest survival under protected conditions
- High vegetation increases the scope for insects and pathogen survival on alternate hosts
- Bacterial wilt and nematodes are a major problem in the warm humid tropics, non-availability of resistant varieties of high value crops suited for protected cultivation is another bottleneck in polyhouse cultivation of vegetables.
- Optimum pollination management in different crops inside protected structures for obtaining high yield and quality produce.

➢ **Opportunities for protected cultivation in tropical region**

- Grafting technologies for vegetable seedlings is a complete non chemical answer for managing the bacterial diseases where resistant cultivars are not available
- Soilless cultivation and multi-tier cultivation of important crops like ginger, turmeric etc is possible inside protected structures
- Use of solar power and rain water harvesting for protected cultivation reduces the cost of cultivation
- Opportunities to grow more crops and makes offseason cultivation possible.
- Skilled manpower is required for the construction and maintenance of protected structures and also for crop management (training, pruning, pinching, pollination, fertigation etc.). Hence there is ample scope for employment generation
- Pollination services are required for good yield. It also creates employment opportunities

➢ **Pollinators and pollination management under greenhouses or net houses**

Pollination management is important in greenhouse structures to ensure high yield and quality produce.

- Use of electric bee/vibrators or air blowers inside protected structures, have very low techno-economic feasibility hence other alternatives have to be employed
- Indigenous bumble bees can be employed for tomatoes or cherry tomatoes and strawberry
- Works are going on to study the potential of carpenter bees as pollinators for curcubits and tomatoes

Nematode infestation in cucumber and tomato grown in infected soil.

Comparison of growth of tomato seedlings grafted on resistant *Solanum torvum* root stocks in root knot nematode infested soil with that of non-grafted seedlings.

Sweet pepper cultivation in insect proof net house. Quality of insect proof net is important in insect proof net houses.

Rain shelters for protected cultivation in China. In hot humid climate, rain shelter cum insect proof net houses, rather than rain shelters alone are suitable to avoid virus vectors from nearby vegetations.

Shade Net house cultivation: Use of different shading intensity shade nets (40-75% shading intensity depending upon different crops) and of different colours allow us to grow different vegetables in shade net house.

Soilless tomato cultivation in bacterial wilt infested area

Use of low pressure drip irrigation system on indigenous platforms at a height of 2 m instead of pressurized drip system inside the protected structures lowers the cost of cultivation in hot humid tropics.

Rain water harvesting can be made possible in protected structures by providing facilities to collect the rain water

Naturally ventilated green houses equipped with mini sprinklers on the roof top for lowering down the temperature during peak summer months by using solar power is recommended for hot areas in western and central plains of India during summer season.

Solar power can be harvested and can be used for protected cultivation in hot and humid areas.

- Stingless bees will be good for cucurbits, capsicum and chilli and studies on this aspect is being carrying out in many places
- Possibility of syrphid flies as pollinator and as biocontrol agent for insects like aphids and white flies etc inside polyhouse is under study.

Post harvest management

Protected structures can be used for post harvest drying of vegetable crops especially vegetables cum spices. It is practiced in drying scented methi, chilli, moringa, mint, kachri etc. It is preferred than open drying as it will take less time, gives uniform drying and produce will be devoid of soil pathogens, dust and soil particles. Traditional system of drying chilli is unhygienic and it creates the problem of aflatoxins which is a major barrier in export of chilli. But drying under walk in tunnels or high tunnels is hygienic and is a part of GAP.

Drying of Nagaurimethi under protected structures ensures better quality (free of soil particles and biotic factors) and less time for drying (takes 2-3 days compared to 4-5 days of drying in open condition

Drying of chilli in protected structures gives uniform colour, superior quality and aflatoxin free produce

Good Agricultural Practices in protected cultivation

Good Agricultural Practices need to be followed and is very important in protected cultivation. It includes several aspects of cultivation inside the polyhouse *viz.*, how to use pesticide, the chemical to be used and at what time and what concentration chemicals should be used, use of pest specific pesticides, cleanliness of the tools, workers, disinfestation of surrounding area to prevent alternate host etc.

GAP under Protected Cultivation

Conclusions

Protected structures open new vista for crop production in various realms. The design of the structure, selection of crop and suitable varieties, use of high quality materials for construction, good quality cladding material and proper maintenance of the structures should be taken care in protected cultivation. In hot humid tropics, structures with maximum natural ventilation on sides as well as on top and rain shelter cum insect proof net houses are highly suitable. Also following good agricultural practices and maintaining the cleanliness inside polyhouse is important in green house cultivation.

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Recent advances in vegetable grafting
&
Prospects for soil less cultivation

Dr. C. Narayanan Kutty
Assoc. Director of Research (Veg Mission) & Nodal Officer, Centre for Hi-tech Horticulture, KAU
Email: cnkutty@gmail.com

Vegetables are a rich and comparatively cheaper source of minerals and vitamins. Some vegetables are also good sources of carbohydrates (leguminous vegetables, sweet potato, potato, onion, garlic and methi) and proteins (peas, beans, leafy vegetables and garlic). The important vitamins present in vegetables are Vitamin A (carrot, tomato, drumstick, leafy vegetables), Vitamin B (peas, garlic and tomato) and Vitamin C (green chillies, drumstick leaves, Cole crops, leafy vegetables and leaves of radish). Leafy vegetables and drumstick pods are good sources of minerals

Vegetable crops are highly sensitive to climatic changes, hence fluctuation in climatic parameters can affect crop at any phase of its growth, flowering and yield. Major limiting factors affecting vegetable productivity are various biotic and abiotic stresses like insect pests, diseases, increasing temperatures, drought, flood, salinity, acidity and alkalinity. Climate change also influence pest and disease occurrences, host-pathogen interactions, distribution and ecology of insects, time of appearance, and migration to new places and their overwintering capacity, thereby causing major setback to vegetable production. To mitigate the adverse impact of various stresses on productivity and quality of vegetable crops, there is a need to develop novel adaptation strategies such as breeding hybrids resistant to biotic and abiotic stresses, grafting to combat biotic and abiotic stresses and management techniques like drip irrigation, mulching, fertigation, use of hydrophilic substances like hydrogel**.** Grafting is widely used to tolerance to biotic and abiotic stresses in vegetables.

Grafting is an art and technique in which two living parts of different plants *i.e.*, rootstock and scion are joined together in such a manner that they would unite together and subsequently grow into a composite plant (Kumar *et al.,* 2018). Rootstock is the lower working part of the plant which interacts with soil to nourish the new plant. Scion is a detached upper part of a plant shoot joined to the rootstock in grafting.

Grafting in vegetables has emerged as a promising and an alternative tool to the relatively slow conventional breeding methods aimed at increasing tolerance to abiotic stresses. Grafting can also improve crop resistance to biotic stress (Padgett and Morrison, 1990), and can also be an important tool for improvingfruit quality (Martínez-Ballesta *et al.,* 2008): Fruits obtained fromgrafted plants may show better quality than those obtained from non-grafted plants as function of the rootstock (Fernández-García *et al.,* 2004). A positive relation was found between using plants grafted on different rootstocksand improvements in production and fruit quality parameters(Giorni *et al.*, 2005). Grafting can determine changes in fruitcomposition that can be deleterious or harmful as reported for the accumulation of nicotine in tomato from plants grafted onto *Nicotiana tabacum* L. (Yasinok *et al.,* 2009) or for scopolamine andatropine accumulated at poisoning levels in fruit of eggplant grafted on to *Daturainoxia* P.Mill. (Oshiro *et al.,* 2008).

Today grafted vegetable transplants arewidely used to provide resistance to soil pests and pathogens, to increase the tolerance to abiotic stresses, to improve water or nutrient uptake, or to enhance the vigour of the scion. Lack of cultivars tolerant orresistant to increasingly important soil biotic and abiotic stresses, together with the prohibition of the use of methyl bromide for soil disinfestations, have led to a worldwide renewed interest in vegetable grafting (Bletsos, 2005).

2. History of grafting

Production of grafted vegetables first started in Japan and Korea in late 1920s, where scions of water melon were grafted onto pumpkin rootstock. In 1930, scions of water melon were grafted onto rootstocks of bottle gourd to overcome the soil-borne diseases like *Fusarium* wilt. In 1950, brinjal (*Solanum melongena*) was grafted for the first time onto scarlet egg plant (*Solanum integrifolium* Poir.) to control soil borne diseases. In 1959, scions of brinjal were grafted onto Scarlet eggplant toavoid the injury caused by soil borne diseases such as *Verticillium* wilt, *Fusarium* wilt, bacterial wilt and nematodes. In 1960, melons were grafted on to *Benincasa* spp. to reduce the effects of low soil temperatures in greenhouses. In 1976 large scale production of grafts of muskelon and watermelon was started in Spain.

Grafting to overcome biotic stress

Soil borne diseases, especially bacterial wilt, are serious problems in growing vegetables in coastal acidic soils in the world. Bacterial wilt caused by *Ralstonia solanacearum* is a soil borne bacterium which enters the plants through root injuries. Inside the plant, bacteria multiply and block the vascular bundles, the chief conducting tissue of water and nutrients, thereby causing sudden wilting of plants. Bacterial wilt is very common in Kerala, especially in solanaceous vegetables like tomato, brinjal and chilli. Grafted plants on resistant rootstocks of solanaceous vegetables were highly resistant to bacterial wilt and high yielding (Narayanankutty *et al.,* 2015). McAvoy *et al.* (2012) evaluated seven hybrid tomato rootstocks with resistance to bacterial wilt along with a known resistant cultivar as a rootstock to impart resistance to a bacterial wilt-susceptible cultivar, BHN 602. Greenhouse studies showed resistance to bacterial wilt in all the rootstocks and the technology holds promise for decreasing the impact of bacterial wilt on tomato cultivars as well as increasing the overall productivity of tomato cultivars.

A wild brinjal (*Solanum torvum*) was completely resistant to *R. solanacearum* in soil drench and also in petiole inoculation. *S. torvum* is used as a potential rootstock in grafting to combat bacterial wilt since it is incompatible with cultivated brinjal for breeding programmes (Ramesh *et al.,* 2016). Rana *et al.* (2015) evaluated five rootstocks of capsicum and three rootstocks of brinjal for bacterial wilt resistance in bell pepper under polyhouse at Palampur (H.P.). They reported chilli rootstock PI-201232 as the most suitable as bacterial wilt resistant rootstock of bell pepper whereas brinjal rootstocks were not suitable for bell pepper scions.

Lin *et al.* (1998) grafted two popular local tomato cultivars, Farmers 301, susceptible to bacterial wilt, and Taichung ASVEG No. 4, moderately resistant to bacterial wilt, onto 12 bacterial wilt resistant rootstocks including six tomatoes and six eggplants. Eggplant accession VI045276 (EG203) and tomato accession VI043614 (Hawaii 7996) were the most stable rootstocks among the 12 tested with bacterial wilt incidence ranging from 0 to 3% and 0 to 23%, respectively, compared with heavy incidence in other susceptible rootstocks. The scion effect was signiûcant in all the trials with less incidence of wilting when a moderately resistant cultivar was used as the scion.

The rootstocks for cucurbits include bottle gourd and *Cucurbitamoschata* × *C. maxima* hybrids both of which are highly resistant to *Fusarium oxysporum* causing severe losses to crop (King *et al.,* 2008). A study conducted by World Vegetable Centre (WVC), Taiwan showed that disease susceptible lines of bottle gourd can be grafted onto Luffa (sponge gourd) or pumpkin to improve crop performance (WVC, 2013). By usingVerticillium wilt tolerant rootstocks; commencement of symptoms can be postponed for three weeks, consequently the watermelon fruits can reach to maturity (Paplomates *et al.,* 2000). The 'Shintoza' rootstock increased fruit size of grafted plants, and improved yield stability by decreasing the coefficient of variation to 20%. This rootstock is an effective alternative to soil fumigation by methyl bromide for the control of *Fusarium* wilt in watermelon production, as it is cheaper and safer, and the yields are higher and more reliable (Miguel *et al.*, 2004). Vitale *et al.* (2014) studied the effect of different tomato scion-rootstock combinations on the susceptibility of plants to *Fusarium oxysporum f.* sp. *radicis-lycopersici (FORL),* the causal agent of crown and root rot. The extent of vascular discoloration caused by FORL in tomato plants grafted on "Natalia" as rootstock was significantly lower than that of plants grafted on sensitive "Cuore di Bue". Proteomic studies showed a higher representation of proteins associated with pathogen infection in the tolerant rootstock, compared to the sensitive one, meaning a direct involvement of plant defence mechanisms in tomato plants.

Thies and Levis (2007) reported that watermelon plants grafted onto wild watermelon rootstocks (*C. lanatus*var. *citroides*), were resistant or moderately resistant to the nematode, *M. incognita*. Pumpkin (*C. moschata)* is a potential rootstock used for cucurbits, having a high intensity of tolerance to root knot nematode (Siguenza, *et al.,* 2005). Thies *et al.* (2010) evaluated four bottle gourd (*Lagenaria siceraria*) cultivars, one squash (*Cucurbita moschata*× *C. maxima*) hybrid and five wild watermelon (*Citrullus lanatus* var. *citroides*) germplasm lines as rootstocks for cultivated watermelon (*C. lanatus* var. *lanatus*) in fields infested with the southern root-knot nematode (*Meloidogyne incognita*). The result showed that plants with the *C. lanatus* var. *citroides* as rootstocks exhibited significantly less rootgalling than plants with the squash hybridand bottle gourd rootstocks. The fibrous root production by *C. lanatus* var. *citroides* accessions and breeding lines were associated with resistance to nematodes.

Grafting techniques to overcome abiotic stresses

a. Salinity

Salinity is one of the most important abiotic stresses, hampering plant growth, development and productivity in many vegetables around the world. High salt concentration causes imbalance in cellular ions, resulting in ion toxicity and osmotic stress leading to the generation of ROS (Reactive Oxygen Species). The deleterious effects of salinity on plant growth is associated with (1) low water potential of the root medium, which causes a water deficit within the plant; (2) toxic effects of ions, mainly Na^+, Cl^-_2, and SO_4^{2-}; (3) nutritional imbalance caused by reduced nutrient (e.g. K^+, Ca_2^+, Mg_2^+) uptake and/or transport to the shoot (Colla *et al.,* 2010).

Grafted cucumber showed increased flavour, taste and nutrient contents compared to non-grafted plants (Zhou *et al.,* 2007). Goreta, *et al.* (2008) reported watermelon cv. Fantasy grafted onto Strongtosa rootstock (*C. maxima Duch* × *C. moschata Duch*) increased the shoot weight and leaf area even under saline conditions. Watermelons grafted onto saline-tolerant rootstocks produced higher yield under greenhouse production (Colla *et al.,* 2010).

Estan *et al.* (2009) tested the effect of hybrid rootstocks derived from salt tolerant lines of wild tomato relatives namely *S. pimpinellifolium* and *S. cheesmaniae* crossed with the salt-sensitive *S. lycopersicum* var. *cerasiforme*. The commercial tomato variety Boludo was used as scion on these rootstocks. Grafting was effective in improving productivity, particularly with respect to fruit number under saline conditions. Crossing with wild relatives was a partially effective strategy in breeding tomato rootstocks for saline soils.

To prevent the negative effect of ROS (Reactive Oxygen Species), plant has developed an antioxidant enzyme system. In grafted plant, the level of antioxidant is higher than the normal plants. Antioxidant enzymes like catalase and peroxidase detoxify the toxic effect of hydrogen peroxide However, superoxide dimustase catalyses the superoxide and break down into water and oxygen. Aascorbate peroxidase reduces the level of hydrogen peroxide by using ascorbate as an electron donor in the ascorbate- glutathione cycle thus, providing tolerance against salinity (Kusvuran *et al.*, 2016). Fruit weight of grafted tomato F_1 hybrid was significantly higher when compared to non-grafted plants under salinity.

b. Drought

Understanding the concept and component of drought resistance is a key factor for improving drought tolerance in any crop. In plants, water deficient condition is first recognized by roots. In grafted plants due to higher activity of H+ ATPase enzyme, the rootstock puts forth a large and deep root system to acquire more water from the soil (Sze *et al.,* 1999).

In drought situation, plants also start the osmotic adjustment by active accumulation of solutes within plant tissue in response to lowering of soil water potential and maintaining the turgor of cell and leaf water potential (lwp). (RanaMunns, 2011). By maintaining lwp, it promotes the stomatal conductance to CO_2 and maintains the internal CO_2 concentration which ultimately increases the rate of net photosynthesis and promotes growth (Roy and Basu, 2009).

Sanchez-Rodrý´guez*et al.* (2012) studied whether scion or rootstock with drought-tolerant characteristics are able to increase fruit quality and production under water stress in grafted plants. Two tomato cultivars, Zarina (drought tolerant), and Josefina (drought sensitive), were grafted onto themselves and reciprocally. The results showed that the use of Zarina as a rootstock resulted in a larger number of fruits per plant when grown under water stress conditions. The grafted plants showed higher level of sugars as well as important minerals, such as K and Mg, which could increase tomato nutritional quality under stress conditions.

Cucurbits grafted onto pumpkin provided drought tolerance in sandy soils. Watermelons grafted onto a commercial rootstock PS1313 (*Cucurbita maxima* Duch × *Cucurbita moschata* Duch) showed an increase of over 60 % higher yield when grown under drought conditions in contrast to non-grafted melon plants (Rouphael *et al.,* 2008). The marketable yield of greenhouse pepper (*Capsicum annum* L.) was improved under water-stressed conditions when grafted onto the rootstocks "Atlante," "PI-15225," and "ECU-973." This was affected by their ability to maintain net photosynthetic rate under deficit irrigation (Penella *et al.,* 2014). Agele and Cohen (2009) demonstrated the effect of scion and grafting methods on leaf water potential (lwp) of grafted musk melon (*Cucumis melo*) using melon cultivar Arava as a rootstock for two genotypes (RS-57 and RS-82) through side and V-method of grafting.Grafting induced modifications in root-shoot ratio, hydraulic characteristics of sap pathway and water relations showed tha tAravais a resistant rootstock under drought condition.

c. Flood

Floods emerged as a major threat to vegetable production in many parts of the world. Flood causes oxygen starvation, which arises due to slow diffusion of gases in water and oxygen consumption by micro-organisms. Grafted plants showed depression in photosynthetic rate, stomatal conductance and transpiration rate under flooded condition.

They also induce a chemical signal in xylem sap under low oxygen condition and stimulate the synthesis of ethylene in roots. Ethylene helps in formation of adventitious roots at the sub-surface region of plant and which in turn helps the plants to absorb oxygen from air and enhanced nutrient assimilation (Schwarz *et al.*, 2010). Due to the accumulation of ethylene in sub-merged parts of plants, the formation of aerenchymatous tissues is stimulated, which favours the longitudinal transport of O_2 from aerial parts of plant to the submerged parts under anoxia condition (Roy and Basu, 2009). The rapid development of epinastic growth of leaves is a characteristic response of tomatoes to waterlogged conditions and the role of ethylene accumulation has been implicated (Kawase, 1981).

d. Acidity

Acidic soils represent 50% of the earth's arable land and in these soils, aluminium toxicity is the main factor restricting crop productivity. In acidic soils with pH lower than 5, Al-containing minerals (*e.g.,* alumina silicates) are solubilised in the phytotoxic form Al_3^+.The root is the first organ showing aluminium toxicity, thus conditioning stress sensitivity and hampering crop productivity (Siguel *et al.,* 2013).

Al concentration in the range of 1–2 mgL^{-1} can inhibit root elongation by damaging the cell structure of the root apex and thus influencing water and nutrient uptake (Rengel *et al.,* 2015). Studies conducted in acidic soils revealed that cucumber plants grafted on pumpkin rootstock exhibited lower yield reduction when compared to plants grafted on fig leaf gourd and non- grafted control (Rouphael *et al.,* 2016).

e. Alkalinity

Alkaline soils are clay soils with high pH (> 8.5), having poor soil structure, hard calcareous layer and a low infiltration capacity. It is due to the presence of sodium carbonate or sodium bicarbonate in the soil. Watermelon plants grafted onto pumpkins and grown in high pH soil had a higher exudation of organic acids through the roots, consequently facilitating the uptake of nutrients (Colla *et al.,* 2010). Mohsenian *et al.* 2012 studied the effect of a wide range of rootstock species *viz.* eggplant (*Solanum melongena*), datura (*Datura patula*), orange nightshade (*Solanum luteum*), tobacco (*Nicotiana tabacum*) and tomato (*S. lycopersicum*) for their tolerance to alkalinity. Grafting improved the alkalinity tolerance of tomato cv. Cal.jn3. Depression of leaf area, plant dry weight and shoot Fe content were seen at the highest level of sodium bicarbonate concentrations in all plants, but it was the highest in the non-grafted controls. The datura rootstock showed alkalinity tolerance. Tolerance was achieved by a better translocation of iron from the roots to the shoots in these grafted plants. The orange nightshade and eggplant rootstocks did not show much promise in providing tolerance to alkalinity.

f. Low temperature

Low temperature affects plant root growth, nutrient absorption, translocation of water osmoregulation and anti oxidants synthesis.

a) Root growth and architecture: Low temperature affects root growth, size, architecture as well as functioning. Under sub-optimal condition, cold tolerant rootstocks maintain higher root growth than the sensitive ones and have a greater capacity to adjust their root/ shoot ratio
b) Nutrient absorption: High root elongation in grafted plants helps in more nutrient uptake and transportation and also improves the phosphorous uptake capacity of plants. In normal plants, phosphorous uptake is depressed at decreasing root temperature and phosphorous starvation may induce ethylene production and decrease the cytokinin content in the root
c) Translocation of water and osmoregulation: Cold tolerant rootstocks overcome the restrictions of water absorption by increased level of root hydraulic conductance, decreased induction of cell wall suberin layers, lipid peroxidation and closure of stomata
d) Lipid peroxidation and antioxidants: Low temperature stress increases production of Reactive Oxygen Species (ROS) in root of chilling sensitive plants, which may cause peroxidation of unsaturated membrane lipid and result in decreased membrane selectivity and fluidity and increased membrane rigidity which cause leakage of electrolytes, water and other soluble materials out of cell into the intercellular space of the roots Grafting on a low-temperature tolerant rootstock (*e.g.Solanumhabrochaites)* appeared to be a useful tool in tomato to increase shoot growth at suboptimal cultivation temperatures due to stimulation of leaf expansion rate (Venema *et al.,* 2008).

g. High temperature

High temperature affects plant morphology, physiology as well as biochemical properties. Under high temperature conditions, potential rootstocks start the accumulation of compatible osmolytes (proline, valine, soluble sugars etc.) which are necessary to regulate the osmotic activities and protect cellular structures from increased temperature by maintaining the cell water balance, membrane stability and buffering the cellular redox potential. This also helps in better stomatal regulation and enhanced photosynthesis.

Heat tolerant rootstocks increase the production of antioxidants with decreased level of ROS generation in plant during stress conditions. It causes less photo-oxidative damage and maintains chloroplast membrane integrity and increases the photosynthetic rate (Waraich *et al.*, 2012). High temperature induces the accumulation of phenolics in tomato plants by activating their biosynthesis as well as inhibiting their oxidation. The concentration of total phenol was higher in non-grafted tomato plants than in grafted plants. Grafted plants showed no massive accumulation of phenolic compounds, this being directly reflected in greater biomass production and better shoot development than in non-grafted plants (Rivero *et al.,* 2003). Abdelmageed *et al.* (2004) cultivated grafted tomato under high temperature condition using heat tolerant cultivar 'Summer Set' and 'Black Beauty' as rootstock and less heat tolerant cultivar UC-82-B as scion under two different temperature regimes 38/27^0 C and 30/22^0 C. UC-82-B grafted onto Black Beauty showed the lowest electrolyte leakage under both temperature regimes. Eggplants (*S. melongena* cv. Yuanqie) grafted onto a heat-tolerant rootstock (cv. Nianmaoquie) resulted in a prolonged growth phase and the total yield increased up to 10 % (Wang *et al.,* 2007).

h. Heavy metals

Increased concentration of heavy metals such as cadmium, mercury, lead, arsenic *etc.,* constitute a rising hazard to plant growth, development and yield and it is also detrimental to human health and environment. The heavy metals come from various sources either from industry, waste water or through soil amendments and accumulating in plants though some of heavy metals are poisonous even in low concentrations while others remain in plant tissues devoid of losing yield and observable symptoms (Oves *et al.,* 2012).

A survey conducted in Japan showed that 7% of eggplant fruits contain high cadmium than the internationally acceptable limit. (Takeda *et al.*, 2007). Heavy metal stress causes oxidative damage to plant through ROS formation. Excess Zn alters mitotic activity, affects membrane integrity and permeability. Rootstocks have ability to limit the heavy metal accumulation in aerial parts of plant. Cadmium is a toxic heavy metal, which negatively affects plant growth and alters the uptake of minerals from the soil Cadmium restricts the photosynthesis, nitrogen metabolism, water transport, phosphorylation in mitochondria and chlorophyll content (Suvas *et al.,* 2010).. Grafted plants were found to reduce the translocation of cadmium from plant roots to shoot and fruits (Arao *et al.,* 2008). Kumar *et al.* (2015) reported that vigorous rootstock Maxifort effectively mitigate the adverse effects of cadmium by increasing the synthesis of antioxidants and proline.

Basic pre-requisites for vegetable grafting

1. Selecting the right rootstock/scion:

Select the desirable rootstock and scion having the same stem girth. Grafting should be done at appropriate stage of growth of scion and stock..

2. Graft compatibility:

Compatible rootstock and scion minimizes the mortality rate even in later stage of growth. Rapid callus formation takes place between scion and rootstock leading to the formation of vascular bundles. Graft incompatibility leads to undergrowth or overgrowth of scion, decreased water and nutrient flow leading to wilting symptoms. Graft incompatibility can be due to tissue structure, physiological and biochemical characteristics, growing stage of rootstock and scion, phyto- hormones and environment.

Grafting aids:

Commonly used aids to perform grafting are grafting clips, tubes, pins, and grafting blade**.**

4.4. Screening house:

Used for growing seedlings prior to grafting. It should be constructed with 60-mesh nylon net. Arrange double door, the upper half of the structure should be covered with a separate UV (Ultraviolet) resistant polyethylene to prevent UV light penetration.

4.5. Healing of grafts:

Healing is most critical to provide favorable conditions to promote callus formation of grafted seedlings. In healing chamber, temperature should be 28-29^{0}C with 95% relative humidity for 5-7days in partially shaded place (darkness for 1-2 days) to promotes callus formation at union. It helps in formation of better graft union by reducing transpiration, maintains high humidity, maintains optimum temperature and reduces light intensity. The main aim is to initiate environment by controlling temperature and humidity.

4.6. Acclimatization of the grafted plants:
Wounded surfaces are healed after the callus formation and plants are kept under a mist chamber, greenhouse or placed under a clear plastic cover for acclimatization to prevent leaf burning and wilting.

5. Methods of grafting:
The familiar methods used for vegetable grafting were

5.1. Cleft grafting:
This is widely used method of grafting in solanaceous vegetables. Here scion plants are pruned to have 1-3 true leaves and the lower stem is cut to slant angle to make a tapered wedge and clip is placed to make contact between scion and rootstock after placing scion into the split made on the rootstock.

Production of grafted vegetable seedlings
Generally inter or intra specific grafting with resistant *Solanum* species is followed in solanaceous vegetables. Under Kerala conditions, tomato and brinjal seedlings can be grafted on to *Solanum torvum* or the wilt resistant brinjal variety Haritha while for chilli and capsicum hybrids the wilt resistant chilli variety Ujjwala is used as the rootstock.

1. Raising root stock seedlings
*Solanum torvum*commonly known as Turkey Berry or Prickly Night shade is most widely used as a root stock for grafting tomato and brinjal. Besides being resistant to bacterial wilt it is also immune to root-knot nematode (*Meloidogyne* sp.) a serious problem in solanaceous vegetables. *Solanum torvum* is a bushy shrub growing to a height of 2.0 - 3.0 m in about two years. It has a single stem at the base but may branch out in the lower stem itself. The plant is spiny bearing numerous white flowers in corymbiform cymes. The fruits are berries borne in clusters, green when immature about 1.0 cm in diameter and turning to uniform yellow when ripe. Fruits contain numerous flat round tiny seeds. Around 1000 seeds weigh 1.0 g. Fresh seeds can be sown immediately within a fortnight after extraction. Seeds loose viability within 4 - 5 months of storage. Treating the seeds with 0.1% potassium nitrate solution for 1.0 - 2.0 hours improved the germination rate of stored seeds.

Chilli and capsicum are grafted on resistant chilli variety Ujjwala developed by the Kerala Agricultural University. The variety has a strong erect stem profusely branching from the base growing to a height of 80 - 90 cm. Fruits are highly pungent borne upright in clusters (8-10 fruits/cluster) green when immature turning to uniform dark red when ripe.

For raising root stock, seeds of *Solanum torvum* and chilli are sown in pro-trays in a soil less medium containing 3 parts by volume of washed coco peat and one part each of vermiculite and perlite. Chilly seeds are sown in trays having 1.0" x 1.0" cell size. For *Solanum torvum* it is better to go for trays having cell size 2.0" x 2.0" to accommodate the vigorously growing roots. *Solanum torvum*takes at least 15 - 20 days to germinate. It is difficult to sow the small seeds individually in pro-trays. Normally 8-10 seeds are sown in a single cell and when the seedlings reach 3-4 leaf stage excess seedlings are transplanted to a new tray retaining one seedling in each cell. Root stock seedlings require daily irrigation and fertigation once in 5-7 days. Water soluble fertilisers 19:19:19, 20:10:20 or 20:20:20 are used for fertigation. Fertilisers are applied at the rate of 350- 400 ppm N along with the irrigation water.

Solanum torvum seedlings have a slow growth rate initially and may take around 25-30 days to grow to a height of 5-8 cm when the seedlings are ready for grafting. Chilly seedlings will be ready for grafting in 20-25 days after sowing.

2. Raising scion seedlings
The desired commercial hybrid/variety is used as the scion. The scion seeds are raised in pro- trays having cell

size 1.0" x 1.0" at the rate of one seed per cell. Irrigation and fertigation is followed as in the case of root stock seedlings. The scion seedling will be ready for grafting in 20-25 days after sowing.

3. Grafting Techniques

Tube grafting, Wedge grafting, Slant/side grafting are the common methods of grafting followed in solanaceous crops. For tube grafting silicon tubes 1.0 cm long are used. Hollow silicon tubes 2.0-3.0 mm diameter holes are used for this purpose. The root stock seedlings are de-topped at a height of 5.0 – 6.0 cm from the base. The silicon tube is slowly slipped over the stock seedling. The seedling is then split longitudinally through the centre to a length of 1.0 – 1.5 cm. with a razor blade. The scion seedling is then detached from the pro-tray by giving a horizontal cut 4.0-5.0 cm above the base. A small tapering cut is then given at the base of the detached scion on both sides so as to make a wedge of length 1.0- 1.5 cm. The prepared scion is then inserted in to the split made in the stock and the silicon tube is raised up so that the scion and stock are firmly held together.

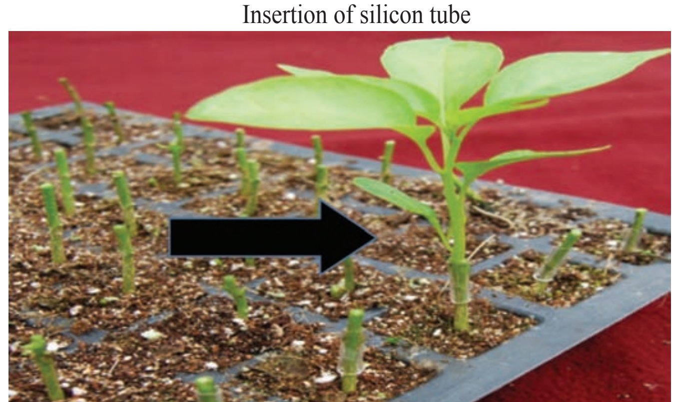
In wedge grafting the same procedure is followed but the stock and scion are held together using a grafting clip made of plastic. This method is comparatively easy when compared to the silicon tube which has to be cut and removed once the graft joint is established. Grafting clips can be easily detached from the graft joint and reused again.

Slant/ side grafting is also carried out in vegetable seedlings. For this the stock is de-topped by giving a slanting cut 5.0 – 6.0 cm above the base. A small polyethylene sleeve (1.0 cm length) is then fixed on the root stock where the slanting cut is given. A matching slanting cut is given on the scion seedling and the scion is inserted in to the polyethylene sleeve attached to the stock so that the slanting cut made on the stock and scion coincide each other.

Preparation of rootsatock

Insertion of silicon tube

Inserting the scion into rootstock



Grafted plant

Plate 1: Tube grafting

Hole insertion grafting is commonly followed in cucurbits. Seedlings with two cotyledon leaves along with a newly emerging true leaf are selected for grafting. The newly emerging leaf of the stock are nipped and a hole is created by piercing a small stick through the middle of the two cotyledon leaves. The stem of the scion plant of the same stage of growth is then fixed in to the hole after giving a slanting cut on both sides of the stem. The grafted plant is then moved to the healing chamber


Longitudinal splitting of rootstock


Preparation of scion into wedge shape


Insertion of scion into rootstock


Grafted plant

Plate 2: Wedge grafting

Rootstock and scion


Prepared rootstock and scion


Joining rootstock and scion


Securing the joint with clip

Plate 3: Splice grafting

Rootstock and scion


Making hole in the rootstock


Inserting scion in the rootstock


Securing the joint with grafting clip

Plate 4: Hole insertion grafting

4. Healing of Grafted Seedlings.

The vegetable seedlings after grafting are immediately shifted to a healing chamber which provides a hot (25 – 30^{o} C), humid (90 - 95% RH) environment for the grafts to heal and establish. High humidity is maintained inside the healing chamber by spraying water or fogging at periodic intervals depending upon the weather. The grafts will heal in a period of 4 -5 days. After this they are transferred to a poly house and kept for a week for further hardening. The hardened seedlings are then taken out for transplanting.

Field trials using grafted seedlings have given encouraging results. There is 100% control of bacterial wilt and yields are better. In field trials conducted at Mannuthy grafted tomatoes yielded on an average 40.0 tons/ha and chilly 15.0 tons/ha. Grafted capsicum yielded 32.0 tons/ha in poly house cultivation. The Asian Vegetable Research and Development Centre (AVRDC) have reported 25% increase in yield in field trials conducted in Karnataka using grafted seedlings produced at Mannuthy. Other states like Odisha and West Bengal have also shown interest in grafted seedlings

SOIL LESS CULTURE

Cultivation of crops in every medium which is not soil and completely detached from the soil

Media for soil less cultivation

Media for soil less cultivation could be organic or synthetic materials which are cheap and locally available. Some of the materials widely used as media are

- Organic - Straw, Coconut, Compost, Peat
- Synthetic - Polyethylene, Styrofoam
- By Product of Thermal Processes - Perlite, Vermiculite, Rockwool
- Volcanic Rock - Tuff, Pumice
- Combinations

Prospects of soil less cultivation

Soil less cultivation has a great potential in future especially in urban and peri-urban areas where there is increasing competition for land and other resources. The major advantages of soil less cultivation are

- Increased yields (by two folds and more)
- Plant population (higher limited only by available light and not from soil nutrient availability)
- Soil borne diseases and weeds (free or much less)
- Improved quality and faster crop ripening
- pH stability (better control)
- Flexibility
- Sterilization (more effective and less amount)

Ideal Substrate for Soil less Cultivation

There is no substrate that can be termed an ideal substrate for soil less culture. Some of the desirable properties a soil less media should have

- Easily available water, oxygen and nutrients
- Quick release of CO_2
- pH and temperature that are compatible
- Free of soil pests and easy to fumigate
- Pore capacity 80 - 90% , pH- 5.5 - 5.8,
- CEC - 40 - 200 meq/100gr

- Low C/N ratio
- Toxic and salty elements absent or negligible

VERTICAL FARMING

Vertical farming or V-farming is a method of soil less farming commonly followed to produce leafy vegetables *viz.*, mint, lettuce, kale, basil and fruits like strawberries where there is nearly no arable land

- Crops are grown in vertically stacked layers made of PVC pipes resembling a multi-storied building of plants. The plants are grown in a controlled environment under artificial lighting using LED bulbs, in a poly house on rooftops or open land.
- V-farming can be in either aeroponics (growing plants in air or mist without the use of soil or an aggregate medium) or hydroponics (growing plants using mineral nutrient solutions in water solvent without soil).

Summary

Although grafting in vegetable seedlings is common in many countries in the West and in Asia, in India this technique has not been commercially exploited so far. The success of grafting technology has now provided an opportunity for commercial cultivation of solanaceous vegetables in coastal acidic soils of the country where bacterial wilt is a severe problem. Standardization of technology for the large scale production of vegetable seedlings in pro-trays has provided a platform to easily undertake the grafting of seedlings. A trained person can easily graft 600-700 seedlings in a day. Grafted seedling production could be taken up as a successful agribusiness venture by the un-employed youth of the country. Soil less cultivation and vertical farming has great potential in Urban areas especially for maximising productivity from limited land area.

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Recent developments in crop management of important vegetables under polyhouse and rain shelter

Dr. Shankara Hebbar, S.
Principal Scientist, IIHR, Bangalore, Email: shankara.hebbars@icar.gov.in

Cultivation of vegetables under protected structures is having several advantages including quantum jump in yield with high quality, protection against abiotic and biotic stresses and off season production. Important protected structures are given below,

- Floating Row covers
- Rain shelters
- Trenches
- Low Tunnels, walk in low tunnels
- Net Houses; shade houses, Cable supported flat roof net houses
- Poly houses
- Glass houses
- Retractable roof greenhouse
- Automatic or semi -automatic curtain movement
- Force air circulation and cooling
- Fan and pad green house cooling
- Fog cooling Computerized greenhouse operations

The design of the polyhouse should be carried out by considering the climatic condition of the area as well as the economics. Naturally ventilated polyhouse have to be designed well depending upon the climatic conditions. Various standards have been developed by different departments and funding agencies. Naturally ventilated polyhouse havingbmulti span with top ventilation and tubular structure should have an ideal gutter size of 4 to 5 meter, 4.0 m minimum from ground level at any point. Hot dipped, Galvanized Iron pipes can be used for the construction. GI pipe wall thickness should not be less than 2mm for all the structural components. Galvanization of structural members should not be less than 300 GSM (grams per square meter). Structural member should be preferably connected with clamps, nuts & bolts and fasteners properly. The quality of the material we are using is very important. The association between length thickness and diameter of the pipes has to be calculated. Pipe specifications are given below,

Sl. No.	Component	OD (inch)	OD (mm)	Minimum wall thickness (mm)	Weight per meter length(Kg)
1	Column Foundation pipe	2½	76	3.0	5.36
2	Corridor Foundation pipe	2	60	3.0	4.20
3	Column (pillar)	2½	76	2	3.75
4	Arch Purlin	1½	48	2	2.30
5	Gutter purlin	1¼	42	2	2.1
6	Boundary or perimeter purlin	1¼	42	2	2.10
7	Balcony/corridor/hockey column	2	60	2	2.85
8	Corridor horizontals	2	60	2	2.85
9	Top and bottom arch of truss	1¼	42	2	2.10
10	vertical and inclined members of truss	1	33	2	1.60
11	Bottom chord of the truss	1½	48	2	2.30

Good agronomic practices under protected structures require good ventilation and light transmission. Light transmission depends on the properties of the covering material and the number of opaque supporting members, as well as the greenhouse geometry and orientation. Among the green house covering materials, polyethylene is most widely used and most economical. The essential pre-requisites of the covering materials are UV stabilized, 200 micron thick, 3/5/7 layered, anti drip/mist, anti dust, diffused 50 to 70 %, having minimum 85% level of light transmittance. Several aspects should consider before selecting the covering material. While installing the multilayer film, first ensure that respective layers are facing the right direction as shown on film (e.g. inside out). The logo, brand name and batch no with code number must be printed at regular interval on poly films that should not get washed easily.

Optional properties of covering materials includes,

- Anti sulphur for the crops where sulphur consumption is high.
- IR Reflective cooling –for high temperature area.

Certificates to be provided:

1) Test report from Central Institute of Plastics Engineering Technology (CIPET).
2) Technical Data Sheet

While selecting the covering material, UV stabilizers, anti-sulphur (Ni-Q), mechanical strength & thermal stabilisers must be added to all the layers for uniform performance of the features. Adding these to only/ any one layer will result in failure of film before promised duration.

Multilayer is constituted as follows,

Outer (1):	Anti-Dust + IR-Cooling
Outer (2):	IR-Cooling +Metalocene (Strength)
Middle (3):	Light Diffusion
Inner (4):	Anti-Drip +EVA (Flexibility)
Inner (5):	Anti-Drip + IR-Thermic

Light is required inside the polyhouse but, high heat is not desirable. That is the major challenge we are facing. The environmental factors like temperature and relative humidity should be properly controlled inside the polyhouse. It is researchable issue.

Rain shelter is suitable for humid tropics with high rainfall. Even in Bangalore with 800 mm rainfall, the rainshelter was a success. Rainshelter cultivation could control the diseases like early blight and late blight. Net houses with different design aspects are there. Flat roof net house with least steal is one of the preferable structure to manage the temperature in hot climate ie. tempetarute more than 38^{o}C in summer months. Nylon net house can exclude all the insects. So that, we can grow safe vegetables. Consumers always prefer pesticide residue free vegetables especially in case of leafy vegetables. In such situation ultivation under nylon net houses is an ideal option.

We can produce quality seedlings in protected structures. Seedlings of tomato, cabbage, cauliflower, capsicum, brinjal, chilli are producing commercially inside the protected structures. Flat or portray seedling production can be done using jiffy media plugs, V shaped plugs, netted pots, or automated seedling production assembly line. Seedlings can be also raised on movable benches. Grafted vegetable seedlings are also produced under protected structures. Webb and flow irrigation or over head boom irrigation can be done in nurseries.

Nethouse is an ideal option for seedling production. The usual mesh size is 40, which is not sufficient for controlling the whiteflies and thrips. They act as the vectors for transmitting viral diseases. Therefore to produce virus free seedlings the mesh size should be decreased.

Coming to the media used for nursery, if cocopeat is using it should be well decomposed. IIHR has developed a product called Arka Fermented Cocopeat. Fermentation is the process of breakdown of complex molecules into simpler products. In this process a fungal consortium is used to breakdown tannins and phenols present in raw coirpith. The end product (cocopeat) is finally enriched with beneficial microbes. In these process no washing or no need of assessing Ph or EC. Raw cocopeat can be used and it is a commercial success.

Fermented Substrate

↓

Fermentation for 30 days **Fungal Consortium**

Arka Fermented Cocopeat

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Arka Microbial Consortium **Enrichment and Stabilization – 1 day**

Capsicum and English cucumber are the two main crops used to cultivate under protected structures. Tomato is not cultivating in a commercial scale under protected structures. Other crops used to cultivate are leafy vegetables (celery and lettuce), bottle brinjal, seedless watermelon, melons, beans, cowpea and peas. But the area under these vegetables is less. Exotic vegetables that can be cultivated are zucchini, broccoli, lettuces, iceberg, vegetable asparagus, chineese cabbage and red cabbage. Exotic vegetables with moderate consumption are cherry tomato, galangal, pakchoi, artichokes, leek, celery, parsely, haricot beans, lettuce and snow peas. Export oriented culinary herbs like oregano, sage, lemon grass, marjoram, rosemary and thyme also can be successfully cultivated under protected structures. There is need to explore this by making tie up with market and the area can be increased by giving the production practices to farmers. Wide variety of crops should be experimented in protected cultivation.

Management of greenhouse environment

Climate is not indented to control inside the poly house. We are only moderating the climate, by providing ventilation through nylon net. Sides and top can be covered with nylon net. If we are decreasing the pore size the temperature will increase. The present recommendation of 40 mesh size can allow the thrips, mites and white flies inside the protected structure. So if we decrease the mesh size from 50-60 then, there will be problem of development of heat inside. But 50 mesh size is good enough, so that it can control the entry of whitefly and thrips. Double door system of entry is also essential. Atleast for nursery we must go for 50 mesh size. So that the virus is not affected the seedling in nursery.

Naturally ventilated greenhouses have to be protected through insect screens to restrict the entry of insects. The disadvantage of insect screens is to restrict airflow. In addition we can avoid the entry of insects. Thrips can enter the most of commonly used screen with good airflow, still, thrips damage is less inside a greenhouse. Insects sizes are: Flower thrips: 340 microns; Aphids: 340 microns, Whiteflies:462 microns and Leaf miners: 640 microns. A 40 mesh nylon net means 40 strands in a linear inch, which means the strands are placed at a distance of 635 microns. Strand thickness is 192 micron, therefore pore size is 445 micron. If 50 mesh, then pore size is 316microns

By providing ventilation through the sides, we can maintain the ambient temperature inside the structure. High temperature is congenial for the occurrence of diseases. Especially in hot humid conditions of Kerala. Shading is another aspect. Generally 30-35 per cent shade is recommended for vegetable crops. 50 per cent shade is required for some vegetables. But for vegetables like cucumber and tomato the requirement of shade is very less. Shade net alone is not sufficient to control the temperature. So aluminized strips which reflect back the sunlight, can use to give shade and at the same time to reduces the temperature. Shade net may be fixed or movable and manual or automatic or semi automatic.UV- Stabilized 40 mesh, white colour on all four sides and of top vent. Monofilament /tape shade net also may be used for better air circulation as demanded by the crop.

Types of nets and color

- Plastic woven or threads (color and thickness of thread influences radiation spectrum reaching the crop)
- Thermal, aluminet (reflective aluminized cloth)
- Chromatinet (HDPE photo selective plastic net)

Shade cloths are typically green, black, red, white or aluminized. The aluminized strips reflect light out through the roof of greenhouse. This reduces the cooling load under the shade considerably. In naturally ventilated low cost greenhouses, HDPE woven fabric of 35-50% light cut are used commonly. Exterior curtain is most ideal since it cuts off the radiation from entering the greenhouse.

Relative humidity is defined as the amount of water vapour in the air compared to the maximum amount of water vapour the air is able to hold at that temperature. The implication is that, given reading of relative humidity reflects different amounts of water vapour in the air at different temperatures. For example air at a temperature of 24° C at a RH of 80% is actually holding more water vapour than air at a temperature of 20° C at a RH of 80%. Higher humidity levels are believed to raise the fungal disease problem, but the literature appears inconclusive.

High relative humidity under protected structure is very dangerous as it leads to the incidents of diseases and affects fruitset. 60-65 percent is ideal. High relative humidity is a big issue in humid tropics, were ambient relative humidity itself is very high (85-90 %). Till now there is no practical way to reduce the humidity inside the protected structure.

General crop husbandry

Fumigation with formaldehyde (4 percent) or formalin (10 percent) at 10 l/m is good for sterilizing the soil. It should be done 15 days before transplanting. Open 3-4 furrows on bed, apply the fumigant, cover with soil & cover with polyethylene mulch. After 3 days open the mulch, rake the soil to remove the fumes. But it is very difficult to apply and all the beneficial microbes get harmful effect. Therefore it is not the practical way.

Instead of chemical fumigants, bio agents can be applied for effective controlling of diseases and nematodes. 15 days before transplanting date, mix the bio agents to powdered, moistened neem cake. Bioagents that can be used are, *Trichoderma harzianum*, *Pseudomonas fluorescens*, *Paecilomyces lilacinus* and *Pochonia chlamydosporia*. Apply 800kg neem cake/acre, 8 days before transplanting.

Basal fertilizer application should be done four days before transplanting. 25 per cent of the fertilizer can applied to soil before transplanting. Apply Carbofuron/ Carbosulfon along with the fertilizers.

Mulching always saves water and control weeds. But it is a debateable issue, because of the incidents of snails. We can avoid mulch in polyhouses but in net house mulch should be there. In tomato, cucumber and capsicum 80 cm bed size and 80 cm walking distance are followed. In cucumber and capsicum, we can follow 2 rows in a bed with 45 cm space between the plants for capsicum and 60 cm between the plants for cucumber. For tomato 45 cm between the plants can be followed, when it is trained as single stem.

Training and pruning is important to get the quality fruit with good size. If we maintain more fruits the size will be reduced. The yield level remains same but the size was increased to 100-200g in pruned capsicum. Training and pruning is required to maintain the fruit size, ideal for export market. Tomato tend to grow up to 40 feet in a polyhouse, we need to regular lowering. Require cost. Determinate hybrids tried in polyhouse. A variety which is growing 5 ft in open field can be conveniently grown up to 10 feet under poly house in a span of 6-7 months. So by using determinate hybrid we can get 150 t/ha from a 6 -7 months time period. Hybrids like ArkaAnanya, Abhinava and NS 501 are tried. Only thing is should not prune it. We have to allow 6-8 branches. And individual branches have to be tied. This is followed for tomato. In areas like Kerala where the transportation of tomato is a big issue. Tomato is comparatively easy to grow compared to capsicum in terms of plant protection. Borers are not usually found in tomato. Fungal and mites. Largely we can produce pesticide free tomato. Safe produce.

Excess irrigation is an issue. For row crops in greenhouse mostly inline drip laterals are used. Drippers are welded inside at regular intervals at the time of manufacturing. Size of laterals, dripper discharges and dripper spacing varies. Drip irrigation is given daily to supply 2-4 litres of water per square meter per day depending on the season. The aim of drip irrigation is to get an equitable distribution. 50 per cent of pan evaporation rate is sufficient for irrigation. In some vegetables 30 per cent is sufficient. If using a mulching system, 70 per cent of water can be saved. Excess irrigation may leads to leaching of fertilizers.

Vegetables should receive about 25 mm of water per week. The tensiometer tells when it is time to irrigate. Most crops should be watered when the tensiometer reads between 30 and 40 centibars. Determining how much water should be applied is the "pan" method of estimating evapotranspiration. Replenishing @ 0.5 – 0.6 E pan losses is all right. Whenever the soil atmospheric pressure is reduces to 0.3 bar the automation is required. When irrigation is through drip irrigation the absolute choice is fertigation. It is the Application of solid or liquid fertilizers via pressurized irrigation system; thus forming nutrient containing irrigation water as per the crop need with desired concentration. Fertigation allows multiple split application of fertilizers. At least once in a day, weekly we can apply the same amount of fertilizer. So that the fertilizer use efficiency will increase.

The important issue is completely water soluble fertilizer is required for fertigation. But it is 3-4 times costlier than the usual fertilizers.

Types of fertilizers

1) Liquid fertilizers
2) Solid water soluble fertilizer

1. Straight fertilizers:
   - Urea Phosphate (17:44:0),
   - Mono Ammonium Phosphate (12:61:0),
   - Mono potassium Phosphate (0:52:34),
   - Potassium nitrate (13:0:46),
   - Sulphate of potash (0:0:50 + 18% S),
   - Calcium nitrate, Magnesium nitrate and
   - Calcium magnesium nitrate
2. NPK formulations
   - 20:10:10 + TE+ Mg,
   - 19:19:19 +TE,
   - 16:08:24 + TE + Mg,
   - 13:40:13 + TE,
   - 20:20:20,
   - 6:12:36, 13:5:26 etc.
3. Chelated micronutrients
   - Fe EDTA (13%),
   - Zn EDTA (15%),

- Fe EDDH-A (6%),
- Chelated combination of micronutrients, Kombi etc.

Features of 100% water soluble fertilizers

- No chloride, no sodium and no salt build up.
- Completely soluble in water.
- Most of the fertilizers are acidic and hence special acidification treatment for dripper clogging may not be necessary.
- Blended with micronutrients

Fertilizer injectors like venturies are more popular one. Many types of fertilizer injectors are there. Like, Fertilizer tank, Non Electrical Positive displacement Fertilizer injector (fertilizer pumps). Computerized control system is at the infant stage because of high cost. Computer provides a faster and precise operation in the Green House. Also it stores, displays and prints the Green House information as needed. 10000-12000 per m^2 is required for the initial establishment of computerized control system while, 800-1000 m^2 is required for build up a polyhouse. That is, 10 times costlier. Under this system, hardly get 10 times higher yield. So computerized control system is still in demonstration stage.

Computer can do the following operations as per the pre-scheduled programme:

- Starting and closing of Micro Irrigation System.
- Application Water Soluble Fertilizer (N:P:K) and other Nutrients to the plant.
- Operation of Misting System as required.
- Opening and closing of ventilators and side wall roll up curtains as needed.
- Operation of shading net / Thermal screen.
- Operation of cooling pad and fan.
- Operation of heating system.
- Operation of CO_2 Generator, Climate Control, Temperature, Humidity, Heat
- Radiation, Control of EC, PH, PPM level in irrigation water etc. as required to the plant.

To economize on the cost of fertilizers preplant fertilizers containing recommended amounts of micronutrients, Ca, Mg, S, Phosphorus and Upto 25 % of the recommended N & K can be applied.

Fertigation schedule for crops grown under protected structures

- Capsicum

Dose	:	200:200:200 kg NPK/ha
Basal application	:	50:50:50 kg NPK/ha
Fertigation start	:	21 days after transplanting
Interval of Fertigation	:	twice a week
Rate/m^2	:	2.2 g 19-19-19/sq.m
Yield	:	127 t/ha in 7 months

- Tomato

Dose	:	250:250:250 kg NPK/ha
Basal application	:	50:50:50 kg NPK/ha
Fertigation start	:	21 days after transplanting
Interval of Fertigation	:	twice a week
Rate/m^2	:	3.7 g 19-19-19/sq.m
Yield	:	152 t/ha in 6 months

- English cucumber

Fertilizer dose	:	125-75-125 kg/ha

20% Basal soil application
Fertigation start date : 15 days after transplanting
Yield : 100 t/ha in 100days

- Muskmelon
  Fertilizer dose : 120-100-160 kg/ha
  20% Basal soil application
  Fertigation start date : 15 days after transplanting
  Yield : 75t/ha in 90 days
- Pole bean
  Variety : NZ
  Spacing : Two rows on the bed: 30cm plant to plant
  Plant population : 18000 plants/acre
  Seed rate : 4 kg/acre
  Fertilizer: 62.5 : 100:75 kg NPK/ha
  Yield : 37.5 t/acre

Crop	Total nutrient (kg/ha)		Crop Development		Injection Rate (kg/ha/d)
	N	K_2O	Stage	Weeks	N & K2O
Pepper	160	160	1	2	1.0
			2	3	1.5
			3	7	2.0
			4	1	1.5
			5	1	1.0
Tomato	200	200	1	2	1.0
			2	4	1.5
			3	8	2.0
			4	3	1.5
			5	2	1.0
Watermelon/cucumber/muskmelon	120	120	1	4	1.0
			2	2	1.5
			3	2	2.0
			4	3	1.5
			5	2	1.0

Foliar nutrition is also effective to increase the fertilizer use efficiency. Capsicum crop is sprayed with water soluble fertilizers like potassium nitrate and calcium nitrate at every 3 week interval after 1.5 months of transplanting @ 3-5g/L as foliar application. Apart from these sprays, vegetable special (a mixture of micronutrients developed by IIHR, Bangalore for foliar spray) @ 5gm/L and 19:19:19 formulations are also to be sprayed.Stock solution for inert media (Rock wool etc) is given below,

Stock Solution A	Kg/1000L water	Stock Solution B	Kg/1000L water
Calcium Nitrate	64	Potassium Nitrate	30
Potassium Nitrate	10	Mono-K Phosphate	20
Ammonium Nitrate	4	Potassium Sulphate	4.5
Iron Chelate (13%Fe)	0.56	Magnesium sulphate	18.5
When 2 stock solutions are diluted at 1:100,		Manganese Sulphate	0.16
combined, & applied will result following		Zinc Sulphate	0.11
concentration:N:165; P:46, K:225, Ca:122, Mg:18;		Borax	0.18
Fe:0.7; Mn:0.4; Zn:0.25; B:0.25Cu: 0.03; Mo:0.05		Copper Sulphate	0.012
Final solution pH:5-6		Sodium molybdate	0.012
EC:2000-2500 micromho/cm			

Fertilizer requirement for capsicum and tomato/acre, starting fertigation 20 days after transplanting

Week	Fertilizer	20-60 DAT	60 to 90 DAT	90 DAT to End
Monday	Calcium Nitrate	3 Kg	5 Kg	7.5Kg
Wednesday	MKP-0:52:34	4-5 Kg	3 Kg	3 Kg
Friday	KN_O3-13:0:45	3 kg	5 Kg	7.5 Kg
	SOP-0:0:50	500 Grams	1.0 Kg	1.5 Kg
Sunday	Fe-EDDHA	200 g	300 g	400 g
	Boron-20%	300 g	500 g	600 g
	Zn-EDTA	300 g	500 g	600 g
	$MnSO_4$	10 gr	20 g	30 gm
	Copper sulphate	25 g	50 g	50 g
	Ammonium molybdate	10 g	10 g	10 g

Substrate cultivation	Capsicum	Tomato
Solution A	100 Litres(Stock)	100 Litres(Stock)
Calcium nitrate	16.5 Kg	16.5 Kg
Potassium Nitrate(13:0:45)	4.0 Kg	3.4 Kg
Fe-EDTA(13%)/EDDHA/DTPA	108 Grams	117 Grams
Solution B		
Pottasium Nitrate(13:0:45)	6.14 Kg	5.5 Kg
Magnesium sulphate(Mgso4)	6.7 Kg	7.78 Kg
MKP (0;52;34)	3.4 Kg	3.70 Kg
Sulphate of potash(0:0:50)	780 Grams	4.72 Kg
Mangnese sulphate(Mnso4)	31 Grams	14 Grams
Zinc sulphate	26 Grams	31 Grams
Copper sulphate	36 Grams	35 Grams
NaorAm.Molbydate	3 Grams	4 Grams
Borax	45 Grams	63 Grams
Target Stage	Sweer pepper	Tomato
EC (Mili Siemens)	EC(ms/cm)	EC(ms/cm)
Initial/seedling stage till flowering	1.5-1.8	1.5-2.0
After flowering	1.8-2.2	2.4-2.8
After first harvest	2.2-2.5	2.2-2.5

Fertilizer requirement for English Cucumber /acre

Week	Fertilizer	12-20 DAT	20-30 DAT	30-45 DAT	45-110DAT
Monday	MAP(12;61;0)	5 kg	3 kg	3 Kg	3 kg
Wednesday	KNO_3(13:0:45)	2 kg	2 Kg	4 Kg	7.5 kg
Thursday	$MgSO_4$	1.0 kg	1.5 kg	1.5 Kg	2.5 kg
	SOP-0:0:50	500 g	1.0 kg	1.5 Kg	3.0 kg
Friday	Calcium Nitrate		2 kg	3 Kg	5 kg
Sunday	Fe-EDDHA	100 g	250 g	300 g	400 g
	Zn-EDTA	100 g	250 g	300 g	400 g
	Boron	150 g	250 g	300 g	500 g
	Copper sulphate			50 g	50 g
	Am. molybdate			25 g	25 g
	(Mnso4)			50 g	50 g

English Cucumber Substrate Cultivation

Solution A	100 Litres(Stock)
Calcium nitrate	18.5 Kg
Potassium Nitrate(13:0:45)	2.0 Kg
Fe-EDTA(13%)/EDDHA/DTPA	125 Grams
Solution B	100 Litres(Stock)
Pottasium Nitrate(13:0:45)	11.80 Kg
Magnesium sulphate($MgSO_4$)	7.4 Kg
MKP (0;52;34)	3.4 Kg
Sulphate of potash(0:0:50)	600 Grams
Mangnese sulphate($MnSO_4$)	34 Grams
Zinc sulphate	29 Grams
Copper sulphate	4 Grams
Na or Amm.Molbydate	3 Grams
Borax	50 Grams

Target Stage	Mini Cucumber
EC (Mili Siemens)	EC(ms/cm)
seedling stage till flowering	1.2-1.4
After flowering	1.5-1.8
After first harvest	2.0-2.2

Rain water harvesting

One of the major problems faced in protected cultivation is ensuring assured irrigation water of good quality. Due to climatic changes with gradual raise in atmospheric temperature coupled with erratic and insufficient rains the shortage is felt all over the world. Making provisions for rain water harvesting with protected structures erected for vegetable production can ensure 180 to 200 days of irrigation with 600 mm of rainfall. The conjunctive use of rain water helps in reducing the adverse effect of bad water in saline regions.

Annual Rainfall in Bengaluru is 850 to 900mm. 24 Lakh liters storage capacity created by way of a pond. From April to November we collect about 54 Lakh liters of rainwater from theroof top RWH from 6336 m^2. Pond top dimensions is 40 m x 20 m and pond bottom dimensions is 36 m x 16 m and side slopes is 0.57 : 1 (60 degrees inclination of side walls). Pond bottom and side walls covered with HDPE liner 750 micron thick. Pond top covered with Weed mat to prevent evaporation losses and also to prevent algae growth. Storage adequate to meet 83 days irrigation requirements of crops inside the polyhouses.

Pollination

Hand held electric vibrator is used widely. All other form to be considered supplemental. RH of 70 % is optimum for good pollination. Pollen do not shed at humidity of >90%. Pollination in each cluster every other day is adequate. Less pollen is produced during cloudy days. We were trying to import bumble bees and trying to do the pollination inside the green house for the last 10 years. But it was not a success. Lot of efforts have been done across the country to use the native species for pollination. In musk melon pollination with little bees were found effective.

Production constraints inside the polyhouse

Pests like thrips, mites and nematodes are serious problem in protected structures. Insect proof net houses with appropriate mesh size can be used to control thrips and mites. Crop Rotation with Marigold is very good to reduce nematode population. Neem based products, *Trichoderma* spp. and *Pseudomonas flurescens*can be used for effective controlling of pests. Conventional products like insect growth regulators, soaps and oils, microbial pesticides, predators and parasites are also effective. Predators and parasites are not produced in the country in large scale. Two companies wanted to import them from other countries like Israel and Holland. But that cannot be demonstrated properly. Instead of that, we can think of microbial pesticides, other natural product and thus reducing chemical pesticide usage. Thereby, we can improve the export potential and also the safe consumption for the country. Powdery mildew and downy mildew, phytophthora wilt are the serious diseases occurred inside the protected structures.Phytophthora wilt is serious disease in capsicum grown under net house. Grafting is good remedy for this. Many varieties available are downy mildew resistant.

Summary

The most important challenge in protected cultivation is to control the temperature. How affordably we can cool the green house, which should be find out. Minimal automation for curtain movements, irrigation and fertigation should be followed. Rain water harvesting and recycling is also important. Crop diversity should be there. Tomato is an ideal crop to give good yield. If pollination problems can be overcome we can cultivate majority of cucurbits like bittergourd, bottle gourd etc. The ultimate objective of the breeder should be the root stock breeding. Conventional breeding is challenging as it take a lot of years for developing a disease resistant or high quality crop. Development of root stock is having immediate result and we will have immediate usage. Soft pesticides, biopesticieds, IPM, pesticide free produce are the need of the hour. Media culture is possible and several farmers were successful in media culture. With little fine tuning research and extension media culture can come immediately. Breeding greenhouse varieties for disease resistance and quality are important. Fully automated greenhouse, NFT and Vertical farming are also other important aspects.

Future vegetables and new generation hybrids

Dr. Pranab Hazra
Professor, Department of Vegetable Science and Dean, Post Graduate Studies
Bidhan Chandra KrishiViswavidyalaya, Mohanpur, West Bengal, Email: hazra.pranab05@gmail.com

Hunger, malnutrition and hidden hunger: major concern of new millennium

Food, at the fundamental level, is viewed as a source of nutrition to meet daily requirements at a minimum in order to survive but with an ever greater focus on the desire to thrive. Nutritional health and well-being of humans are entirely dependent on plant foods. Hunger and malnutrition refers to the lack of macronutrients like carbohydrates and protein in the diet and shows classic symptoms of starvation like, stunting, underweight, "skin and bones" look, protruding abdomen, etc.Hidden hunger is a disorder caused due to lack of essential micronutrients (vitamins and minerals) required for physical and mental development, immune system functioning and various metabolic processes. This disorder is considered "hidden" due to the absence of the classic symptoms as found in hunger.

In the world at present, more than 1.00 billion (100 crore) people are hungry and about 3.00 billion (300 crore) are suffering from micronutrient deficiency or hidden hunger. At the same time, more than 1.1 billion (110 crore) people are suffering from obesity due to intake of excess carbohydrate and protein and imbalanced micronutrient. According to Global Hunger Index 2020, India ranks 94 out of 107 countries lower than neighbours such as Bangladesh (75) and Pakistan (88) and it has the highest prevalence of wasted children less than five years in the world, which reflects acute under-nutrition and the situation has worsened in the 2015-19 period, when the prevalence of child wasting was 17.3%, in comparison to 2010-14, when it was 15.1%.

Chronic malnutrition in many less developed countries in contrast to dramatic increases in the occurrence of obesity and related ailments in developed countries entails to ensure a varied food intake, comprising all the essential macro- and micro-nutrients, plant pigments and other functional phytochemicals through a diversified diet. Vegetables are considered essential for well-balanced diets since they supply vitamins, minerals, dietary fibre and phyto-chemicals which reduce risk of heart disease, stroke, chronic diseases such as diabetes and some forms of cancer.

Future vegetable crop: under-utilized traditional vegetable crops

Agriculture is under increasing pressure to produce greater quantities of food, feed and biofuel on limited land resources for the projected 9.7 billion people on the planet by 2050 (Godfray *et al.*, 2010). It is envisioned that agricultural production has to increase by 70% by 2050 to cope with an estimated 40% increase in world population (Bruinsma *et al.*, 2009). Reliance on a handful of major crops including vegetable crops has inherent agronomic, ecological, nutritional and economic risks and is probably unsustainable in the long run, especially in view of global climate change (Ebert, 2014).

Modern mono-culture production system resulted many of those local, traditional crop species and varieties have been replaced by high-yielding crop cultivars and hybrids developed through modern breeding programmes. Traditional crops typically do not meet modern standards for uniformity and other characteristics as they have been neglected by breeders from the private and public sectors (Stamp *et al.*, 2012). Thus they tend to be less competitive in the marketplace compared with commercial cultivars and hybrids. Landraces and crop wild relatives have hitherto been increasingly valued and exploited for genes that provide increased biotic resistance, tolerance to abiotic stress, yield and quality (Frison *et al.*, 2011). However, use of agricultural biodiversity should not be restricted to exploiting valuable genes for use in breeding programmes if our aim is to create more robust and resilient production systems. Currently underutilized food sources ranging from minor grains and pulses, root and tuber crops and fruits and vegetables to non-timber forest products have the potential to make a substantial contribution to food and nutrition security, to protect against internal and external market disruptions and climate uncertainties, and lead to better ecosystem functions and services, thus enhancing sustainability (Keatinge *et al.*, 2010). A wider use of neglected and undervalued crops and species, either intercropped with main staples in cereal-based systems or as stand-alone crops, would provide multiple options to build temporal and spatial heterogeneity into uniform cropping systems, thus enhancing resilience to biotic and abiotic stress factors and ultimately leading to a more sustainable supply of diverse and nutritious food.

It is now generally accepted that climate change will have a major impact on both biotic and abiotic stresses in agricultural production systems and threaten yield and crop sustainability (Keatinge *et al.*, 2012). Greater diversity, which builds spatial and temporal heterogeneity into the cropping system, will enhance resilience to abiotic and biotic stresses (Newton *et al.*, 2011).

Underutilized traditional vegetables have the potential to contribute to food and nutritional security, income and more sustainable production systems. In contrast to the major crops, underutilized, undervalued or neglected crops are also branded development opportunity crops (DOCs) (Kahane, 2013). As source of essential vitamins, micronutrients, protein and other phyto-nutrients, traditional or indigenous vegetables have the potential to play a major role in strategies to attain nutritional security and are considered important for sustainable food production (Keatinge *et al.*, 2011; Ebert, 2014).Many traditional or indigenous vegetables are characterized by a high nutritional value compared with global vegetables like tomato and cabbage (Keatinge *et al.*, 2011).Many under-utilized and traditional vegetable crops are hardy, adapted to specific marginal soil and climatic conditions, and can be grown with minimal external inputs (De la Peña *et al.*, 2011 ; Hughes *et al.*, 2013).

In Eastern Africa and Southeast Asia selected traditional vegetables are becoming an increasingly attractive food group for the wealthier segments of the population and are slowly moving out of the underutilized category into the commercial mainstream (Weinberger, 2007). In India, many under-utilized and traditional vegetable crops which have strong consumer preferencedeserve due attention to move them in commercial mainstream market. Government level initiatives should begin to explore the possibility of developing these popular crops for the formal market and seed sector. Some of such vegetable crops are mentioned below.

Leafy greens: *Amaranthus* spp., *Ipomoea aquatic, Chenopodium album* L., *Trigonellafoenum-graecum, Bacopamonnieri*, *Corchoru solitorius*, *Basella alba*, etc.

Different cucurbits:*Momordica subangulata* subsp. *renigera*, *Momordica dioica* Roxb.*,Cucumis melo* var. *momordica, Trichosanthes dioica* Roxb., *Benincasahispida* (Thunb.) Cogn., *Luffacylindrica* Roem., *Sechium edule* (Jack) Sw., *Cyclanthera pedata* Schrad., *Coccina grandis* (L.) Voigt. etc.

Bean crops: *Lablab perpureus*(L.) Sweet., *Psophocarpus tetragonolobus* (L.) Taub., *Vicia faba* L., *Mucuna deeringiana* (Bor.) Merr., etc.

Solaneceous fruit vegetables: *Solanum lycopersicum* var. *cerasiformae, Cyphomandra betacea;*

Baby potato: Wide array of cultivars available in the north-eastern part of India

Different tuber crops: *Alocasia macrorrhiza* (L.) Scott, *A. indica* (Roxb.) Scott., *Colocasia esculenta* var. *stolonifera, Amorphophallus paeoniifolius* (Dennst.) Nicolson, *Dioscorea* spp., *Solenostemon rotundifolius (Poir) Morton ,* etc.,

Perennial vegetablecrop: *Moringa oleifera* Lamk., *Sauropus androgynus* (L.) Merr. , etc.

Hybrid technology in vegetable crops

When science-based plant breeding began at the beginning of the twentieth century,breeders at first produced only pure-line cultivars in self-pollinated species or open-pollinated cultivars in cross-pollinated species. Butfollowing the success of hybrid maize in the United States of Americain the 1930s, breeders of field and horticultural crops began to look for ways tobreed and produce hybrid seeds of different crops other than maize. Hybrid maize, made by crossing inbred lines of maize, was introduced to farmers in the United States of America in the late 1920s and early 1930s (Crabb, 1993). However, Hayes and Jones (1916) much earlier recorded the possibility of exploiting hybrid vigour in Cucumber. First hybrid in vegetable crops was commercialized in Brinjal in Japan (Kakizaki, 1931).

Advantages of the hybrids

- **Increased yield and profitability for grower:** For most crops, the best hybrids out yield the best non-hybrid cultivars, when both types are adapted to the same local conditions
- **Increased dependability of performance:** Heterosis *per se* can increase stress tolerance (Duvick, 2005); heterosis *per se* plus ability to combine tolerance traits from two parents into one hybrid does give a unique advantage to hybrids. In most of the cases, successful hybrids are more tolerant of Biotic and abiotic stress than the open pollinated cultivars (OPCs) that they replace (Pixley and Banziger, 2004). However, breeding for tolerance to biotic and abiotic stress at one location does not necessarilygive adequate tolerance to that stress in a markedly different location.
- **Uniform expression of desired traits:** Uniform expression of traits is automatic in the case of cultivars of self-pollinated crops but not so for cross-pollinated crops; hybrids in cross-pollinated crops like, onion, cabbage, cauliflower, carrot, garden beet, etc. present new opportunities for producing a uniform product.
- **Greater range of useful traits:** Where important traits (such as disease resistance) are controlled by dominant genes, a hybrid can contain (and express) the dominant genes from both of its parents, when neither of them has the full set of needed dominant genes. The hybrid therefore will have better protection than either of the parents (more tolerance to biotic stress), and the goal of broad protection is reached in one generation rather than the long-term back-crossing and selection needed to place all of the needed genes in a single, inbred cultivar.
- **Customers can dictate traits of hybrid cultivars:** Existence of commercial seed companies depends on seed sales hence, they must develop the hybrids that the customer (farmer) wants to buy. The hybrids must be adapted to the environment and farming practices of each adaptation region where the seed is to be sold, and additionally the hybrids must have specific traits and quality as desired by farmers, their potential customers.

Pollination control mechanisms for development of hybrids

Development of hybrid maize was relatively simple because of the separation of male and female flowers. Hand emasculation followed by hand pollination is commercially used in the hybrid seed production of many vegetable crops particularly, tomato, brinjal, sweet pepper and okra mainly because of relatively low seed requirements, and relatively abundant seed numbers per cross pollination. Monoecious, gynoecious or andromonoecious sex form common in many crops of the Cucurbitaceae family are manipulated to produce hybrid seed with hand pollination or sometimes, using bees as pollinators. However, breeders had to look for other ways to produce hybrid seed efficiently and economically in many vegetable crops in which flowers are small and thus very difficult to manipulate and each cross pollination results few seeds. Major genetic and physiological consequences to establish "Hybrid vegetable Industry" are mentioned below.

- First utilization of self-incompatibility system, Cabbage: Pearson (1931)
- First utilization of cytoplasmic - genic male sterility mechanism, Onion : Jones and Clarke (1943)
- First Identification of gynoecious sex form, Cucumber: Peterson (1960)
- First identification of cytoplasmic male sterility, Radish: Ogura (1968)
- First ethylene-induced femaleness in cucurbits : Rudich *et al.*, (1969)
- First identification of cytoplasmic - genic male sterility in carrot: Morelock *et al.*, (1996)

Self-incompatibility, present in several species of horticultural crops was used to make seed of hybrid cultivars. The term 'self-incompatibility' as means the inability of a plant to set seed when self pollinated, even though it can form normal zygotes when cross-pollinated, and its pollen can fertilize other plants. Breeders used two types of self-incompatibility: gametic and sporophytic, depending on which kind prevailed in a given crop species. Nuclear genes govern both types, and genetic interactions can be complicated but manageable for development of lines to be used as seed parents or pollinators. Sporophytic self-incompatibility system was utilized for development of hybrids in different cole crops like, cabbage, cauliflower, broccoli, etc.

Cytoplasmic-genic male sterility resulted from interactions between a specific cytoplasmic genotype and a specific nuclear genotype. Plants with sterile cytoplasm plus nuclear non-restorer genes were male sterile; plants with sterile cytoplasm plus nuclear restorer genes produced fertile pollen (fertility restoration). In contrast to plants with sterile cytoplasm, plants with normal cytoplasm were male fertile when they carried either of the nuclear genes: restorer or non-restorer. Fertility restoration was not needed for onion and carrot hybrids, grown for their vegetative parts, but it was needed when cytoplasmic male sterility was used to make hybrids of crops like rice which is grown for fruit production.

Genetic male sterility was used to make hybrid seed of a few crops like chilli, although, like hand emasculation, its use required considerable inputs of hand labour. Segregating populations of heterozygous lines could be grown as female; pollen-fertile plants would be removed at the time of flowering, or earlier if they could be identified with a linked marker gene.

Wide array of hybrids available in vegetable crops

A variety of methods has been developed and is now employed to produce seed of hybrids ofdifferent vegetable crops. Choice of a specific method depends on the species and how it is utilized. Growers of vegetable crops in developed countries have adopted hybrids extensively. In recent years, the area planted to hybrids of different vegetable crops has expanded markedly in a number of developing countries including India.Wide array of hybrids available in vegetable crops are mentioned below.

Cross-pollinated crop

- **Cole crops**: Cabbage, cauliflower, broccoli, Brussels sprouts, Chinese cabbage
- **Bulb and root crops**: Onion, carrot, beet, turnip, radish
- **Cucurbits**: Watermelon, musk melon, cantaloupe, pumpkin, summer squash, winter squash, bottle gourd, bitter gourd, ridge gourd, sponge gourd, cucumber, gherkin
- **Other crops**: Sweet corn, coriander, spinach, etc.

Self-pollinated crop

- **Solanaceous crop**: Tomato, brinjal, chilli, sweet pepper
- **Other crop**: Okra, lettuce, etc.

Vegetable hybrids - Market segments and Successes in India

The Indian Seed Industry was valued at 2,078.3 million US dollar (about Rs. 20,000.00 crore) in 2017 and is expected to register a CAGR of 6.4% during the forecast period (2018-2023). Out of this, vegetable seed market is worth Rs. 4000 Cr. (Rupees Four thousand crore) including both hybrid and open-pollinated seeds. Vegetable seeds are estimated to witness a higher CAGR of 6.8% during the forecast period which may double the market size of vegetable seeds from the current levels to around Rs. 8,000 crore in the next five years. Increasing seed replacement rate in the country, as well as the adoption of hybrid and biotech crops are the major drivers for the market.

In India, share of hybrid seed of okra is the largest by volume. However, by value, tomato hybrid seed occupies the highest share followed by cabbage, okra, chilli, cauliflower, water melon, cucumber, gourds (bottle gourd, bitter gourd, ridge gourd, etc.), muskmelon, sweet pepper, etc. Acceptance of hybrids of tomato, chilli, okra, cabbage, cauliflower and watermelon has been spectacular over last two decades. These are examples of successes in seed trade, stimulating growth of the industry. The area under hybrids in cabbage, tomato and watermelon is estimated to be in excess of 50% of the total area under the respective crops. The farmers are willing to pay more for the hybrids seeds, especially if they possess some traits which add value to the product. There is a necessity for continuous flow of value added genotypes employing conventional breeding method and/ or biotechnological systems in order to match the ever changing needs of the vegetable growers.

Estimated market size of hybrid seeds of different vegetable crops in India

Vegetable crop	Market size (tonne)
Okra	1000
Different gourds (mainly bottle gourd, bitter gourd and ridge gourd)	150
Watermelon	80
Bitter gourd	70
Bottle gourd	70
Tomato	60
Cabbage	60
Cauliflower	50
Chilli	50
Ridge gourd	45
Cucumber	40
Eggplant	30
Melon	15
Sweet pepper	02

Source: Verma (2008)

Development of parental lines: the key to new generation hybrids

Widely divergent parental lines: Assembling and enrich breeding populations holds the key for the success in hybrid breeding technology. Novel traits from landraces, mutants and crop wild relatives need to be incorporated to develop "Smart parental line" with broad gene base with a view to develop nutrient-rich and climate resilient hybrids (Tanksley *et al.*, 1996) .This practice is not unique to hybrid breeding but as noted above, introgressed genes may be used more easily in hybrids.

Heterotic pools: As hybrid breeding programmes mature, breeders tend to sort inbreds into two or more groups based on their complementary interactions (Melchinger and Gumber,1998). Heterotic pools assembling genotypes as divergent as possible need to be developed, because heterosis depends on the differences in allele frequency between two populations. Such contrasting groups are formed because in breds from one group can supply strength in traits that are not expressed or weakly expressed in inbreds of the other group (Tracy and Chandler, 2004).

Built-in resistance: Incorporation of specificresistant genes in the parental lines like, tomato leaf curl virus resistant genes *Ty-1*, *Ty-3*, *Ty-4* and *Ty-6* originating from different accessions of *S. chilense* , *Ty-2* originating from *S. habrochaites* accession and a hybrid can contain (and express) the dominant genes from both of its parents

Applications of double haploid technology: Haploid induction and subsequent genome doubling, the two main steps for double haploid technology is an effective alternative to produce homozygous parental line, gene stacking and a variety of other genetic analysis.

Application of Molecular biology in hybrid breeding programme

Morphological markers played a major role in determining genetics of many traits although, morphological markers are not necessarily simple Medelian inherited genes. Plant breeders always try to identify stable detectable variation among the parents to be employed in the crossing programme for both improvement of line bred variety and development of the hybrids.

There is an enormous amount of genetic diversity at the DNA level in higher plants such that no two organisms are likely to be identical in DNA base sequence. Molecular biology has offered molecular markers to detect such DNA variation, which can be used to guide traditional plant breeding including development of hybrids. Once linkage between a marker locus and the gene governing the trait of interest has been established, DNA diagnostic tests can be used to identify that trait in the segregating generations to enhance the breeding value. Another important use of molecular markers is to identify superior alleles after mining the genetic resources for plant breeding. An understanding of germplasm diversity and genetic relationships among breeding materials is the most important aid for crop improvement strategies. In general, diversity studies focused on inventory and establishing core collections, assessment of the mating system and the population structure and heterotic grouping of potential lines suitable for hybrid breeding.

- ❖ Marker assisted transfer of specific genes/QTLs controlling desirable traits
- ❖ Usage of new molecular technologies in breeding like, gene insertion, gene editing, etc. to breed improved parental lines for developing unique hybrids
- ❖ Assessment of molecular divergence of the parental lines based on a large number of markers to establish heterotic pool
- ❖ Assessment and maintenance of genetic purity of parental lines and hybrid seed

Evaluation of the experimental hybrids: Experimental hybrids are tested in various ways before some of them are chosen for production and sale to farmers. During the performance trials, hybrids are rated for quality traits that are important for the crop. Finally, those few hybrids that have shown superior performance for all needed traits in both small-plot and farmer trials will be released and offered for sale. An essential element of "superior" performance is "reliable" performance; the hybrids must out perform other cultivars in both good and bad growing conditions of the adaptation area in which they are to be sold.

Disadvantages of the hybrids

Annual capital investment by the grower: Farmers are compelled to purchase the hybrid seed for each planting. If the market is unstable or offers prices that are too low particularly because of the absence of minimum support price for vegetable crops in India as a whole, farmers will not make annual investments in hybrid seed. Such non-investment applies equally to other inputs requiring outlays of scarce cash or credit. A second consideration is related to the kind of environment in which the crop is to be grown. Farmers may choose to not spend money on hybrid seed for planting in a potentially very unfavourable season.

Poor performance in risky environments: In most of the cases, Farmers often plant saved open pollinated cultivars (OPC) seeds of many crops in the risky season (high temperature / drought/ excess rainfall and/or floods) because in most of the cases performance may be so low that the cost of cultivation with hybrid seed will not be matched by the value of extra yield of the hybrids.

Potential uniform susceptibility to new pest genotypes: The hybrids may be uniformly resistant to important diseases or insect pests, but they also may be uniformly susceptible to new and unexpected pests, or to an unexpected and highly unfavourable growing season.

Difficult to serve unique small adaptation areas: Seed companies usually cannot afford to breed and produce seed for very small, specialized markets with location specific crop, special quality requirement, unusual growing conditions, etc.

Requirements of the good "new generation" hybrid

- The hybrids must be well adapted to the farmer's location and they must have preferred requirements in nutritional quality or other traits.
- New generation hybrids should show adequate tolerance to the targeted biotic and abiotic stress in a markedly different location
- Hybrid seed deliveries must be adequate and timely, and seed must be of stated quality

Thrust areas of research on hybrid breeding technology

Research works on hybrid breeding of vegetable crops need to be intensified in the public sector preferably in collaboration with the private sector. Some of the focused research areas are-

- Development of widely divergent and "Smart" parental lines through incorporation of traits from non-adapted genetic resources including landraces, mutants and crop wild relatives
- Marker assisted transfer of specific genes like, resistance to biotic and abiotic stress, fertility restoration in cytoplasmic-genic male-sterile lines, nutrient enhancing genes, etc.
- Assessment of molecular divergence among the parental lines based on a large number of markers that probe into the coding regions.
- Applications of "Double haploids (DH)" in development of parental line
- Identification of superior hybrid combinations involving indigenous and adaptable parental lines, integration between heterosis and resistance breeding for biotic and abiotic stresses
- Identification of stable self-incompatible and cytoplasmic male-sterile lines in cabbage and cauliflower for utilization in Indian condition.
- Identification of suitable genic-cytoplasmic male-sterile lines of chilli to develop suitable hybrids
- Development of cytoplasmic-genic male-sterile lines in pink bulb cultivars of onion to develop onion hybrids with pink bulb colour, pungency, uniformity in bulb size and good storage capacity
- Development of suitable parental lines with monoecious sex form in place of usual andromonoecious sex form in muskmelon to reduce the cost of hybrid seed production
- Development of tropical gynoecious sex form for the production of promising hybrids of cucumber and muskmelon
- Identification of suitable locations for maintenance of the genic-cytoplasmic male sterile lines of carrot, cauliflower, cabbage and subsequent hybrid seed production.

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National Webinar
"Challenges and opportunities of vegetable production in warm humid tropics"

Session 2

Breeding of cucurbits for humid tropics

Chair :
Dr. B.S. Tomar
Head, Division of Vegetable Crops, ICAR, IARI

Mr. Mohammad SaleemSenior Breeder
Namdhari Seeds Pvt. Ltd.
Bangalore

Dr. T.K. Behera
Professor, Principal Scientist
IARI, New Delhi

Dr. T. Pradeepkumar
Professor & Head
Dept. of Vegetable Science
College of Agriculture
KAU, Vellanikkara

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Chairman : Dr. B.S. Tomar, Head, Division of Vegetable Crops, ICAR, IARI

5 Breeding for biotic stress resistance in cucurbits
- Mr. Mohammad Saleem, Senior Breeder, Namdhari Seeds Pvt. Ltd, Bangalore.

6 Molecular breeding in cucurbits
- Dr. T.K. Behera, Professor, Principal Scientist, IARI, Bew Delhi

7 Exploitation of Parthenocarpy and polyploidy in cucurbits
- Dr. T. Pradeepkumar, Professor & Head, Dept. of Vegetable Science, College of Agriculture, KAU, Vellanikkara

Breeding for Biotic Resistance in Cucurbits: Approaches Reported in Cucumber (*Cucumissativus L.*)

Mohammed Saleem
Namdhari Seeds Pvt. Ltd. Bengaluru, E.mail: salim@namdhariseeds.com

Introduction:

The Cucurbitaceae family hosts 67 species that are economically important across the globesuch as cucumber, melon, watermelon, pumpkin/squash, and various gourds.Cucurbitacae is a family that offers mankind with diverse kind of tastes sweet, bitter, acidic and nutrition, it also helps us maintain a healthy source of lifestyle. The family fits itself into different cuisines ranging from salads to completely cooked format. You name the cuisines the members blend into it. 'The cucumbers' *Cucumis sativus* L. is one such versatile member of the family. Being true to their family, cucumbers fit in every kind of cuisines and are mostly loved as salads in different forms. Cucumbers come in various forms from a parthenocarpic baby cucumbers of 10 cm length to the 25 cm monoecious types. Cucumbers cover approximately 30% of the area of the Cucurbit family and is grown in various climatic conditions of the globe. With this global adaptability cucumbers face lot many challenges during their growth both in biotic and abiotic formats.

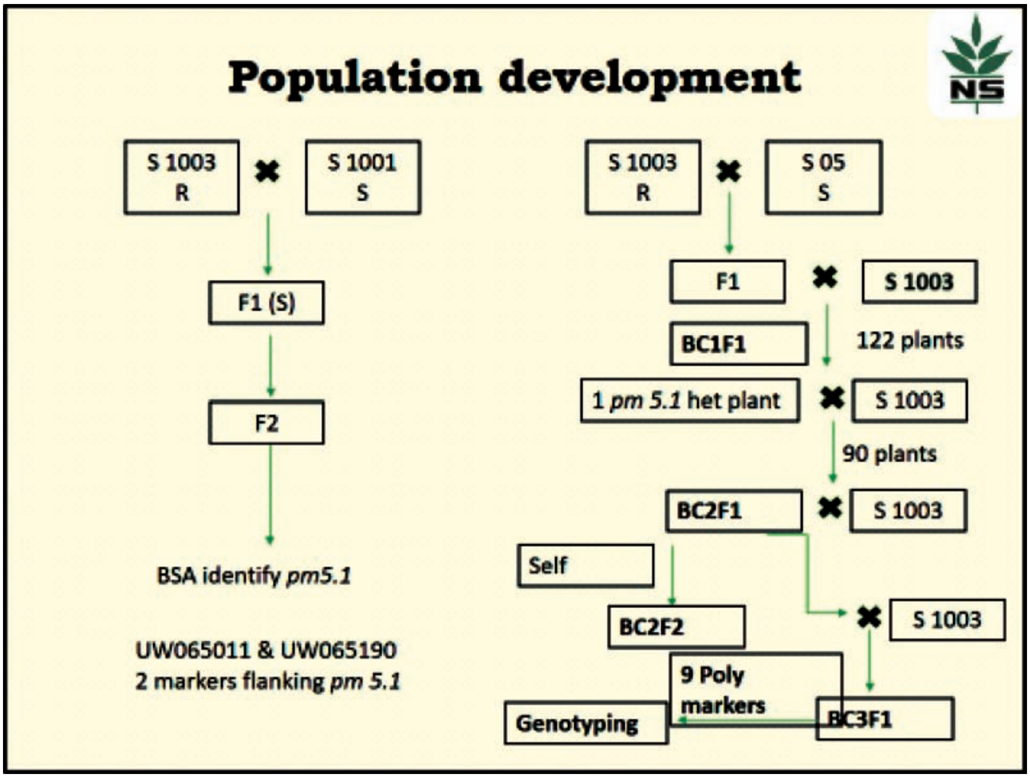
This review majorly covering on the biotic stresses that a cucumber plant faces and focus on genetic mitigation of these challenges at different stages so that farmer is able to harvest best cucumbers from seed to our plates. Many options are available for chemical control of fungal and bacterial diseases in cucumber which are mostly preventive and lack curative measures. While in case of viral disease we lack any options other than genetic resistance mechanisms. Thus breeding for biotic resistance in cucumber is most required. Below are some of the options that have been reported so far in mitigating the disease which can be utilized efficiently to improve the cultivars in near future.

Powdery mildew

Powdery mildew caused by Podosphaeraxanthii is one of the major diseases in cucumber, that effects both yield and quality of cucumber. Genetic resistance against PM has been reported as early as in 1940s. Many reports suggest the resistance in governed by major recessive alleles (He *et al.*, 2013). Sakata *et al.*, in 2006 for the first time reported 6 temperature dependent QTLs governing resistance, of which one QTL was functional at both 20^0 and 26^0 C. Further Liu *et al.*, in 2008 confirmed involvement of two linked QTL governing resistance to pathogen in two different environments. Zhang *et al.*, (2011) reported four QTLs conferring resistance against the pathogen, further reported the QTL on chromosome 5 acted as a major QTL. Fukino et. al., in 2013 validated the presence of these four QTLs in addition to 5 other QTLs that conferred resistance against powdery mildew. Zhang et.al.,in 2008 used the technique of Bulk Seggregant Analysis (BSA) to identify a major locus that governed resistance against the powdery mildew in Cucumber. Most of the studies reported a major gene QTL that governs resistance against PM. In the recent reports Nie *et al.*, in 2015 conclusively reported in their studies using F2 BSA and alternate segregating populations of BC_3F_1 and BC_2F_2 that *pm 5.1* is the major QTL present on long arm of chromosome 5 of the cucumber. Based on the QTL analysis they also reported MLO like genes being responsible for resistance against powdery mildew in cucumber. They went on to clone the MLO like gene and confirmed its involvement in conferring resistance in other resistant lines as well.

Downy Mildew

Caused by *Pseudoperonospora cubensis*, downy mildew is major disease across the globe in cucumber. Reported in early 90's, this was found epidemically impacting cucumber crop in USA in the year 2004 (Collucci *et al.*, 2006). Since then induced systemic resistance has been applied to manage the disease with minimum success.



Ref: Nieet.al., 2015

Historically, the DM resistance is being reported to be in linear segregation with powdery mildew resistance in cucumbers. QTL mapping for DM resistance (DMR) has been conducted in PI 197085, PI 197088, WI 7120 (PI 330628), WI 2757, S94, TH118FLM, IL52, and K8. Sixteen QTL were identified in PI 197088, and four of them are major-effect QTL contributing to DMR (dm4.1,dm5.1, dm5.2, and dm5.3. PI 330628 carries five DMR contributing QTL with dm4.1 and dm5.2 having thelargest effect. WI 2757 exhibits moderate resistance to post-2004 field DM strains and carries both dm1 from PI197087 and dm5.2 with unknown origin. Among the 17consensus DMR QTL, 11 could be detected in at least two resistance sources.Interestingly, the two major-effect QTL, dm5.1 and dm5.2were detected in five resistance sources, whereas dm1.1and dm6.4 were each identified in four lines. These observations suggest that cucumbers from different origins may share some comment genetic basis for DMRalthough the magnitude of these QTL are affected by genetic backgrounds and environmental conditions.

Cucumber Mosaic Virus (CMV)

CMV is transmitted by aphids, the disease is estimated to result in loss upto 60% in cucumber (Plapung *et al.*, 2004) (Verma and Giri, 1998). Most of the commercial cultivars are susceptible, adding to this the both vector and pathogen have wide host range of 1200 species belonging to more than 100 families of dicotyledons and monocotyledonous plants increasing the importance for identification of resistance to CMV in cucumber. Reports of inheritance of resistance to this disease is not consistent because of various sources of infection and experimental designs. The chi square analysis of F2 population and test cross populations developed between *Cucumis sativus* and *Cucumis hardwickii* revealed the resistance in population was mainly recessive monogenic trait and can be transferred by simple back crossing (Munshi *et al.*, 2007). Yang *et al.*, 2018 used resistant inbred line '02245' and susceptible '65 G' to develop RIL population and genetic analysis of the trait reveled CMV is quantitative trait. The QTL *cmv 6.1* was seen to govern 31.7% in 2016 and 28.6% in 2017 variations with respect to the resistance against CMV. Nine candidate genes identified, were cloned in different lines and the lines with such genes revealed 4.4 times higher resistance than 65G.

Conclusion

With nature posing new challenges to every new technology developed, it is need of the hour for breeders to be on the toes to use and disrupt the latest technologies in combating the challenges so that farmers face minimal losses and develop resilient varieties that can withstand any sort of challenge therefore protect the interest of farmers and in turn ensure food and nutrition security to the mankind.

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Molecular breeding in cucurbits

Dr. T. K. Behera
Professor & Principal Scientist, IARI, New Delhi, E.mail: tusariari@gmail.com

Cucurbits belong to the largest family of vegetables. Cucurbits contain a lot of species and many of them are immature edible. They are one among the sequenced vegetables. Cucumbers and melons are where the molecular breeding have been exploited.Cucurbit breeding started with the studies in manifestation of hybrid vigor in brinjal and bitter gourd in 1946 by Pal and Singh. After this Singh, Ramanujam and Pal (1948) reported the inheritance of sex forms in ridge gourd. The variety of sponge gourd Pusa Chikniwas developed in way back by Dr. B.P. Pal and the first public sector hybrids was developed by Choudhary in 1971 in bottle gourd Pusa Meghdoot (Pusa Summer Prolific long x Sel-2) and Pusa Manjari (Pusa Summer Prolific round x Sel-11).

Major breeding objectives in cucurbits are:

Yield improvement
- Good plant vigour
- High female: male ratio
- Early maturity/harvest
- Disease resistance/tolerance
- Adaptation

Quality improvement
- Intrinsic fruit quality with antioxidant property (saponin, cherantin, polypeptides, momordicin etc)
- Extrinsic fruit quality (shape, size, colour, tubercles, ridgeness, extended shelf life)

Extended growing season
- Off season
- Protected cultivation

The traditional approach to transferring genes from wild to cultivated species is based on interspecific hybridization followed by selection of hybrids that combine the trait with the cultivated genetic background. This breeding strategy is achieved by various backcross generations in which the selected hybrids at each generation are crossed back to the cultivated genotype with the aim of reducing the wild genome and its undesirable traits. The use of molecular markers has allowed this breeding approach to be greatly improved, since these markers directly reveal genetic variability through DNA analysis (Staub *et al.* 1996), and therefore their detection is not influenced by environmental effects. Since the development of numerous molecular markers for plant genome analysis, the possibility to select the genotype instead of the phenotype has been closely examined, leading to the concept of molecular marker-assisted selection (MAS; Paterson *et al.* 1991). Molecular breeding is defined as use of geneticmanipulation performed at DNA levels to improve traits of interest and it may also include genetic engineering or gene manipulation, molecular marker assisted selection and genomic selection. It implies broadly as molecular marker assisted breeding (MAB) and is defines as application of molecular biotechnologies, specifically molecular markers, in combination with linkage maps and genomics to alter and improve traits on the basis of genotypic assays. There are several approaches in molecular breeding.

Biotechnological interventions

Tissue culture

Asexual propagation
- Vegetative propagation through nodal segments – which is practiced at a lesser extend
- Micropropagation – practicing in a medium scale
- Somatic embryogenesis(large scale)- obtain thousands of clones in a small physical space and at a small

cost per unit

Synthetic seeds

- Encapsulated somatic embryos in culture medium

Double haploid

- For obtaining breeding lines or inbreds
- Protoplast fusion – helps to overcome genetic barriers of extra chromosomal inheritance

Genetic transformation

- It has been widely used in basic studies of gene expression and regulation
- Engineered synthetic genes – contains deletions or insertions which may increase the deficiency of transformation events
- Site directed genetic transformation – helps to exchange sequences in specific loci and to practice corrections of defective genes or to alter protein activity
- Plastomic transformations – it helps to study circumstantial increase of gene expressions
- Crisper/ cras9 and targeted genome editing – new era in molecular biology

Genome assisted plant breeding – Use of genomic technologies integrated with traditional technique, in order to obtain faster results in less time and with greater magnitude. Genome has sequencing was successfully practiced in 42 vegetables and among them 11 are from cucurbits.

Milestone in genome sequencing in important vegetable crops

2009 – Cucumber

2011 – Potato, Chinese cabbage

2012 – Water melon, musk melon, tapioca, tomato

2013 – Brinjal, French beans

Reference genome vs. pan-genome

A single reference genome sequence is not sufficient for identifying the best candidate gene for molecular breeding or for understanding the genomic background of a population due to the prevalence of genomic structural variations. Pan genome can helps to understand the size of a core genome (defined as the conserved part among the related genome). This detects the amount and nature of variations within a species or a genus, which improve our understanding of the evolutions of a species/ genus, as well as of agronomic traits.

Xing-ping zhanganalyzed the draft genome of water melon and found that assembled sequence covers 83.2 % of genome. He also tried the genetic linkages of 11 chromosomes and also resequenced 20 diverse accessions of water melon. In the resequencing he studies 466 water melon accessions and gave the relationships with *Citrullus naudinianus*, *C. colocynthis*, *C. rehmii* etc.

Development of markers and mapping of traits

Most monogenes or major quantitative trait loci (QTLs) can be tagged using a technique called bulked segregant analysis (BSA) first developed by Michelmore *et al.* (1991) to identify RAPD markers linked to a disease resistance gene in lettuce. In this technique, marker patterns from two DNA bulks, each comprised of DNA from individuals exhibiting the extreme phenotypes (i.e., high/low or resistant/susceptible) of a particular trait in a segregating population are compared. The two bulks have completely random genotype for most of the genome other than the region around the gene conferring the trait of interest. So the presence of polymorphism between the marker patterns of the two bulks is expected only when they are genetically linked to the underlying gene (Giovannoni *et al.*, 1991). To construct the bulks, 10-20 individuals are commonly included in each bulk, mostly in the form of equal amount of DNA. For example, Tezuka *et al.* (2009) constructed two resistant and two susceptible bulk each with 12 plants in an effort to identify markers linked to Fom-1, the gene that confers resistance to the melon Fusarium wilt causal agent *Fusarium oxysporumf.*sp. melonis race 2. The bulks were screened with AFLP markers detected using ethidium bromide-stained polyacrylaminde gel. Two markers were found to be tightly linked to Fom-1: one was at 0.5 cM and the other was cosegregating with the gene in a population of 125 F2 plants (Tezuka *et al.* 2009).

A number of markers have been developed and used in cucurbit genome mapping due to the availability of sequenced data. The work of development of markers have started in bitter gourd using transcriptome analyses where, bitter gourd ESTs from gynoecious and a hermaphrodite flower buds were generated using Roche – 454. Novel SSR markers in bitter gourd were developed using enriched genomic libraries. The same were utilized in analyzing the genetic diversity and cross species transferability. 160 novel microsatellite markers developed in bitter gourd through sequencing. Diversity analysis conducted in 54 bitter gourd accessions in 51 loci indicated that 20 % of loci were polymorphic with the PIC values ranging from 0.13 - 0.77.

He *et al.* 2013 tried out the QTL mapping of powdery mildew resistance in cucumber in 132 $F_{2:3}$ families derived from 2 cucumber inbred lines WI-2757 (resistant) and trues lemon 9 susceptible). A genetic map covering 610.4 cM in 7 linkage groups were developed with 240 SSR marker loci. From the map it was found 2 major QTL, pm5.1 and pm5.2 were observed to be located in interval of 40cM in chromosome 5 with each explaining 21.0-74.5 % phenotypic variations. Fukino *et al.*, 2013 obtained the population of 111 F8 RILs from a cross between CS-PMR 1 (a weedy cucumber of Indian origin, highly resistant powdery mildew in a temperature manner) and Santo (a Japanese native cucumber cultivar, moderately resistant to powdery mildew). They validated 4 QTL (pm3.1, pm5.1, pm5.2 and pm5.3) for powdery mildew resistance using different cucumber accessions. Genotyping by sequencing also have been used for mapping of different traits in bitter gourd where SNPs are the most used one. Detection of sequence differences (namely SNPs) in a large segregating mutant population. Rapid and direct study of its diversity targeted towards the mapping of a trait or a mutation of interest.NGS libraries are made for this purpose (whole genome library, RAD library, GBS library, cDNA library etc.), from which the sequencing is done for identifying the SNPs. QTL mapping in bitter gourd using GBS, for which 93 libraries (90 F2, each one from 2 parents and F1) were sequenced using Illumina True Seq Version 3 on HISEQ 2000 platform (Gangdhar Rao 2018). A length of 2392.2 cM was covered to develop 2013 SNP markers. Finally in the Linkage map LG-20 generated, the chromosome 6 had the genes for fruit diameter, and on chromosome 5 fruit number which together contributes to fruit yield.Inheritance and mapping of gynoecious (*gy-1*) trait in bitter gourd (DBGy-201 x PDM) based on GBS study showed that the gene is located on linkage group (LG-12) which is in close proximity to flanking markers TP 54865 and TP 54890 and the latter being more closer.

Identification of candidate gene through linkage analysis

Identification of linkage genes is very important after getting your genes of interest. Identification of candidate gene for the carpel number (*Cn* locus) through combined linkage mapping and association analysis in cucumber was conducted in US. Carpel number variations is a complex trait. This gene has been identified in Arabidopsis and the CN variations is complex signaling pathway involving interactions between the CLAVATA (CLV) and WUSCHEL (WUS) proteins. Plants defective in any one of the three CLV genes (CLV 1,2 and 3) may exhibit increased size of shoot apical meristem, inflorescence or floral meristem. Thus the gene for carpel number helps in determining the fruit shape. Gene mapping was done to identify this gene and the segregating analysis in multiple bi-parental mapping populations (F2, F3, and RILs) derived from WI27857 (CN=3) x True Lemon (CL=5) and result showed that the CN is controlled by a simply inherited gene, Cn, with CN=3 being incompletely dominant to Cn=5. Distribution of 106 SNPs in Gy14 cucumber scaffold03078 suggested a 47 kb region was associated with carpel number variation in cucumber natural populations. The association analysis delimited the Cn locus into a 16 kb region with 5 predicted genes. The association analysis in natural populations confirmed CsCLV3 as the candidate gene for Cn. 47 selected cucumber lines fingerprinted with dCAPS marker CN_D1 which was based on an SNP within the CsCLV3 candidate gene region. All 7 cucumber lines with CN=5 shared the same small band pattern and all remaining was with CN=3 lines, had the large band. Microscopic examination of the meristem was done to find the relationship between carpel number and meristem size. It was observed that as the carpel number varies the size of meristem increased. In the gene expression studies it was found that the expression of CsCLV3 gene in WI2757 was 2.8, 5.1, and 5.6 times as high as in true lemon. The expression was lower in ovaries of both parents as compared with in other 2 tissues.

Chromosomal locations of vegetable organs, flower and fruit set QTL was found on chromosomes 1,5, and 6 (Wang *et al.*, 2020). This is of great importance in developing lines with all these traits. The gene for downy mildew resistance was reported in chromosome 1, 2, 4, 5, 6 and 7. The gene for gummy stem blight is found in chromosome 3, 4, 5 and 6. In the case of melons and cucumbers a large number of genes and their associated markers have been reported. There are also reports on molecular markers linked to virus resistance in different cucurbits which are very helpful for breeding for virus resistance in different cucurbits.

A large number of population can be studied using high throughput phenotyping. HTP genotyping was successfully used for identifying the SNP marker for fusarium wilt (Fon 1), and powdery mildew resistance on chromosome 2, for ZYMV resistance on chromosome 5 in watermelon, which is very helpful in breeding. Thousands of population can be screened easily using HTP. Genome editing was also done in watermelon like small deletions, large deletions, small insertion, epigenome editing and replacement through knock out/down, down-regulation, precision tuning of expression etc. With this genome editing technology many desirable mutation can be created, like herbicide tolerance, virus resistance, bacterial resistance, fungal resistance, haploid inducer, lycopene. Herbicide tolerant watermelon mutant have been induced using single base replacement (C to T).

Marker assisted breeding

MAS refers to the use of DNA markers that are tightly linked to target loci as a substitute for or to assist phenotypic screening. It is based on the assumption that DNA markers can reliably predict phenotype. MAS provide significant advantages to traditional phenotypic screening because it directly select for genotype. MAS procedure is rapid, effective, relatively inexpensive and is not limited by environmental conditions (Behera *et al.*, 2010; Robbins and Staub, 2009), since it can be performed off season using DNA already isolated. And best of all it allows simultaneous screening for multiple traits if markers linked to these traits are available. To demonstrate how powerful this can be, we will use again the a gene as an example. When 497 melon genotypes were typed for the a gene, all the 146 monoecious and three gynoecious genotypes contain the dominant A57 allele while all 347 andromonoecious and hermaphrodite genotypes the recessive V57 allele (Boualem *et al.*, 2008). This clearly indicates that by typing this locus alone using DNA isolated from seedlings, one can easily determine whether a particular plant is monoecious or andromonoecious without growing the plants to the flowering stage. This is significant because the breeder can now directly select for the monoecy genotype which is an important goal for melon breeding. Monoecious plants used in production of F1 hybrid, which produces higher quality fruits, do not require the labor-intensive hand emasculation (Périn *et al.*, 2002).

MAS can also reduce ambiguity in phenotyping. In melon, resistance to powdery mildew is controlled by two dominant genes in melon variety PMAR 5, both of which are necessary for complete resistance (Fukino *et al.*, 2004). When lines are evaluated under some conditions, one resistance gene is sufficient for complete resistance, and individuals with one resistance gene cannot be distinguished from those with two (Fukino *et al.*, 2008). This makes it impossible to pyramid both genes based on phenotype alone. But use of linked markers will obviate this problem (Fukino *et al.*, 2008). Because of this, MAS can effectively reduce the cost of phenotyping and selection in plant breeding. In cucumber, MAS has been shown to be very effective in increasing multiple lateral branching and consequently fruit yield (Robbins and Staub, 2009).

Combined approaches:

In some cases, a combination of phenotypic screening and MAS approach may be useful

1. To maximize genetic gain (when some QTLs have been unidentified from QTL mapping)

2. To reduce population sizes for traits where marker genotyping is cheaper or easier than phenotypic screening

Marker assisted breeding for development of gynoecious cucumber lines in Pusa Uday background to produce Pusa Uday 1 with 100% female flowers and earliness like donor parent (G421) and 5-6 later branches, indeterminate growth habit, 3.70 L:D ratio like that of recipient parent. It has 40.40% higher yield than monoecious Pusa Uday, Pant Khira, Punjab Naveen.

Marker assisted backcross selection can also broaden the genetic base of cucumber (*Cucumis sativus*) and provide tolerance to root knot nematode, resistant to gummy stem blight and resistant to downy mildew which otherwise are susceptible to the same. MABC could change the sequential fruiting habit and a comparatively high number of primary lateral branches (> 4) and yield, it bears warty, light-green fruit of commercially unacceptable shape and quality with Introgressed sequential fruiting habit with high number of primary lateral branches (> 3) and yield, it bears attractive green fruits of commercially acceptable shape and quality.

Limitation in molecular breeding

- Genomic information not available for most of the vegetable crops
- Inaccuracy of QTL mapping studies
- QTL effects may depend on genetic background or be influenced by environmental conditions
- Lack of marker polymorphism in breeding material
- Poor integration of molecular genetics and conventional breeding
- The initial cost is high
- Molecular breeding required team of well-trained manpower for handling of costly equipment's, chemicals and glassware
- Gene technology involves transgene and thus requires biosafety and bioethical measures
- In gene technology, the frequency of desirable transformants is very low which restricts the use of this technology

Several horticultural traits are controlled by quantitative trait loci (QTLs). The goal of QTL mapping is to dissect the complex inheritance of quantitative traits into Mendelian-like factors amenable to selection through the analysis of the flanking molecular markers. These markers can then be used in molecular breeding and to clone the genes controlling the QTLs. Although any segregating population can be used for RIL mapping, use of RILs has certain advantages. RILs are near homozygous, which allows multiple replicates to assess phenotypic values, reducing the environmental effects and increasing the power and accuracy to detect QTL. Once QTLs are identified, they can be introgressed to elite germplasm through MAS, much like monogenic traits.

Exploitation of parthenocarpy and polyploidy in cucurbits

Dr. T.Pradeepkumar
Director of Planning, Kerala Agricultural University, Thrissur, Vellanikkara, Email: pradeepkau@gmail.com

Cucurbits belong to family Cucurbitaceae, includes about 118 genera and 825 species. In India, a number of major and minor cucurbits are cultivated, which share about 5.6 % of the total vegetable production. They are consumed in various forms i.e., salad (cucumber, gherkins, long melon), sweet (ash gourd, pointed gourd), pickles (gherkins), and deserts (melons). The main goal of research on Cucurbitaceae in India is to improve productivity and breeding programme for development of biotic and abiotic resistant variety/hybrids coupled with quality attributes is now undertaken in some centres. Parthenocarpy and polyploidy are two phenomenon widely exploited in cucurbits for developing quality genotypes. The genetic diversity in cucurbits extends to both vegetative and reproductive characteristics and considerable range in the monoploid (x) chromosome number including 7 (*Cucumis sativus*), 11 (*Citrullus* spp., *Momordica* spp., *Lagenaria* spp., *Sechium* spp., and *Trichosanthes* spp.), 12 (*Benincasa hispida*, *Coccinia cordifolia, Cucumis* spp. other than *C. sativus*, and *Praecitrullus fistulosus*), 13 (*Luffa* spp.), and 20 (*Cucurbita* spp.)

Rapid extinction of pollinator species have led to a widespread concern that we are facing a 'pollinator crisis' in cross pollinated crops. In this context, development of fruit without pollination and resultant seedless fruit is having great importance. Seedlessness in horticulture crops has been evolved either through "Parthenocarpy" or through "Stenospermocarpy".

Parthenocarpy can be defined as the capability to develop fruits without pollination and fertilization. A plant is considered to be seedless/parthenocarpic if it is able to produce a fruit with

- ✓ No seed
- ✓ Traces of aborted seeds
- ✓ A much reduced number of seeds

It is generally driven by genetic factors; nonetheless, seedlessness can be also be induced with the application of various hormones to young inflorescences. Genetic parthenocarpy can solve the problem of low pollen viability and poor pollen release, which often occurs under low light, low or high temperatures under open and protected growing conditions. Genetic parthenocarpy can be classified as

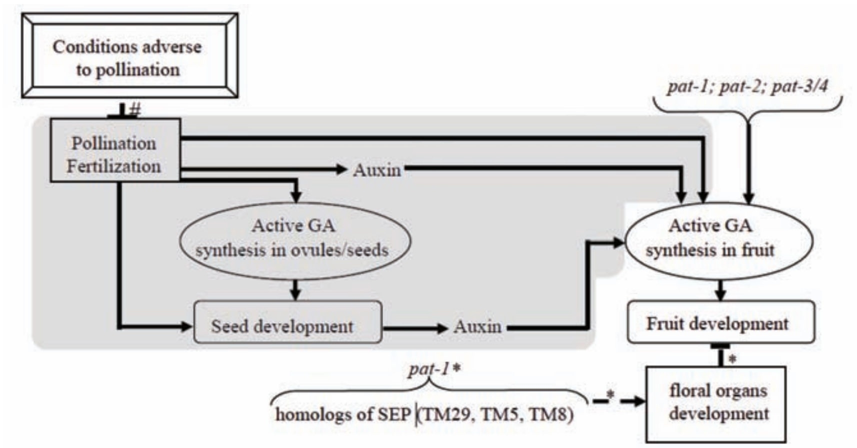
1. Obligatory : Fruit develops without any external influence Ivy gourd, cucumber
2. Facultative : Fruit develops under adverse conditions for pollination and fertilization cucumber

Phytohormones especially, auxins and gibberellins play an important role in parthenocarpic fruit development. Increased levels of these hormones in the ovary or ovule substitute pollination for fruit development, which has been exploited through biotechnological tools. Parthenocarpy along with gynoecious sex expression is an asset for the protected cultivation of cucumber. Parthenocarpic hybrid, KPCH-1 is a boon for the protected cultivation farmers in Kerala as well as at the national level because of low seed cost and wide adaptability (Pradeepkumar *et al.*, 2018). Parthenocarpic watermelon can be developed either by using irradiated pollen (Qu *et al.*, 2016) or by pollinating with bottle gourd pollen (Sugiyama *et al.*, 2014).

Parthenocarpic marketable fruits can be obtained under environmental condition which, normally limit fruit setting and growth. Many environmental factors hamper processes such as formation, dispersal and germination of pollen, fertilization and seeds formation and maturation which are crucialfor fruit set and growth.

Classical methods based on agronomical and genetical tools have been used to overcome these problems. Agronomical techniques have focused on the modification of environmental conditions by cultivation under protected structures protect plants from adverse climatic effects. Exogenous phytohormone sprays and use of pollinator insects are other popular methods to improve fruit set, but these approaches are costly and/or labour-intensive adding extra costs to production process. Development of parthenocarpic varieties represents the most cost effective solution to improve the capacity of fruit set and development under adverse climatic condition. Hybridization, mutation breeding, polyploidy breeding and biotechnological approaches are adopted for developing seedlessness.

Mechanism of parthenocarpy



- ✓ Adverse environmental conditions
- ✓ Protected cultivation
- ✓ Novelty – seedless parthenocarpic cucumber, seedless watermelon
- ✓ Improved quality and shelf life
- ✓ Improved taste, TSS
- ✓ Earlier yield

Exploitation of naturally available parthenocarpic gene in cucumber

Sex expression and especially gynoecy is an important factor which has a positive effect on yield and constitutes a major component of cucumber improvement programs (Serquan *et al.* 1997) and this feature can easily be manipulated for production of F_1 hybrid seeds. Another important feature which can be clubbed with gynoecy in cucumber is Parthenocarpy, which occurs within the species of *Cucumis sativus* L. as reported long back by Sturtevent (1890). Utilization of parthenocarpic gynoecious lines in breeding programme favored maximum exploitation of heterosis in cucumber. Heterosis has contributed towards increased crop production and it has become the basis of multi-billion dollar agro-business in the world (Phillips, 1999). Hybrid under optimum crop production and protection management, give economically more yield than that the improved varieties and also provides uniform size, earliness, better keeping quality and resistance to boiotic and abiotic stresses (Kalloo *et al.* 2000). The term parthenocarpy was introduced by Noll (1902) and observed it for the first time in cucumber. In other words, the process which limits female fertility and allows growth of seedless fruits without fertilization is known as parthenocarpy (Schwabe and Mills, 1981).

The majority of the studies which concerns the causes of abortion and parthenocarpy have focused on the four theoretical determinants for the study of the biological problems: causes (physiological, genetical, and ecological), development, evolution, and function (Verdu and García-Fayos, 1998). Several hypotheses were formulated regarding causes and function of abortion (Stephenson, 1981), but parthenocarpy has received much less attention.

Hypotheses in relation to abortion can be placed into three groups, (i) environmental uncertainty (ii) the male role of hermaphroditic flowers, and (iii) the improvement of the quality of seed produced through selective abscission (Stephenson, 1981).

Genetics of parthenocarpy

Chen and Cao (1994) overviewed that the evidence on the inheritance of parthenocarpy is conflicting, with reports of control by a single partially dominant gene *P* and by three independent major genes with additive and epistatic effects, as well as reports of inheritance typical of quantitative traits. Yan *et al.* (2008) investigated the inheritance of the parthenocarpy in gynoecious cucumbers using a joint analysis of multi-generations from crossing a highly parthenocarpic gynoecious line with two non-parthenocarpic inbred lines and found that the inheritance with different genetic backgrounds was fitted into the same genetic model. It was expressed as incompletely recessive and controlled by two additive-dominant-epistatic major genes and additive-dominant polygenes. Yan *et al.* (2012) also analysed the inheritance of parthenocarpy in cucumber in four generations derived from crosses of a highly parthenocarpic monoecious line and a gynoecious line to a non-parthenocarpic inbred line. The inheritance of parthenocarpy in gynoecious cucumber was controlled by two additive-dominant-epistatic major genes and additive-dominant polygenes, and the major gene heritability of F_2 was 83.5 per cent. While that in monoecious cucumber was controlled by two additive-dominant-epistatic major genes and additive-dominant-epistatic polygenes, and the major gene heritability of F_2 was 42.1 per cent. An incomplete dominant gene *Pc* administers inheritance of parthenocarpy in cucumber.

Breeding for gynoecious parthenocarpic cucumber

Sex inherence plays an important role in cucumber breeding. In the cucumber, several primary sex types have been reported namely: monoecious (separate pistillate and staminate flowers on the same plant), androecious (staminate flowers only), gynoecious (pistillate flowers only), hermaphroditic (hermaphrodite flowers only), andromonoecious (staminate and hermaphroditic flowers on the same plant) and dioecious (plants bearing either all-male or all-female flowers). The cucumber produced by hermaphrodite flowers is unmarketable (as a result of its large seed cavities). Therefore the only option is to cultivate either monoecious or gynoecious plants. Gynoecious plants assure high yield as they bear only female flowers. Gynoecious plants require the presence of a monoecious pollinator in the ratio 10:1 (gynoecious: monoecious) to ensure fruit set. The maintenance of appropriate number of pollinator is mandatory and manual pollination or insect pollinators too is a must. This could be overcome by introducing the gene for parthenocarpy in gynoecious cucumber plants. Parthenocarpic cultivars exist and they are intensively cultivated; in addition, they have the advantage that fruit setting is not dependent on weather conditions, or on manual or insect pollination.

Important genes to be considered in the development of parthenocarpic hybrids in cucumber

Gene	Synonym	Character
F	*Acr, acr^F, D, st*	*Female*. High degree of pistillate sex expression; interacts with *a* and *M*; strongly modified by environment and gene background. *F* and *f* are from 'Japanese'. Plants are andromonoecious if (*mm ff*); monoecious if (*MM ff*); gynoecious if (*MM FF*) and hermaphroditic if (*mm FF*).
Gy	-	*gynoecious*. Recessive gene for high degree of pistillate sex expression.
Pc	*P*	*Parthenocarpy*. Sets fruit without pollination. *Pc* from 'Spotvrie'*; *pc* from MSU 713-205*.
Mp	*pf^+, pf^d, pf^p*	*multi-pistillate*. Several pistillate flowers per node, recessive to single pistillate flower per node. *mp* from MSU 604G and MSU 598G.
Mp-2	-	*Multi-pistillate-2*. Several pistillate flowers per node. Single dominant gene with several minor modifiers. *Mp-2* from MSU 3091-1.

Considering these aspects a study was conducted at Department of Horticulture, Mahatma Phule Agricultural University, Rahuri to develop parthenocarpic gynoecious line by Moore and Budgujar in 2002. They attempted the development of tropical gynoeciousparthenocarpic lines and succeeded in developing 7 gynoeciousparthenocarpic lines with high percent of parthenocarpy. These included 4 yellow skinned lines (PKG-1-2, PKG-1-11, PKG-1-12 and PKG-1-15) and 3 green skinned lines (PKG-1-21, PKG-1-23 and PKG-1-24).

An attempt to develop parthenocarpic seedless cucumber hybrid was successful in the Department of Vegetable Science, Kerala Agricultural University. The parthenocarpic cucumber hybrid namely KPCH-1 has been developed and notified after a focused breeding programme initiated during 2011. The seeds are now available for the cultivation of farmers. Some of the salient features of KPCH-1includes:

Features of KPCH-1

Characters	Description
Days to first harvest (days)	35.83
Number of fruits / plant	21.83
Average weight of fruit (g)	240.75
Fruit length (cm)	20.98
Fruit perimeter (cm)	15.88
Parthenocarpy (%)	92.18
Average yield/ plant (kg)	5.26

Parthenocarpic cucumber varieties/lines from public sector

Sl. No	Name of the variety/line	Source
1	Pant Parthenocarpic Cucumber-1	GBPUAT, Pant Nagar
2	Pant Parthenocarpic Cucumber-2	GBPUAT, Pant Nagar
3	Pant Parthenocarpic Cucumber-3	GBPUAT, Pant Nagar
4	Pusa seedless cucumber – 6 (DPaC-6)	IARI, New Delhi
5	DPaC-9	IARI, New Delhi
6	DPaC-10	IARI, New Delhi
7	KPCH-1	KAU

Parthenocarpic cucumber hybrids from private sector

Sl. No	Name of the hybrid	Source of seed
1	Isatis	Nunhems India Pvt. Ltd
2	Hilton	Nickerson Zwaan
3	PY-1026	East West Seeds India Pvt. Ltd
4	NS-492	Namdhari Seeds India Pvt. Ltd
5	NS-498	Namdhari Seeds India Pvt. Ltd
6	NS-499	Namdhari Seeds India Pvt. Ltd
7	Claudia	Tropic Seeds Pvt. Ltd
8	Aviva	Tropic Seeds Pvt. Ltd
9	Asma	Tropic Seeds Pvt. Ltd
10	Kian	Nunhems India Pvt. Ltd

Kian and Hilton are the most popular private sector hybrids among the farmers which is largely cultivated.

Stages in development of KPCH-1

1. Collection of parthenocarpic and gynoecious genotypes
2. Maintenance of parthenocarpic lines through tissue culture and their testing for parthenocarpic expression

3. Induction of male flowers in parthenocarpic lines through hormonal regulation
4. Development of inbreds and isolation of parthenocarpic lines with improved quality in advanced generations
5. Development of crosses involving parthenocarpic and gynoecious lines
6. Evaluation of F_1 hybrids under polyhouse

Transgenic parthenocarpic lines

Genetic engineering aimed at obtaining parthenocarpic fruits was first successful in tobacco and eggplant, with the introduction of the *iaaM*gene. This gene is under control of the placenta and ovule-specific *DefH9* promoter from *Anthirrhinum majus*. The *iaaM*gene codes for a tryptophan mono-oxigenase that converts the tryptophan into indolacetamide, which is then converted to auxin. The *DefH9* promoter is active during early stages of flower development. Seedless fruits were produced from emasculated flowers, and seeded fruits from pollinated flowers. This has been exploited in the crops like tomato, brinjal, cucumber, muskmelon etc. (Rotino *et al.*, 1997).

Use of plant growth regulators for the development of parthenocarpic fruit development

Plantgrowth regulators at correct concentration and time of application proves to be an easier and quicker method for developing parthenocarpic vegetables. Studies by Choudhury and Phatak (1958) showed that Pre-anthesis sprays of GA@100mg/L helps in inducing parthenocarpy in cucumber. Similarly CPPU @ 0.5 mL/L sprays can be used to induce parthenocarpy in watermelon (Kawamura *et al.,* 2018).

Polyploidy breeding

The seedless watermelon which contains partially developed seeds, is a classical example of stenospermocarpy. Seedless watermelons are mainly produced employing the polyploidy breeding technique. To obtain such a seedless water melon plant (triploid), a cross is made between a tetraploid maternal parent and a diploid pollinator, resulting in a triploid plant that is self-infertile because of a gametic chromosome imbalance. This triploid plant must be pollinated by a diploid plant in order to produce a seedless watermelon. Now a days these seedless watermelons have gained much popularity and the aborted seeds are very soft and offer little inconvenience to the consumers. Pusa Bedana is the first parthenocarpic triploid watermelon developed from IARI.

The research conducted at the Department of Vegetable Science, Kerala Agricultural University has been successful in developing two triploid seedless water melon hybrids namely Shonima (red fleshed) and Swarna (yellow fleshed). In the study, Pradeep Kumar *et al.*, 2016 developed a tetraploid inbred line KAU-TETRA-CL-1 in the watermelon cultivar Sugar Baby through treatment of seedling shoot tips with colchicine solution (0.5%) followed by selection for increased fertility in the C2, C3, C4, and C5 generations. The higher ploidy level was confirmed by Chloroplast count and guard cell measurement and tetraploidy was confirmed by flow cytometry in the C5 generation. The difference in stomata, number of chloroplasts of diploid sugar baby and tetraploids in C5 generation clearly helped in the identification of diploids and tetraploids. Tetraploids were selected based on the number of seeds per fruits (>100), as increased fertility is very important to reduce the cost of triploid production. The more stable and fertile tetraploid line (KAU-CL-TETRA-1) thus obtained from the C5 generation was then used for producing two triploid hybrids. Shonima was obtained when CL-4 was used as the diploid female parent and swarna was obtained when CL-5 was used as the diploid female parent. These triploid hybrids were then evaluated along with their parents and in the evaluation, the hybrids proved to be superior in terms of horticultural traits like rind thickness, TSS, number of fruits per plant, earliness etc. and also recorded good yield. The mean yield over two seasons was 12.256 kg fruits/plant for the red-fleshed KAU-CL-TETRA-1 × CL-4 and 10.168 kg fruits/plant for the yellow-fleshed KAU-CL-TETRA-1 × CL-5 seedless hybrids. The triploid hybrids have excellent fruit quality compared to diploids in terms of sweetness and absence of seeds.

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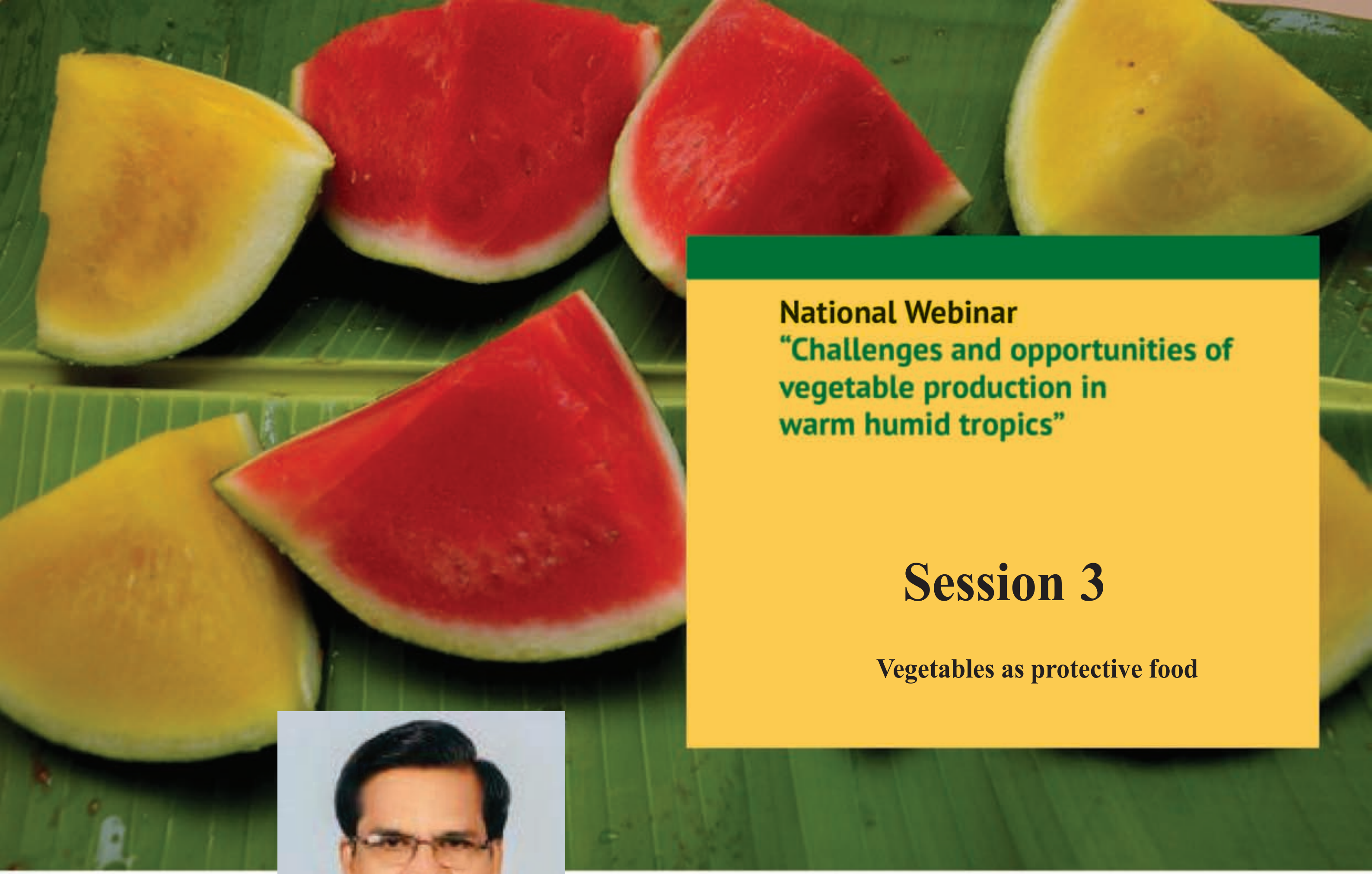

National Webinar

"Challenges and opportunities of vegetable production in warm humid tropics"

Session 3

Vegetables as protective food

Chair :

Dr. Gopalakrishnan T.R.

Former Director of Research

Kerala Agricultural University

Dr. Veena Gupta

Head of Division, Economic Botany,

Division of Germplasm Conservation

NBPGR, Delhi.

Dr. Ramesh P.R.

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8 Prospects of underexploited vegetables
- Dr. Veena Gupta, Head of Division, Economic Botany, Division of Germplasm Conservation, NBPGR, Delhi.

9 Vegetables as immunity boosters in COVID scenario
- Dr. Ramesh P.R., Chief (Clinical Research), Kottakkal Arya Vaidya Sala, Kerala

Prospects of underutilized Vegetables

Veena Gupta and Chithra Devi Pandey,
Principal Scientist, *Division of Germplasm Conservation*
ICAR-National Bureau of Plant Genetic Resources, New Delhi-110 012
veena.gupta@icar.gov.in

Agriculture is under increasing pressure to produce greater quantities of food, feed and biofuel on limited land resources for the projected nine billion people on the planet by 2050 (Godfray *et al.*, 2010). It is envisioned that agricultural production has to increase by 70% by 2050 to cope with an estimated 40% increase in world population (Bruinsma, J., 2009). Vegetables are the key component of balanced human diet and also the main drivers in achieving global nutritional security by providing nutrient, vitamins and minerals. The spectacular growth in vegetable production has increased and due to the development of improved varieties/hybrids/ production and protection technologies through systematic research coupled with large-scale adoption in only few major vegetables. Diverse agro climatic conditions of India allow growing more than 60 cultivated and about 30 lesser known vegetable crops (Jena *et al.*, 2018) So far research work has been confirmed to only 30 of them. Of these, crop like tomato, eggplant, chilli, okra, cauliflower, melon, onion, peas, etc have received adequate attention and emphasis. Another 25 have remained less popular, as no concerted research and development effort have been made to promote these crops. In addition, there are many crops, such as faba bean, lima bean, winged bean, jack bean, sword bean, velvet bean, tree bean, chive, leak, welsh onion, broccoli, Brussels sprouts, Chinese cabbage, celery, lettuce, globe artichoke, sweet corn, baby corn, asparagus, Indian spinach (*Chenopodium*), water leaf, drum stick, curry leaf, ash gourd, Snake gourd, *Momordica dioca*, M. *Cochinchinensis*, *Coccinia indica, C. cordfolia*, *Melothria heterophylla* (Dioceous), pointer gourd, etc. Which are grown, but no systematic research and development effort have been made, therefore, genetic diversity found in these crops is under-utilised and offers a great opportunity for genetic diversity (Singh & Chitra Pandey, 2005). The possible reasons for the low utilization of underutilized vegetables, in spite of their recognized importance are lack of availability of planting material, lack of awareness on nutritional and medicinal importance and lack of information on production techniques. So, there is a need to take up programme on genetic resources exploration, management, utilization and improvement of underutilized vegetable crops to ensure food and nutritional security for future.

National Bureau of Plant Genetic Resources (NBPGR) is the nodal institution at national level for management of PGR in India under the umbrella of the Indian Council of Agricultural Research, New Delhi. The Bureau after its creation in 1976 has developed a very strong Indian Plant Germplasm Management System which operates in a collaborative and partnership mode with other organizations. The system has contributed immensely toward safeguarding the indigenous crop genetic resources and introducing the useful PGR from other countries for enhancing the agricultural production and productivity in country. India being one of the gene-rich countries of the world faces a unique challenge of protecting its natural heritage and evolving suitable mutually beneficial strategies for germplasm exchange with other countries.

The National Genebank Network consists of the National Genebank at ICAR-NBPGR, New Delhi, which is primarily responsible for conservation of germplasm on long-term basis along with 10 regional stations and the 59 National Active germplasm Sites (NAGS) (Fig.1) are the integral component of the Network. The NAGS are based at the premier institutes for specific crops or crop groups and are entrusted with the responsibility of multiplication, evaluation, conservation of active collections and their distribution to users both at national and international levels. Various other National institutes, All India Coordinated Crop Research Projects, State Agricultural Universities, International Agricultural Research Centers involved in conservation and use of PGR and other stakeholders are also effectively linked to the network.

1. Vegetables – GBPUA&T, Pantnagar
2. Cotton – CICR, Nagpur
3. Cotton – AICRP, CICR RS, Coimbatore
4. Crops of North East – ICAR RC NEH, Meghalaya
5. Chickpea – AICRP, IIPR, Kanpur
6. Forages – IGFRI, Jhansi
7. Forages – AICRP, IGFRI, Jhansi
8. Field Crops – VPKAS, Almora
9. Groundnut – DGR, Junagarh
10. Fibres – CRIJAF, Barrackpore
11. Maize – IIMR, Ludhiana
12. Pulses – MULLaRP, AICRP, IIPR, Kanpur
13. Oilseeds – IIOR, Hyderabad
14. Pearl millet – AICRP, ARS,RAU, Jodhpur
15. Pigeonpea – AICRP, IIPR, Kanpur
16. Pulses – IIPR, Kanpur
17. Rapeseed & Mustard – DRMR, Bharatpur
18. Rice – NRRI, Cuttack
19. Rice &Lathyrus – IGKVV, Raipur
20. Sesame & Niger – AICRP, JNKVV, Jabalpur
21. Small millets – SMIP, UAS, Bangalore
22. Sorghum – IIMR, Hyderabad
23. Soybean – IISR, Indore
24. Sugarcane – SBI, Coimbatore
25. Sugarcane – AICRP, IISR, Lucknow
26. Underutilized crops – NBPGR, New Delhi
27. Wheat & Barley – IIWBR, Karnal
28. Agro forestry crops – NRC, IGFRI, Jhansi
29. Arid fruits – CIAH, Bikaner
30. Banana – NRC, Tiruchirapalli
31. Cashew – DCR, Puttur
32. Citrus species – NRC, Nagpur
33. Flowers – DFR, Pune
34. Grapes – NRC, Pune
35. Leechi, Bael, Aonla& Jackfruit – NRC, Muzaffarpur
36. Medicinal & Aromatic plants – DMAPR, Anand
37. Mango – CISH, Lucknow
38. Sub tropical fruits – AICRP, CISH, Lucknow
39. Mulberry – CSGRC, Hosur
40. Oil Palm – IIOPR, Pedavegi, West Godavari
41. Onion & Garlic – DOGR, Pune
42. Orchids – NRC, Pakyong
43. Ornamental &non traditional crops – NBRI, Lucknow
44. Plantation crops – CPCRI, Kasargod
45. Potato – CPCRI, Shimla
46. Spices – IISR, Calicut
47. Spices – AICRP, IISR, Calicut
48. Tea – UPASI TRF, Coimbatore
49. Temperate horticultural crops – CITH, Srinagar
50. Temperate horticultural crops – NBPGR RS, Shimla
51. Tobacco – CTRI, Rajahmundry
52. Tropical fruits – IIHR, Bangalore
53. Tropical fruits – AICRP, IIHR, Bangalore
54. Tuber crops – CTCRI, Thiruvananthapuram
55. Tuber crops – AICRP, CTCRI, Thiruvananthapuram
56. Vegetables – IIVR, Varanasi
57. Vegetables – IARI RS, Katrain
58. Ornamental crops – IIHR, Bangalore
59. Tea – Tea Research Association, TES, Jorhat

Figure1. National Active Germplasm Sites

National Genebank

The major components of the National Genebank include the seed genebank, field genebank, cryo genebank and the *in vitro* genebank (Fig 2.) The *ex situ* seed genebank at NBPGR comprises 12 long-terms modules (total capacity: 1 million accessions) maintained at -18^{0}C for hosing the base collections. The active collections are distributed in 22 medium-term modules maintained at 4^{0}C for storing germplasm at active sites. At present, the genebank holds more than 4.50 lakhs accessions (Table 2). The accessions held in the long-term storage for 10 or more years are monitored for their viability, seed quantity etc. as per the genebank standards. According to the monitoring results the samples/lots registering viability below the specified standards are sent for regeneration at the NAGS . The cryobank facility in the National Genebank has accessions of varied germplasm of orthdox, intermediate and recalcitrant seed species including pollen samples. The *in vitro* genebank conserves various priority crops which are maintained under short- to medium-term storage periods (Table 3). These include tuberous and bulbous crops, tropical fruits species and industrial crops, medicinal and aromatic plants species. The cultures are maintained at standardized temperatures and are sub-cultured after 4 to 24 months' intervals. There is a need to adopt complementary conservation strategies involving both *in situ* and *ex situ* approaches. For *in situ* conservation due attention is required to be given to genetically rich hotspots including all the stakeholders, including and expand the network of germplasm conservation by including all the stakeholders, including the communities. It is to be ensured that a set of the available PGR with associated database must be deposited as base collection with the genebank, and one set maintained as active collection with the accessible for plant improvement. There is an urgency to assess the germplasm collection in the genebank to understand the gaps and also identify the duplicates.

Figure 2. National Genebank at ICAR-NBPGR

Table 2: Status of base collections conserved in the National Genebank (as on 28 February 2021)

Crop Groups	Present status of accessions
Cereals	167859
Millets	59748
Forages	7359
Pseudocereals	7868
Legumes	67499
Oilseeds	60990
Fibre	16230
Vegetables	27491
Fruits & Nuts	295
Medicinal & Aromatic plants	8393
Ornamental	671
Spices, Condiments and Flavour	3303
Agroforestry	1663
Duplicate safety Samples (Lentil, Pigeonpea)	10235
Trial Material (Wheat, Barley)	10771
Total	450375

*The figure includes 5,034 Released Varieties and 4,316 Genetic Stocks; regenerated accession not included.
No. of Crop Species conserved: 1,762 (Source: http://www.nbpgr.ernet.in)

Table 3. Crop diversity conserved *in-vitro* in the National Genebank (As on 31 August 2020)

Crop / Crop Group	Present Status	Crop / Crop Group	Present Status
In-vitro bank		Cryobank	
1. Tropical fruits	443	1. Recalcitrant	0
2. Temperate and minor tropical fruits	364	2. Intermediate	6,948
3. Tuber crops	526	3. Orthodox	3,911
4. Bulbous crops	171	4. Dormant bud (Mulberry)	389
5. Medicinal & aromatic plants	227	5. Pollen	591
6. Spices and industrial crops	185	6. DNA	2,194
TOTAL	1916	TOTAL	14,033

(Source: http://www.nbpgr.ernet.in)

Under Utilized Cucurbits:

Minor neglected and under-utilized cucurbits (MNUC) are now getting ecause of their nutritive and medicinal value including antioxidant properties. The MNUC include vegetables like sponge gourd, wild gourd, sweet gourd, spiny gourd. Most of them are important minor vegetable crops of Northern, Eastern and Southern India. Sweet gourd is rich in â-carotene and lycopene; spine gourd is a rich source of protein; ivy gourd leaves are also better source of vitamin A (4036 µ/100 g) and vitamin C (13 mg/100 g) and chayote is fairly high in calcium. There is ample scopes to utilize these indigenous germplasm in crop improvement programme are given in table (4).

Table 4 - Minor Cucurbitaceous Vegetables Conserved in National Genebank

Common Name	Botanical Name	Genebank Status
Kachari	*Cucumis melo* subsp. *agrestis*	96
Orietal pickling melon	*C. melo var.conomon*	24
Long melon	*C. melo var.utilissimus*	46
Snap melon	*C. melo var. momordica*	210
Spine melon	*Momordica dioica*	55
Mountain spine gourd	*M. sahyadrica*	09
Sweet gourd	*M. cochinchinensis*	05
Teasle gourd	*M. subangulata* subsp. *renigera*	11
Bird bitter gourd	*M. charantia* var. *muricata*	105
Balsam apple	*M. balsamina*	03
Pointed gourd	*Trichosanthes dioica*	01
Snake gourd	*T. cucumerina*	132
Ivy gourd	*Coccinia grandis*	22
Wild cucumber	*Cyclanthera pedata*	81
Mateera (Water melon)	*Citrullus lanatus*	253

Under Utilized legumes

Underutilized legume crops are an important source of vitamins, micronutrients, protein when compared to other foods. Soybeans and lima bean are high in phosphorus and, thus, a valuable component to attain nutritional security. Significant research, breeding and development efforts are needed in the underutilized legume crops to convert existing local landraces into competitive varieties with wide adaptation and promising commercial potential. The list of beans underutilized as fresh vegetables are conserved in National Genebank are given in table 5.

Table 5. Underutilized leguminous Vegetables Conserved in National Genebank

S. No.	Common name	Botanical Name	Genebank Status
1	Broad bean/ Faba bean	*Vicia faba* L.	856
2	Winged bean	*Psophocarpus tetragonolobus (*L.) DC	213
3	Cluster bean	*Cyamopsis tetragonoloba (*L.) *Taub*	4053
4	Indian bean	*Dolichos lablab* (L.) *Sweet*	38
5	Sword bean	*Canavalia gladiate*	40
6	Lima bean	*Phaseolus lunatus*	48
7	Jack bean	*Canavalia ensiformis*	56
8	Vegetable soybean	*Glycine max* L.	12
9	Yard long bean	*Vigna unguiculata* var. *Sesquipedalis*	130
10	Velvet bean	*Mucuna pruriens*	114
11	Scarlet runner bean	*Phaseolus coccineus*	13
12	Moth bean	*Phaseolus acontifolius*	1509
13	Rice bean	*Vigna umbellata*	1982

Under Utilized Leafy Vegetables:

Green leafy vegetables are a very good source of minerals and vitamin like Vitamin A (Carotene), Vitamin C, Folic acid, Riboflavin, Thiamine, Iron and Calcium. ICAR-NBPGR, New Delhi, has made concerted effort to augment the plant genetic resources from indigenous and exotic sources. Several explorations have been made in India and a large number of accessions of various lesser known and underutilized leafy vegetable have been collected and conserved in National Genebank (Table 6).

Table 6. Under Utilized Leafy Vegetables Conserved in National Genebank

S. No.	Common Name	Botanical Name	Gene bank Status
1	Indian spinach	*Basella alba, B. rubra*	01
2	Dill	*Anethum graveolens*	72
3	Indian Sorrel	*Hibiscus sabdariffa*	996
4	Water Spinch	*Ipomoea reptans, I. aquatica*	01
5	Portulaca	*Portulaca oleracea*	18
6	Black nightshade	*Solanum nigrum*	73
7	Bathua sag	*Chenopodium album*	168
8	Mustard green	*Brassica campestris*	33
9	Lettuce	*Lactuca sativa*	25
10	Asparagus	*Asparagus officinalis*	03
11	Leek	*Allium porrum*	01
12	Kale	*Brassica oleracea* var. *acephala*	55
13	Parseley	*Petroselinum hortense*	
14	Celery	*Apium graveolens*	16
15	Drumstick leaves	*Moringa oleifera*	09

Registered Germplasm of Underutilized Vegetable Crops conserved in National Genebank

Landraces, traditional cultivars and other germplasm which have unique traits including tolerance/ resistance to disease(s), pests and other biotic and abiotic stresses but do not qualify for release and notification because of poor agronomic performance. These materials are novel, unique, and distinct with academic, scientific or applied value do not have a direct commercial value. With the objective of recognizing the contribution of scientists who have developed or identified such promising experimental materials Indian Council of Agricultural Research (ICAR) has established a mechanism to register the trait-specific germplasm through ICAR-NBPGR in 1996. NBPGR is entrusted the responsibility for registration of germplasm that provides soft protection to the germplasm having unique traits.

- Two accessions of *Amaranthus tricolor* are registered under this mechanism for the traits such as thick stem type (Dantu soppu:IC395324) and resistance to white rust (IC395327);
- *Chenopodium album* (Brown seeded : IC 258253);

- *Spinacia oleracea* (Terminal flower, Thick leaf, big seed mutant of (IC565527)
- Fenugreek (*Trigonella foenum*-graecum: Light green narrow leaves , downy mildew resistant, quick germination, fast initial growth, long pod, bold seed with green tan seed coat color (IC296791) and tall, erect plant type with multi-branched habit, whitish green stem, dark green narrow leaves, powdery mildew resistant and downy mildew tolerant (IC 296792) are conserved in NGB.

The details of the traits of registered germplasm may be obtained from NBPGR website http://www.nbpgr.ernet.in/ IRCG%20Search/index.htm. The registered germplasm is available in public domain and it is obligatory on part of the developer to maintain, multiply and supply the registered germplasm to the bonafide users.

Conclusions

Traditional and underutilized vegetables are an important asset for meeting the present day challenge as many have high nutritional value, low water requirements, adaption to poor quality soils, and good resistance to pest and disease, but, lack of knowledge and research generally challenges the promotion and use. Eroding knowledge of traditional vegetables has been observes in many places around the world, which threatens their persistent into the future and limits the delivery of their benefits to society. Therefore, development of new varieties to combat climate change as well as nutritional (cheap, alternative rich source of protein and nutrient) requirement of ever increasing population should be the target of future breeding programmes. NGB at ICAR-NBPGR conserves and distribute the potentially valuable germplasm to the farmers and breeders to popularise the same and their use in crop improvement programmes. The availability of these under exploited vegetable crops will go a long way in overcoming the malnutrition of the people living in the rural areas. The increase in area and production of these underutilized vegetable crops will not only provide nutritional security but also gives stable income to the rural poor.

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Vegetables as immune modulators- COVID scenario

Dr. P.R. Ramesh
Chief (Clinical Research), Arya vaidyasala, Kottakkal- 676503
rameshvarier@aryavaidyasala.com Ph: 0483 2806650

Humans are mostly made up of microbes, over hundred trillion of them. Microbes outnumber our human cells in a ratio 10 to 1. The majority of them lives in our gut particularly in the large intestine. Microbiome is the genetic material of all the microbes- bacteria, fungi, protozoa and viruses present in our body. One third or more of earth's biomass is made up of these microbes.

Human skin is a habitat for many useful bacteria and it can be called as "virtual zoo". Same way human gut is a "rain forest of bacteria". Metabolism is actually an amalgamation of both microbial and human attributes. The number of genes in all the microbes in one person's micro biome is 200 times the number of genes in the human genome.

Human microbiome is responsible for improved metabolism, vitamin production (B complex and K), detoxification of harmful materials, protection against pathogens, regulation of immune system, improving heart cell functions and controlling allergies, asthma, mood swings and blood sugar levels. Many more functions of the body are yet to be revealed as the functions of micro biota is being explored for more information.

Diversity is the key of healthy microbiota. 70- 80 % of immune cells are in the gut. The bacteria living in and on are not invaders, but beneficial colonizer. Disease causing microbes accumulate over a period of time, changing gene activity and metabolic processes and resulting in an abnormal immune response. Auto immune diseases such as diabetes, Rheumatoid Arthritis (RA), muscular dystrophy, Multiple Scleroses (MS) and fibro mayalgia are associated with dysfunction in the microbiome. Inheritance of microbiota, not DNA is the probable cause of disease inheritance.

Many viruses are stable members of the human microbiome. Viruses of the human microbiome provide evolutionary advantages to some bacteria. Virobiotatransverse human mucosalbarriers. Bacteriophage is in the microbiome protects mucosal barriers from potential pathogens. Virobiota may be involved in dysbiosis that results in human disease. Microbiome in a human body can be influenced by factors like host genotype, host physiology, host immune system, transient community members, host environment, host pathobiology and finally host life style. Human diet also can influence by modification of gut microbiota resulting in too many metabolic disorders, immune related conditions, psychological diseases, autism and even our faculties likeintelligence also can be affected. The dysbiosis of gut microbiota influenced by the factors like age, life style, genetics, and antibiotic usage can lead to the initiation of conditions like obesity, IBD(Irritable Bowel Disease), diabetes, cancer, autism etc.

Auto Immunity Research Foundation, Institute of National Health(INH), USA has been working on human microbiome project since 2007 by conducting study and collecting data on human microbiome research.

Dr. Margaret Chan, Director General, WHO (2006-2017), in her speech in traditional medicine conference has mentioned about the three major concerns of twenty first century namely rapid unplanned urbanization, globalization of unhealthy life styles and demographic aging. These three factors have contributed substantially in the universal rise of chronic non communicable life style disorders (NCD) like cardio vascular diseases, chronic respiratory disorders, diabetes, cancer, stress related disorders etc. In effect, a global transition in the disease pattern from communicable to non communicable diseases has been evidenced and a transition from acute death to chronic disease also is a matter of concern as far as the disease management strategies are concerned. Chronic ill health with disability and dementia make the life of elderly people difficult to cope with. More over the WHO predicts that the probability of premature NCD mortality is more than 25% in Russia and in India, the highest in the group. This probability estimates that the people dies between the ages of 30 and 70 years from the above mentioned NCDs

However the post COVID scenario of health is still not clear but the management of chronic non communicable life style disorders has become very relevant in the present era.

Human beings are nature's unique creation inanimate and animate objects follow nature's laws. Existence or survival depends on learning to live with nature. Somewhere during the renaissance period human being, in an attempt to understand nature and conquer it, developed an attitude to drift away from its encompassing effects. Rapid scientific progress diverted our mind to ignore certain phenomena like animals, birds, trees and flowers. We tend to ignore the fact that human body does react to the natures ever changing moods and suffer. Chronobiology, seasonalvariation, diet changes, environmental alterations and changing life style due to industrialization are all contributing factors.

Ayurveda is the traditional medicine system of India. It is widely practiced uninterruptedly at least from beginning of the Buddhist period in India. There are codified literature dated thousands of years back. For example,Charakasamhita,Susruthasamhita, Ashtangahridayam, Ashtangasangraham etc. (~400BC – 200 AD). All these texts are written in Sanskrit versus. It is the first organized form of medicine in the planet and still continues to be a vibrant system of health care for millions.

The word meaning of *Ayu* is "knowledge" and *veda* is "life"- thus ayurveda means knowledge of life. It is described in two parts namely *swasthavritham* (healthy man's regiment) and *athuravritham* (description of diseases and its management).

Ayurveda perceives man as integral part of nature, treating him for his ailments taking his body, mind and spirit together and its approach to his well being is philosophical in principle and holistic in techniques. Every state of ailment is considered as a psychosomatic manifestation and its eradication procedure is functional and integrative rather than symptomatic or factorial. Along with medication, ayurveda insists good habits and dietary controls. Thus it becomes a comprehensive health care system with holistic approach.

In Charakasamhita, one of the classical texts of ayurveda evolution of a pandemic by the pollution of air, water, location and seasons has been described and its management guidelines have also been narrated to help the people. Susruthasamhita, another classical text of ayurveda give descriptions about communicable diseases which can spread through contact like dinning, sleeping and sitting together or by touch and inhaling the contaminated air also. In a nut shell, both the ancient acharya of ayurveda discusses about the important strategies like antipathogen and immunity protecting approaches to manage the pandemic in an effective manner. Personal hygiene, environmental hygiene, using of medicines which have antipathogen, antiinflammatory and immunomodulatory effects are recommended clearly. Purificatory therapies and*dhoopana* (disinfection by fumigation) are also recommended as it is the holistic nature of the treatment.

Balam and *Ojus* are the two key words used in ayurveda to describe immunity. *Sahajabalam* (innate healing potentials), *Kalajabalm* (immunity by season and age) and *yuktikrithabalam* (acquired immunity) are the descriptions in ayurveda which very well coincides with the understanding of modern medicine. *Ojus* is the supreme state of being functional or fit.

For the maintenance of an effective immune system the following factors are very important. Using pure water, good air, exposure to sun light, having nutritious food, doing regular exercise, keeping a stress free mind, getting adequate sleep, maintaining a vibrant metabolism and diversity of micro biota, inheriting healthy genetic factors and appropriate use of immunomodulating diet and medicines- are all important to maintain an effective immune system in a healthy individual.

Let us examine the positive effects of vegetables and fruits on our body in the present COVID scenario.

In general, the immune parameters affected by food are as follows.
Vitamins, minerals, amino acids, proteins, carbohydrates and lipids enhances parameters of acquired immunity- antigen- specific exclusion of pathogens. Pro biotic, including lactic acid bacteria mainly augment parameters of innate immunity- antigen independent manner.

The potential disease preventive mechanism of vegetables and fruits are expected to be as follows according to the substantial evidences collected from various research papers.

Anti oxidant activity- anti oxidants like flavonoids present in vegetable and fruits reduces oxidative stress and inhibits the initiation of cardio vascular disease, cancer, cataract formation, aging process etc.

Modulation of detoxification enzymes- the process of detoxifications, or drug- metabolizing, enzymes are essential for the biotransformation of many important endogenous compounds and in the detoxification of numerous xenobiotics. This process is being carried out inside our body when we consume vegetables and fruits.

Stimulation of immune system- Natural killer cells (NK cells) play an important role in immune surveillance. Nutrients and photochemical tend to affect NK cell activity without influencing cell number. In many studies NK cell activity approximately doubled at three different effecter- to target cell ratios especially with garlic intake study.

Decreased platelet aggregation- studies on garlic to assess the capacity to prevent excess and abnormal platelet aggregation have proved its efficacy positively and thus it may be helpful in preventing cardiovascular and cerebrovascular disorders.

Alteration in cholesterol metabolism- isolated dietary fiber and pectin containing fruits and vegetables have hypocholesterolemic actions in humans.

Modulation of steroid hormone concentration and hormone metabolism- certain CYP enzymes that metabolize phytochemicals are modulated by phytochemicals, or both, contribute to the inactivation of endogenous steroid hormones. They alter the potency of testosterone, estrogen and their derivatives via oxidation and hydroxylation reactions.

Blood pressure reduction- replacing animal products with vegetable products, lower fat intake and higher intake of dietary fiber and mineral trials have shown blood pressure reduction in normotensive and hypertensive individuals.

Antibacterial and antiviral activity- studies have proven that garlic, ginger, basal, turmeric etc have both anti bacterial and anti viral activity by its internal and external usage.

Ayurveda mainly depend up on herbs for the preparation of many medicines which are being used effectively in the management of various chronic life style disorders. There are many medicines which have proven its efficacy in the management of infectious diseases of bacterial or viral origin. Ayurveda describes the properties of these herbs through its *rasa* (taste), *guna* (quality), *veerya* (potency), *vipaka* (end taste) and *prabhava* (special therapeutic effect) as the knowledge of ayurveda was evolved thousands of years back and its philosophy is based on the*sanghya* school of thought mainly. More over the modern biochemical and other parameters were not developed this extent during that time to explain it as envisaged by modern scientist. However the researches on herbs like ginger, garlic, cinnamon, gooseberry, pepper etc shows many positive aspects of the drug which can be translated back to the ancient wisdom of its properties. Thus it becomes very much comparable with the modern scientific findings.

Ayurvedic literature like Dhanwantarinikhandu, Raja nikhandu, Bhavaprakashanikhandu, Kaiyadevanikhandu, Chakradhatam, Shargadharasamhitha and so on described the properties of herbal drugs which were considered primarily for the preparation of single or compound medicines used for treating various ailments diagnosed using ayurvedic parameters.

As an example, the following table of herbs, vegetables and fruits can be considered and compared with modern studies and it has been proved positively that the vegetable and fruits have immense potency to make positive changes in the self healing mechanism of our body and thus protect the ailing humanity from many infectious disorders like COVID 19.

SI No.	Common name	Botanical name	Ayurvedicdescription	Modern study results
1	Ginger	*Zingiber officinale* Rosc.	Carminative, Appetizer, Anti-inflammatory	Antioxidant, Anti-inflammatory, Anti bacterial, Cardio protective
2	Turmeric	*Curcuma longa* L	Anti-inflammatory, Diabetes, Anti-anemic, Skin diseases	Antioxidant, Anti-inflammatory, Anti diabetic, Anti cancer, Immuno modulator.
3	Garlic	Allium sativum L.	Anodyne, Anthelmintic, Anti hyperlipidaemic, Expectorant, Antibacterial and antifungal	Anti-viral, Anti hypertensive, Anti microbial (protozoa, fungi, bacteria), Anti tumour
4	Snake gourd (Patola)	*Trichosanthes anguina*	Cardiac tonic, Appetizer	Antibiotic and antioxidant
5	Bitter gourd (Karavellaka)	*Momordica charantia*	Pungent taste, Carminative	Antibacterial, Antiviral, Immunomodulatory and Antioxidant
6	Brinjal	*Solanum melongena*	Promotes appetite, Stomachic, Enhances taste	Antipyretic, antioxidant, Anti-inflammatory, Antiasthmatic
7	Ribbed gourd	*Luffa acutangula*	Antimicrobial, antioxidant and immunomodulatory	Antimicrobial, antioxidant and immunomodulatory
8	Tanduliya	*Amaranthus spinosus*	Intoxication, Disorders of blood	Antioxidant Immunomodulatory
9	Spinach	*Spinace aoleracea*	Laxative, Improves body immunity, Antioxidant	Antioxidant
10	Upodaka (Indian varieties of Spinach)	*Basella rubra/alba*	Pacifies intoxication, Laxative immunomodulatory	Antioxidant
11	PhalaSakaVarga Kusmanda	*Benincasa hispida*	Increase kapha and vata, purgative, abdominal distention, Increased secretion	AntioxidantAnti-allergic and immunomodulatory
	Tumba	*Cucurbitalagenaria*		
	Trapusa	*Cucumis sativus*		
12	Ash gourd	*Benincasa hispida*	Clears urinaryBladder, Aphrodisiac	Diuretic property, Antioxidant and immunomodulatory

SI No.	Common name	Botanical name	Ayurvedicdescription	Modern study results
13	Cucumber	*Cucumis sativus*	Appetizers, Carminative, Stomachic, Abdominal distension, Increases urine, Antioxidant	Antioxidant
14	Aquatic stem vegetables	*Nelumbo nuceifera*	Rejuvenating, Good for skin, Improves strength	Anti-inflammatory, antioxidant
15	Thazhuthama	*Boerhaavia diffusa*	Carminative, Purgative	Antioxidant and immunomodulatory
16	Indian mustard	*Brassica juncea*	Obstructsurine and faeces, Carminative, Anthelmintic, Anti-inflammatory	Carminative, Anti-inflammatory, digestive, anthelmintic
17	Root Vegetables (RAPHANUS SATIVUS)			
	Tender Raddish		Abdominaldistension, Cough, Emaciation,Asthma Disorders of eye, Disorders of throat, Hoarseness of voice, Decrease in Appetite, Retrograde intestinal movements, Rhinorrhea	LaxativeAnti-inflammatory HepatoprotectiveDiuretic
	Mature Raddish		Increased secretion, Antioxidant	LaxativeAnti-inflammatory Hepato protective Diuretic
	Pindalu(Yam)		Laxative, Anti-inflammatory, Strength giving	Antioxidants, immunomodulatory
18	SalanaSakaVarga			
	Muringa	*Moringa oleifera*	Immunomodulatory, Stomachic, Carminative, Appetizer	ImmunomodulatoryAntioxidant and anti toxic
	Lemongrass	*Andropogon citratus*		
	Lemon	*Citrus limon*		
19	Tulsi	*Ocimum sanctum*	Cough, Asthama, Immunostimulatory	Anti-viral, antibacterial and antioxidants
20	Onion- small and large	*Allium cepa*	Carminative and improves appetite, improves digestion, improves body strength	Anti-inflammatory Anti haemorrhoid Antihelmentic
21	Elephant foot yam	*Amorphophallus paeoniifolius*	Carminative,Appetizer	Anti haemorroid and antioxidant
22	Mushroom	*Vitiates tridosha*	Antihelmentic anti-inflammatory	Antioxidant, improve microbiome functions
23	Green coriander	*Coriandrum sativum*	Diuretic, anti-inflammatory	Antioxidants and anti-inflammatory
24	Coriander	*Coriandrumsativum* L.	Anti-inflammatory, Diuretic, Anthelmintic, Carminative, Antipyretic, Appetizer, Expectorant & Anodyne	Antidepressant, Antimicrobial, Antioxidant, Antidiabetic, Antiepileptic, Antihypertensive, Neuroprotective
25	Curry leaf	*Murraya koenigii*(L) Sprengel	Aromatic, Anthelmintic, Anodyne, Carminative, Anti-inflammatory, Hyperdipsia, Skin diseases, Colic	Anthelmentic Hypoglycaemic and anti- inflammatory
26	FRUITS Grapes	*Vitis vinifera*	Cough, Fever, Asthma, Soreness of throat, Thoracic trauma, Emaciation	LaxativeAntispasmodic, Cardio tonic, Haemostatic

SI No.	Common name	Botanical name	Ayurvedic description	Modern study results
	Pomegranate	*Punica granatum* L.	Anti pyretic, Anti anemic, Anti ulcer, Bestows intelligence, Bestows strength, Cardio protective, Anti diarrheal,	Cardio vascular disease, Anti atherosclerotic, Anti hypertensive, Antioxidant, Anti-inflammatory, Anti diarrheal, Amoebicide
	Banana	*Musa paradisiaca*	Nutritive, Burning Sensation, Effects of trauma, Emaciation, Purify blood, Constipation with abdominal distension during digestion	Antioxidants Anti-inflammatory
	Dates	*Phoenix dactylifera*		
	Jackfruit	*Artocarpus heterophyllus*		
	Coconut	*Cocos nucifera*		
	Koovalam	*Aegle marmelos*	Carminative, Constipative	Anti-diarrheal, hypoglycemic, anti ulcer and Chemo preventive
	Jamun	*Syzigium cumini*	Abdominal distention, Vitiates vata, Obstruction to urine and faeces, not good for throat, Kaphapittahara	Hypoglycemic, Anti-inflammatory and antioxidant
	Tender Mango Ripe mango	*Mangifera indica*	Bleeding disorders Vatahara, Increases kapha and sukra	Antioxidant, immunomodulatory Antioxidant, immunomodulatory
	Matulunga	*Citrus medica*	Cough, Asthma, Hiccups, Alcoholic intoxication, dryness of mouth, Constipation,vomiting, Anorexia, Abdominal fullness, Ascites, Haemorrhoids, Colicky pain, weakened digestivepower	Antioxidants, immunomodulatory
	Common plum	*Prunus domestica*	Digestive, Antioxidants, immunomodulatory	Antioxidants, immunomodulatory
	Orange	*Citrus reticulate*	Vitiate Pitta and Kapha, Vatahara, Laxative	Antioxidants, Anti-inflammatory and immunomodulatory

We need to realize the fact that there is not a single compound derived from the plant based food as a magic bullet preventing the whole mariyad of diseases but the synergic effect of many compounds derived from the vegetables and fruits can nourish our body and soul and hence we must consume them adequately to keep our life healthy and happy.

The complete mechanisms of the immune modulating effects are still not fully understood. To confirm the scientific basis of these activities there is a need to continue these kinds of studies further in order to establish the facts more precisely.

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National Webinar
"Challenges and opportunities of vegetable production in warm humid tropics"

Session 4

Breeding for biotic stress resistance of Solanaceous vegetables in humid tropics

Chair :
Dr. L. Pugalendhi
Dean, HC & RI
Tamil Nadu Agricultural University
Coimbatore

Dr. A.T. Sadashiva
Director (R&D)
Nethra crop Sciences Pvt. Ltd
Bengaluru

Dr. Vijeeth C. Hegade
Breeder (R&D)
Namdhari Seeds Pvt. Ltd.
Bengaluru

Dr. Major Singh
Director, ICAR
Directorate of Onion
and Garlic Research
Pune

Session 4

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Chairman : Dr. L. Pugalendhi, Dean, HC & RI, TNAU, Coimbatore

10 New approaches and progress in breeding for multiple disease resistance in tomato
- Dr. A.T. Sadashiva, Director (R&D), Nethra crop Sciences Pvt. Ltd, Bengaluru

11 Breeding for resistance against bacterial wilt and virus in chilli : Progress made by Indian Seed companies
- Dr. Vijeeth C. Hegade, Breeder (R&D), Namdhari Seeds Pvt. Ltd, Bengaluru

12 Bt Brinjal and recent alternatives to transgenics –
- Dr. Major Singh, Director, ICAR, Directorate of Onion and Garlic Research, Pune.

New approaches and progress in breeding for multiple disease resistance in tomato

Dr. A.T. Sadashiva
Director (R & D), Nethra Crop Sciences, Bengaluru
Email: atsbrs@gmail.com

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the leading vegetable crops across the world. In India the popularity of tomato comes just after potato where tomato is grown in an area of 778 thousand hectares with production of 19,397 thousand tonnes and productivity of 24.93 t/ha (Anonymous, 2019). Crop improvement programme on tomato was initiated at ICAR-IIHR, Bengaluru during 1970 with the objective of developing fresh market tomato varieties & F_1 hybrids for high yield and good fruit quality attributes as a result two fresh market varieties *viz;* Arka Vikas & Arka Saurabh were developed through pure line selection & identified for release at National level during 1987. Pure line selection from exotic tomato varieties also resulted in development of two processing varieties *viz;* Arka Ashish & Arka Ahuti during 1990. Two high yielding F_1 hybrids *viz.,* Arka Vishal & Arka Vardan were also developed through heterosis breeding and both were recommended for release at National level during 1993 & 1995 respectively. A rainfed variety Arka Meghali was also developed through pedigree method & was recommended for release at state level of Karnataka during 1996.

Production constraints in tomato

Low productivity of tomato in India is due to several biotic and abiotic stresses. Among the biotic stresses,Tomato leaf curl disease (ToLCD), bacterial wilt (*Ralstonia solanacerum*), early blight (*Alternaria solani*) and late blight (*Phytophthora infestans* Mont. de Bary) are major production constraints causing yield loss ranging from 25 to 100 per cent (Table 1).

Table 1. Yield loss in tomato due to mmajor diseases

S.N.	Diseases	Yield loss (%)	References
1	Tomato leaf curl disease (Begomoviruses)	Upto 100	Saikia and Muniyappa (1989), Pico *et al.* (1996), Polston *et al.*, (1999), Varma and Malathi (2003)
2	Bacterial Wilt (*Ralstonia solanacerum*)	11-93	Ramkishun, (1987), Mishra *et al.*, (1995)
3	Early blight (*Alternaria solani*)	Up to 79	Basu (1974) , Singh (1985), Datar and Mayee (1981) , Yadav and Dabbas (2012)
4	Late Blight (*Phytophthora infestans* (Mont.) de Bary	41-100	Nowicki *et al.*, (2012)

Breeding for resistance to bacterial wilt (BW) Disease:

Bacterial wilt caused by *Ralstonia solanacerum* is one of the serious soil borne diseasesin major tomato growing states in the country. Disease incidence is more severe under hot&humidclimate including coastalregions. Bacterial wilt disease causes yield loss ranging from 70 to 100 per cent. Race 1 & 3 biovar III have been reported to cause bacterial wilt in Indian sub-continent.If the soil concentration of bacteria reaches thresh hold level of 1 x10^3 c.f.u /g of soil which makes it BW sick soil, where in the susceptible genotypes of tomato start expressing typical disease symptoms of sudden wilting at flowering & fruiting stage and browning of xylem vessels. It can be further confirmed by the ooze test.

Sudden wilt –typical symptom of bacterial wilt

Bacterial wilt sick soil (1 x 10^3 cfu/g)

Browning of xylem vessels

Bacterial ooze

Identification of stable sources of resistance to BW

SN	Lines	Source	Pedigree	Reaction
1	IIHR-2610	WVC	Hawaii-7996	HR
2	IIHR-2296	WVC	CLN-1463	HR
3	IIHR-2867	IIHR	38-10	HR
4	Arka Alok	IIHR	CL114-5-1-0	R
5	Arka Abha	IIHR	VC-8-1-2-1	R
6	IIHR-2826	IIHR	TLBR-1	R
7	IIHR-2828	IIHR	TLBR-4	R
8	IIHR-2657	IIHR	TLBR-6	R
9	IIHR-2197	WVC	CLN-2116DC1 F1-180-31-9-11-12	R
10	IIHR-2200	WVC	CLN-2116DC1FC1-180-31	R
11	IIHR-2201	WVC	CLN-2116DC1 F1-180-31-10-25-22	R
12	IIHR-2761	OUAT	BT - 218	R
13	IIHR-2834	IIHR	TLBER 12-21-43-1	R
14	IIHR-2920	IIHR	ToLCVR F3-38-1-1	R
15	IIHR-2888	IIHR	TLBER-38-7-41-43	R
16	IIHR-2042	WVC	EC-357846	R

Breeding for BWR at ICAR-IIHR, Bengaluru: Breeding forresistance against bacterial wilt was initiated during 1987 and the following bacterial wilt resistant (BWR) varieties & F_1 hybrids were bred.

Variety / F_1 hybrid — **Salient features** — **Photograph**

Arka Abha (BWR-1)

Bacterial wilt resistant variety developed by pure line selection from IIHR-663-12-3-SB-SB-SB (VC-8-1-2-1) from AVRDC, Taiwan. Fruits oblate with light green shoulder having stylar end scar with average fruit weight of 75g. Develops deep red color on ripening.. Yields 43 t/ha 140 days. Recommended for release at state level of Karnataka during 1990.

Arka Alok (BWR-5)

Bacterial wilt resistant variety developed by pure line selection from IIHR-719-1-6 (CL-114-5-1-0) from AVRDC, Taiwan. Fruits on the lower clusters are round, large (120g) and in later clusters oblong, medium (80g) firm fruits with light green shoulder. Resistant to bacterial wilt. Bred for fresh market.Yields 46 t/ha in 130 days. Recommended for release at state level of Karnataka during 1990.

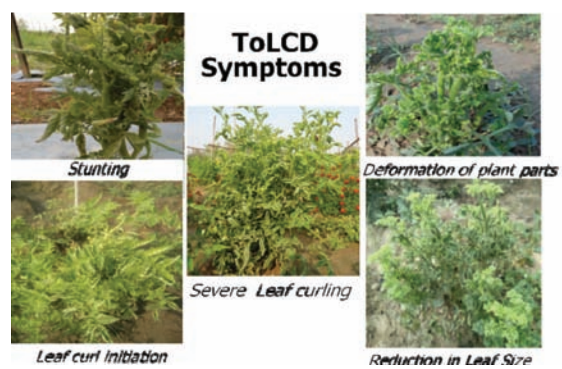
Arka Shreshta (BRH-1) High yielding bacterial wilt resistant F_1 hybrid developed by crossing 15 SB SB x IIHR-1614 (E-6203) Fruits medium large (70-75g.), round with light green shoulder. Deep red, firm fruits. Suitable for both fresh market and processing. Yields 76 t/ha. in 140 days. Recommended for release at state level of Karnataka during 1996.

Arka Abhijit) (BRH-2 High yielding bacterial wilt resistant F_1 hybrid developed by crossing 15 SB SB x IIHR-1334. Fruits medium (65-70g.), round with green shoulder. Deep red, firm fruits Suitable for fresh market. Resistant to bacterial wilt. Yields 65 t/ha. in 140 days. Recommended for release at National level during 1998 Recommended for release at National level to zone VII (Dapoli & Jabalpur)..

Breeding for resistance to Tomato Leaf Curl Disease

***Tomato Leaf Curl Disease*(ToLCD):**

ToLCD is one of the most devastating diseases of tomato from a long time and it is caused by Begomoviruses that are easily transmitted by white fly (*Bemisia tabaci*). This disease causes up to 100 per cent yield loss if the crop is infected at initial stage (before 20 days), however if the disease infection occurs at 35 days after transplanting, then it causes 74.1 per cent yield reduction. Moreover, if the disease infection occurs at 50 Days after transplanting then it causes 28.9 per cent yield loss (Malathi, 2013). So far, the initial infection can cause the huge loss to tomato growers.



Disease Symptoms:

The different symptoms associated with this disease are reported by various workers e.g., leaf curling, leaves puckering, yellowing of veins, stunting plant growth, bushy plant, discolouration of leaves from pale yellowing to deep yellowing and small leaves size.

Disease Scoring in ToLCD:

Disease Severity Index (DSI) & Percent Disease Index (PDI) have been estimated on 0-4 scale as described by Lapidot *et al.,* (2007) at 30, 45, 60, 75 & 90 days after transplanting. Based on the intensity of symptoms observed both DSI & PDI were estimated by adopting the following formulae.

$$\text{DSI (\%)} = \frac{\text{Sum of all ratings x 100}}{\text{Total no. of plants x maximum rating on scale}}$$

$$\text{PDI (\%)} = \frac{\text{Number of diseased plants x 100}}{\text{Total number of plants observed}}$$

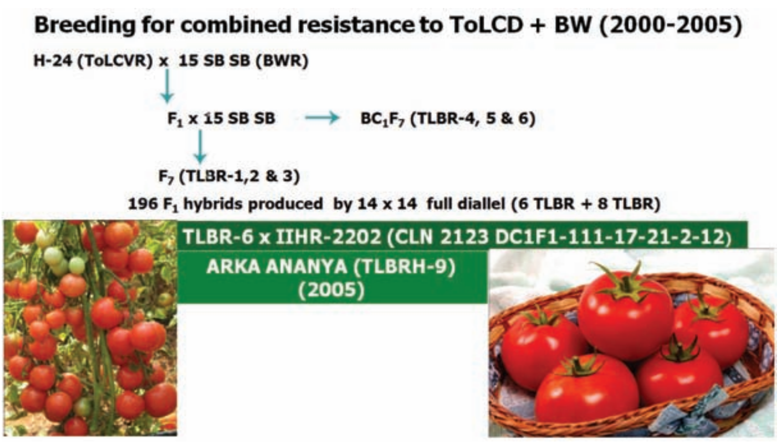
Scale	DSI (%)	Symptoms	Response
0	0	no visible symptoms	HR
1	1 - 15	very slight yellowing of leaflet margins on apical leaf;	R
2	16 - 25	some yellowing and minor curling of leaflet ends;	MR
3	26 - 50	a wide range of leaf yellowing, curling, and cupping, yet plants continue to develop;	S
4	> 50	very severe plant stunting and yellowing, pronounced cupping and curling, plants stop growing	HS

Identification of sources of resistance to ToLCD.

Seven lines viz; IIHR-2101 (*S habrochaites-LA 1777*), IIHR-2195 (CLN-2114), IIHR-2611 (TV-55), IIHR-2413 (FLA-496-11), IIHR-2406 (FLA-456), IIHR-2205 (FLA-744)&IIHR-1970 (*S. peruvianum*) were resistant to ToLCBV on artificial screening .

Disease Scoring for ToLCD on the basis of intensity of symptoms observed

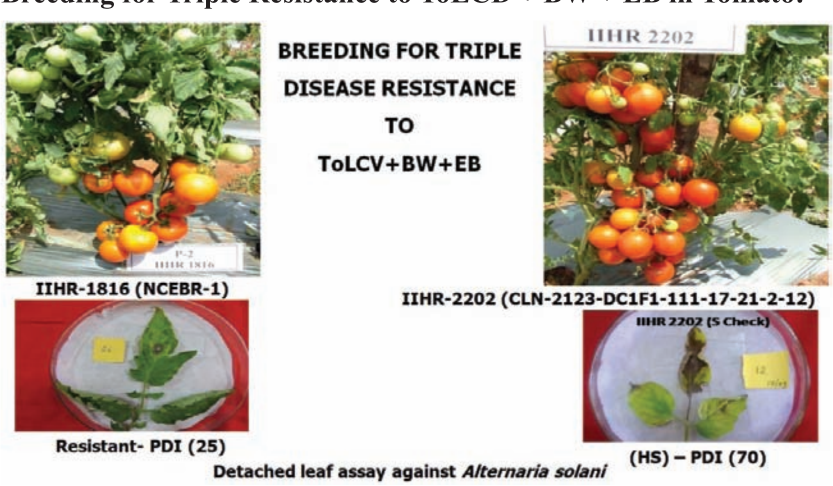
Breeding for Combined Resistance to ToLCD + BW in Tomato:



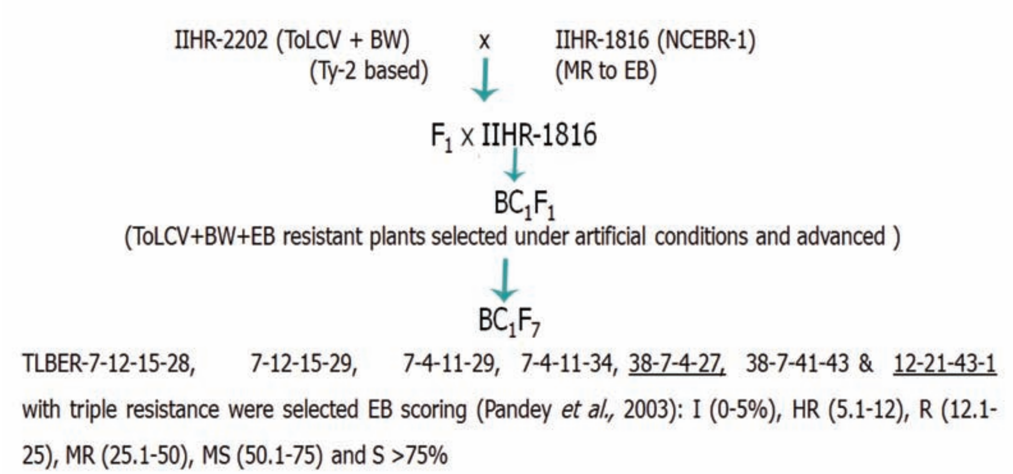
3. Early Blight (EB) Disease:

Early Blight (*Alternaria solani*) is a severe fungal disease that occurs on tomatoes throughout India and causing upto 79 per cent yield loss. The infected plants display collar rust on the stems, infected older leaves, and fruits that crack at the stem end. The circular spots on leaves and pitted fruits are characteristic symptom of this injurious disease.

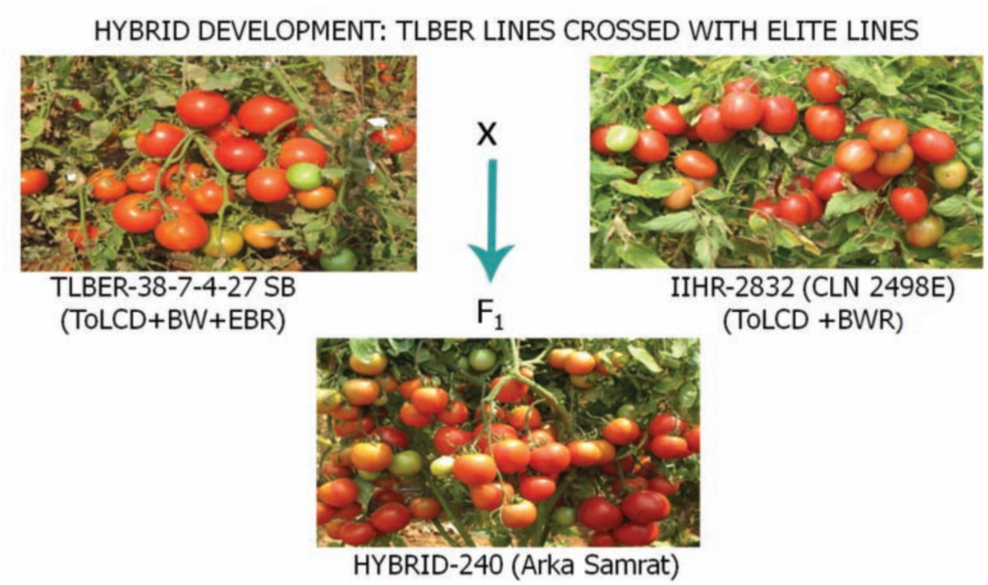
Breeding for Triple Resistance to ToLCD + BW + EB in Tomato:



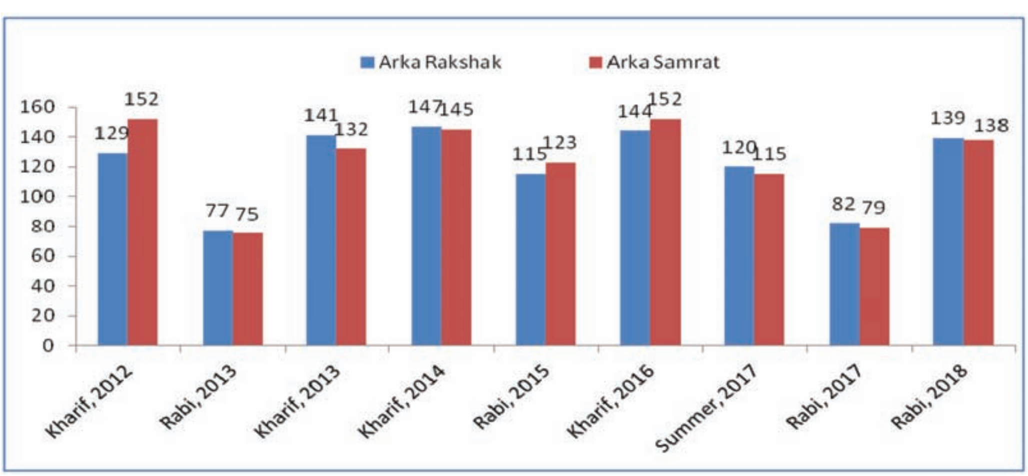
Development of Triple Disease Resistance (ToLCD+BW+EB) in Tomato:



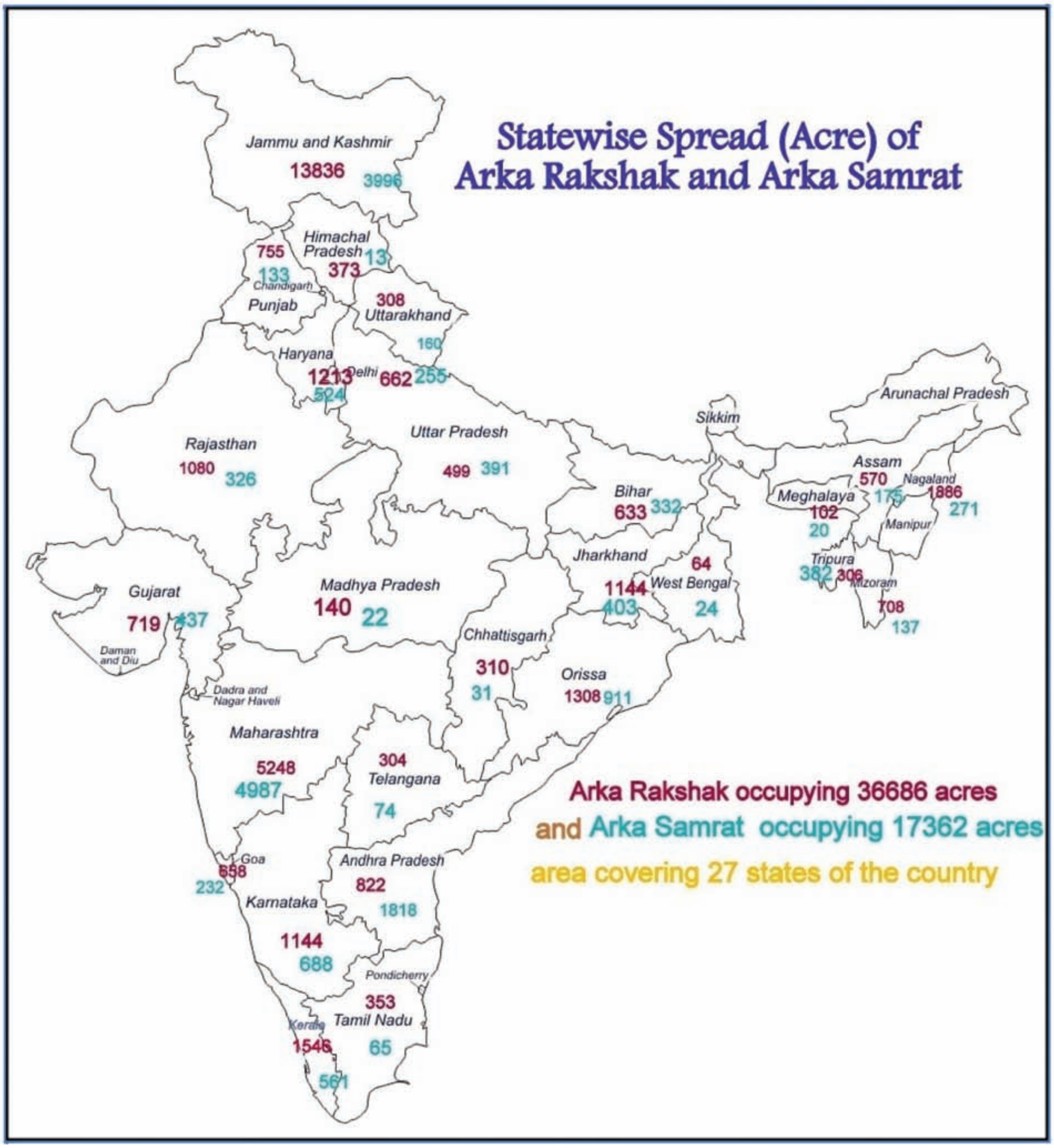
Achievements of Triple Disease Resistance (ToLCD+BW+EB) in Tomato:



Performance of Arka Samrat and Arka Rakshak at ICAR-IIHR, Bengaluru (Estimated yield in Demo t/ ha)



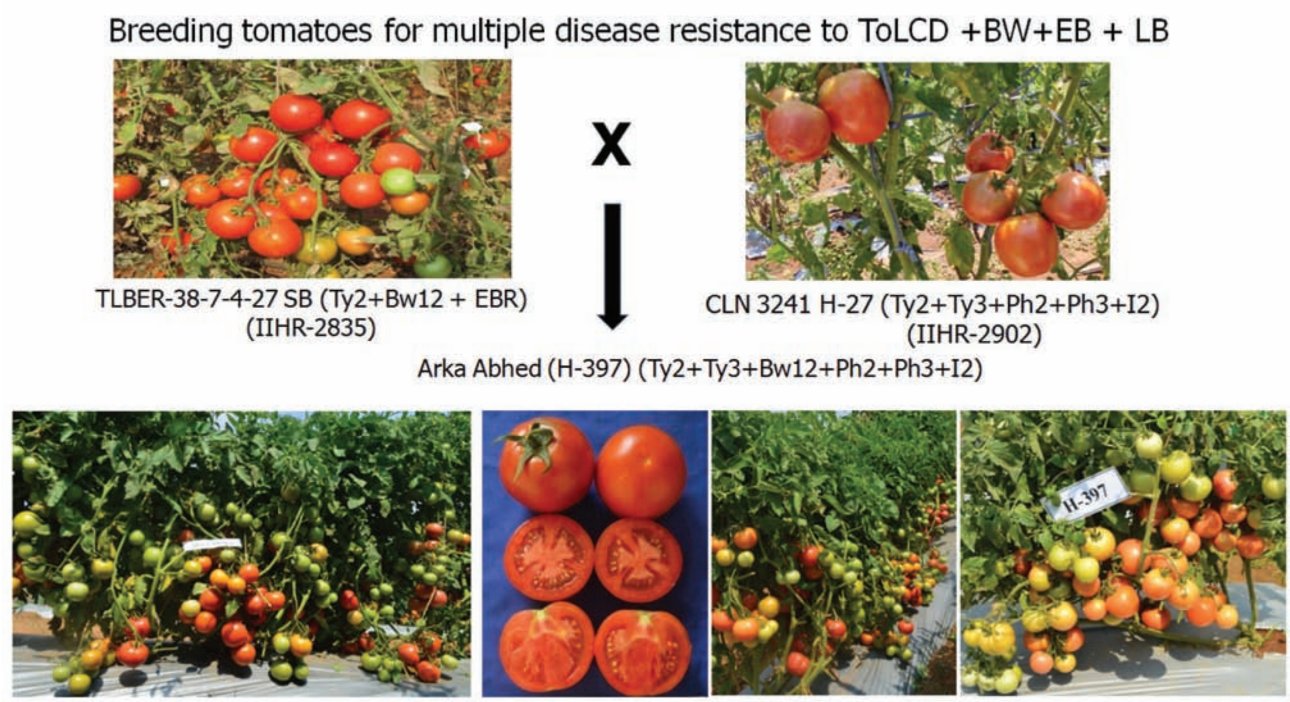
The revolutionary tomato hybrid Arka Rakshak covering 27 states of the country



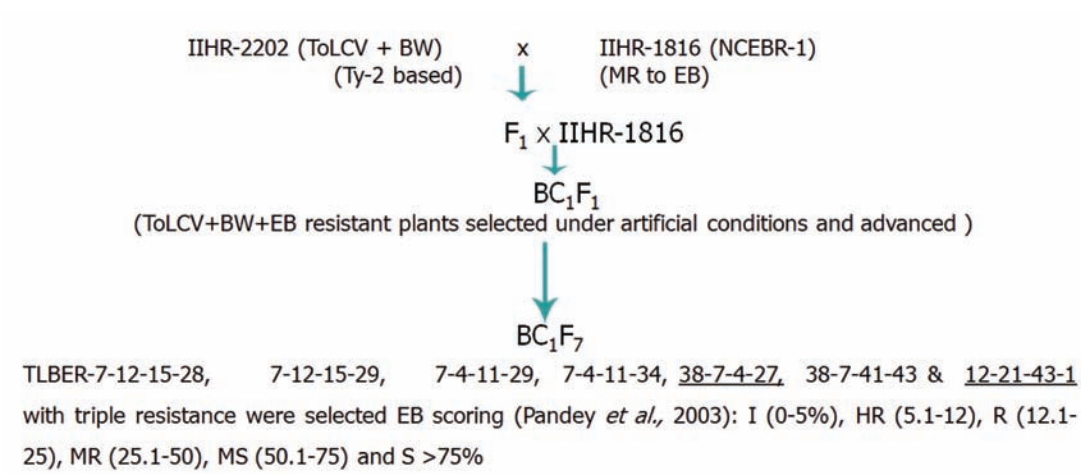
4.Late Late Blight (LB) Disease:

Late blight ((*Phytophthora infestans* Mont. de Bary) is a potentially devastating disease of tomato as well as potato. This disease damages all aerial plant parts of tomato i.e., leaves, stems and fruits. The disease spreads speedily in fields and can cause 41-100 per cent yield loss in tomato.We can predict its damages by knowing about Irish potato famine of the late 1840s. The characteristic symptom of this disease is firm, deep brown, irregular spots grow to cover large parts of leaves, stems and fruits. The patches may become mushy as secondary bacteria invade. In cool along with high humid conditions, thin powdery white fungal growth appears on infected leaves, fruit and stem. The cool, wet weather are promoting condition for this disease and under this situation entire field turn brown and wilted as if hit by frost.

Development of Multiple Disease Resistance (ToLCD+BW+EB+LB) in Tomato:



Achievements of Multiple Disease Resistance (ToLCD + BW + EB + LB) in Tomato:



Arka Abhed (H-397)

- Major disease resistance against tomato leaf curl disease (*Ty2*), bacterial wilt, early blight and late blight
- Plants are semi-determinate with dark green foliage.
- Fruits are firm, oblate round and medium large (90-100g).
- Suitable for summer, *kharif* and *rabi* cultivation.
- Bred for fresh market and yields 70-75 t/ha in 140-150 days.

Arka Aditya (H-331)

- High yielding F_1 hybrid with triple disease resistance to tomato leaf curl disease (*Ty2+Ty3*), bacterial wilt and early blight.

- Plants are semi-determinate with dark green foliage.
- Fruits are firm, deep red, oblate round, medium large (90-100g).
- Suitable for summer, *kharif* and *rabi* cultivation.
- Bred for Fresh market and yield potential 60 to 70 t/ha in 140-150 days.
- Identified at National level during 2019 for Zone VIII

Development of Triple Disease Resistance (ToLCD + BW + EB + LB) in Processing Tomatoes:

IIHR, Bengaluru has recently developed (2019) two promising F_1 hybrids of processing tomatoes namely, Arka Apeksha and Arka Vishesh. The significant characters of these varieties are tabulated below:

Characters	Arka Apeksha (H-385)	Arka Vishesh (H-391)
Plant Type	Semi-determinate	Semi-determinate
Avg. Fruit Weight	90-100g	70-80g
Fruit Appearance	Oblong,deep red, firm, jointless for MH	Oblong,deep red, firm, jointless for MH
TSS	4.0-4.7 ^{0}Brix	4.0-4.6 ^{0}Brix
Lycopene Content	11 mg/100g	8-10 mg/100g
Yield Potential	> 120t/ha	> 100t/ha

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Breeding for resistance against bacterial wilt and viruses in chilli – A review

Dr. Vijeeth C. Hegade,
Plant Breeder, Namdhari Seeds Pvt. Ltd., Bengaluru, Email: vijeethhegade@namdhariseeds.com

India is second largest producer of vegetables in world. However, Kerala is one of the major consumer state as far as vegetables are concerned. The land of Kerala is blessed with rich fertile soils, unique agro climatic conditions and characteristic monsoon. So, there is a vast scope for vegetable cultivation in Kerala. Chilli (*Capsicum* spp.) is a fruit vegetable originated in the American tropics, is the most important vegetable in our cuisines – It's our daily need vegetable.

Around the genus *Capsicum*, there is an increasing interest due to the amazing diversity in plant and fruit characteristics, which make this crop extremely versatile and suitable for innumerable uses. The consumption of pepper has been increased in the last 20 years with a production ranging from 19 to about 40 million tons and a surface area from 2.5 to about 3.8 million of hectares (FAO, 2018). Further increases are expected due to the greater demand for high-value nutritional products by consumers. Indeed, pepper is a rich source of health-promoting compounds with important nutraceutical and anticancer properties.

The range of pathogens affecting chilli is very vast and includes fungi, bacteria, viruses, nematodes and insects. Cultural methods and pesticides are applied to ensure a healthy and profitable pepper crop. Considering the increasing need for sustainable agriculture, the use of resistant plants represents the main strategy to protect pepper cultivation against biotic stresses. In the last decades, most of the pepper breeding programs have been addressed to the development of cultivars or hybrids against a wide range of pathogens and pests. Despite the efforts made, the exploitation of *Capsicum* germplasm (pre-breeding materials, landraces, wild relatives and closed related species) and its use in breeding programs for biotic stress resistance still represent challenging tasks (Parisi *et al.*, 2020).

Bacterial wilt (BW) is one of the most important diseases which is widely distributed among the pepper growing areas of the world (Hayward, 1991; Denny, 2006). The disease is most commonly seen in the coastal regions and foothills of India (Jyothi *et al.*, 2012).

BW is caused by *Ralstonia solanacearum*, phylotype I, *R. pseudo solanacearum*, phylotype I and III, and *R. syzyngii* subsp. *indonesiensis* phylotype IV. The three species were previously grouped in *R. solanacearum* species complex (RSSC) and classified into "races" and "biovars" (Genin and Denny, 2012; Buddenhagen *et al.*, 1962).

The pathogen enters the plant through root wounds or penetrate the plant at sites of secondary root emergence and spreads to the plant through the vascular system. Pathogen remains in the deeper layers of soil, grows endophytically, moves with water and also have an association with the weeds. Young plants are rapidly infected and destroyed after the infection. Older plants first show wilting of the youngest leaves during warm or hot weather day conditions and after a temporary recovery under cooler temperatures can permanently wither. In the cross-section, plant vascular bundles show a brown discoloration and ooze a white bacterial exudate.

Due to soil- borne nature of the pathogen, the commonly used management practices like soil treatments, crop rotation and adjustment of planting time are not much successful. Hence, the phenomenon of host plant resistance is effective, economic, long-lasting and environmentally safe for soil borne diseases.

A Malayan germplasm PM687 was found to have stable resistance to BW. Lafortune et. al. (2005) reported two to five genes with additive effects responsible for resistance.A major QTL, spanning between CTGAAG178 (AFLP) and Hpms E062 (SSR) was designated *Bw1* (Bacterial wilt 1), found to be responsible for resistance to BW (Mimura *et al.*, 2009).This QTL was mapped on LG 11 which corresponds to pepper chromosome 1. Although BW-resistance is thought to be polygenically controlled, use of this linkage marker may improve the efficiency of breeding BW-resistant cultivars.

Kang *et al.*, (2016) resequenced pepper parental lines YCM334 and Taean for genetic analysis of BW resistance. YCM334 was reported to be highly resistant to BW. The authors haveidentified novel single nucleotide polymorphisms (SNPs) and insertions/deletions (Indels) that are only present in both parental lines, as compared to the reference genome and further determined variations that distinguish these two cultivars from one another. These novel SNPs could be used in Marker Assisted Breeding for BW resistance.

Chilli production is hampered by many plant pathogenic viruses. Among those, roughly 10 viruses, such as - Cucumber Mosaic Virus (CMV), ChilliVeinal Mottle Virus (ChiVMV), Chilli Leaf Curl Virus (ChiLCV), Tobacco Mosaic Virus, Tospo viruses, have become serious threat affecting the yield. Control of such viral pathogens can be challenging due to their broad host range and the large number of insect vectors.

Cucumber Mosaic Virus (CMV) is found to be a serious pathogen causing mosaic disease which exhibit wide pattern of symptoms including mottling, mosaic, yellow discolouration, vein clearing, leaf deformation and shoestring leaves. In addition, CMV has a wider range of host plants including weed species and crops with widespread distribution throughout the world. Management of CMV is mainly dependent on morphological diagnosis of infection. Very recently molecular profiling of protein sequence to discriminate the phylogeny of the pathogen to identify the proper management strategies was reported by Rajamanickam and Nakkeeran (2020). The authors have reported sequence analysis of the coat protein gene of CMV isolates from India and worldwide had nucleotide similarity of 96 to 94 per cent with known strains of CMV. Proper diagnosis of CMV infection through molecular approaches could help in timely adoption of management strategy.

Rahman *et. al.* (2016) reported two *C. annuum* genotypes CA23 (Noakhali) and CA12 (Comilla-2) which were previously undescribed and potentially useful sources of CMV resistance. The genetic basis of resistance to CMV in these plants needs to be clarified and the identified accessions with new resistance specificities can be used for transferring resistant alleles to susceptible modern chilli varieties as single genes or gene cassettes. Kang *et al.,* (2010) showed that the *C. annuum* cultivar 'Bukang' contains a single dominant resistance gene against CMV_{Korean} and CMV_{FNY} strains. The authors named this resistance gene *Cmr1*(*Cucumber mosaic resistance 1*). Analysis of the cellular localization of CMV using a CMV green fluorescent protein construct showed that in 'Bukang,' systemic movement of the virus from the epidermal cell layer to mesophyll cells is inhibited. Genetic mapping and FISH analysis revealed that the *Cmr1* gene is located on chromosome 2 and markers linked to *Cmr1* have been developed and utilized for breeding.After being deployed for many years, *Cmr1* was found to be overcome by a new CMV isolate, CMV-P1. Choi *et al.* (2018) reported a novel CMV resistance gene, CMV resistance gene 2 (cmr2), which confers resistance to CMV-P1 in a recessive manner. This single recessive gene is reported to provide broad spectrum resistance.

Chilli Veinal Mottle Virus (ChiVMV) is probably the most prevalent virus infecting peppers across South, East, and Southeast Asia. Characteristic symptoms of infection can be leaf mottling, dark green vein banding and leaves may be small and distorted. Lee *et al.* (2017) evaluated different pepper varieties and reported three inheritance patterns for resistance to ChiVMV: one representing a single dominant resistance source *Cvr1,* one representing oligogenic resistance (*Cvr2-1 and Cvr2-2*) and one representing recessive resistance (*Cvr4*). They have developed SNP markers and mapped *Cvr1* on short arm of chromosome 6 and *Cvr2-1* and *Cvr2-2* on chromosome 6 and chromosome 10 respectively.

Chilli Leaf Curl Virus (ChiLCV) a member of Genus *Begomovirus* is one of the major virus infecting chilli and distributed in almost all equatorial regions of the World. This virus is transmitted by the whitefly *Bemisiatabaci* in persistent manner. Distinctive symptoms ascribed to three types: vein yellowing, yellow mosaic and leaf curl. In severe cases, 100 per cent losses of marketable fruit have been reported.

Kumar *et al.*, (2006) reported three genotypes GKC-29, BS-35 and EC 497636 to be highly resistant to leaf curl virus. Absence of viral genome in these genotypes was confirmed by PCR amplification. Raj *et al.*, (2014) confirmed high resistance of GKC-29 ad BS-35 and identified Bhut Jolokia as new source of resistance. They revealed that the inheritance of this resistance was due to singe resistant gene. They have also reported that BhutJolokia can serve as donor for the development of pepper cultivars with commercially acceptable fruit morphology and pungency.

Tospoviruses of the family Bunyaviridae are very significant viral pathogens and major constraints in vegetable and pulse crops in India. A total of 11 tospovirus species has been recognised worldwide, of which five tospovirus species, Groundnut bud necrosis virus (GBNV), Groundnut yellow spot virus (GYSV), Iris yellow spot virus (IYSV), Watermelon bud necrosis virus (WBNV) and Tomato spotted wilt virus (TSWV) are known to occur in India (Basavaraj *et al.,* 2017). Recently Chilli production has been limited due to the incidence of thrips transmitting the Groundnut bud necrosis virus (GBNV). Constraint of such viral pathogens is challenging due to their broad host range and also ineffective chemical means to control the vector populations. Pavithra et. al. (2019) reported eight highly resistant genotypes to GBNV with no symptoms on artificial inoculation.Reports of new viruses infecting chilli fields in India are being reported recently. Symptoms indicative of tospovirus infection were noticed in several commercial fields of chili pepper in Karnataka and Tamil Nadu. Disease incidence was more than 20% with symptoms of chlorotic and necrotic spots and rings on leaves, apical necrosis, and leaf distortion. The disease was identified to be caused by Capsicum chlorosis virus (CaCV) of Genus Tospovirus (Haokip et. al., 2006 and Reddy et. al., 2008).

Various other viruses and pathogens infect chilli crop and put hurdles for good production. Application of integrated pest and disease management prove to be better approach profitable production. Growing concerns in society for food safety points at use of resistant varieties rather than chemical control of diseases and pests. Development of resistant varieties is the major task for plant breeders as it reduces total cost of cultivation and improves farmers lives. No resistance in the world is permanent. Continuous search for new sources of resistance, studying the stance mechanisms and its inheritance, utilizing it in crop improvement are the never ending process. While developing resistant varieties, gene pyramiding could be better solution as it provides broad spectrum and more durable resistance. Many resistant chilli hybrids, to different diseases, are available in market today. Detailed information on resistances and important traits of chilli hybrids are available in the websites of agricultural universities and major seed companies in India. Selection of proper hybrids based on the location, season of cultivation and market demand is the clever decision which every farmer has to take before sowing or planting.

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Development of fruit and shoot borer resistant Bt brinjal

Dr. Major Singh
Director, ICAR – DOGR, Pune, Email: singhvns@gmail.com

Brinjal is one of the common vegetables consumed in India and has a strong identity in Indian culture and among Indian vegetables. It is consumed by a large percentage of poor, hence called the poor man's crop and is mostly cultivated by small and marginal farmers. The important fact about brinjal is that, it is the largest consumer of pesticide after cotton.The fruit and shoot borer is a major threat to brinjal cultivation all over the world and damage caused by this pest is the main cause of low productivity of brinjal in India. The crop loss is estimated to be about 37 to 63 % in India and 86 % in Bangladesh. The larvae cause direct damage to fruit and shoot and indirect damage to flowers and growing tips, theybore holes into the shoot and fruits andgrows inside them and thereby affecting the marketability and quality of fruits. Global distribution of this pest shows that they are mostly distributed in tropical countries like India, Thailand and African countries andnot in the temperate countries.

Global distribution ofBrinjal Fruit and Shoot Borer

Problems in management of Brinjal Fruit and shoot borer

Problems encountered in the management of this pest are:

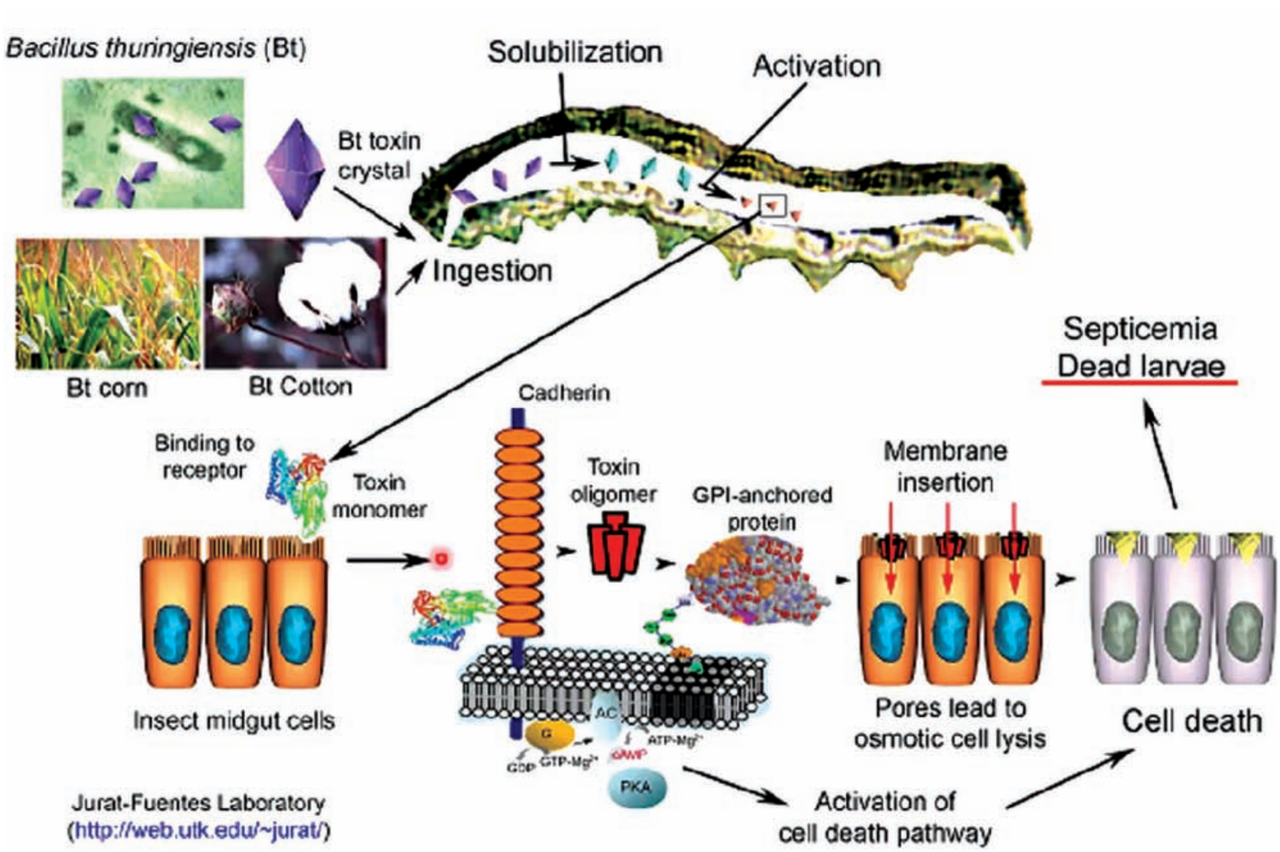
- Quick entry of larvae into fruit and shoot and hence they respond less to insecticide application.
- Therefore, farmers go for multiple sprays to keep pest to satisfactory levels which triggers resurgence of mite and sucking pest
- Plant protection become very expensive
- Cause pollution and health hazards.
- Insecticide sprays kills the beneficial microorganisms.
- No natural resistant sources have been reported in wild germplasm and cultivated brinjal

Adult and larvae of Brinjal Fruit and Shoot borer

Bt Brinjal and mode of action of Bt gene

Bt brinjal is a genetically improved brinjal developed by inserting a Bt gene *cry1Ac* into the brinjal genome. In Bt brinjal, Bt stands for *Bacillus thuringiensis*a naturally occurring soil bacterium from which the gene was taken. The genic form is *cry1Ac* and this gene gives plant an inbuilt resistance against pests such as brinjal fruit and shoot borer. Once the larvae ingest Bt crops cry protein get crystalized and when it reaches the mid gut of the larvae the protein bind with the receptors present in the intestine and became poisonous to the larvae.

Mode of action of the protein is very specific to this particular class of insects and does not have any negative effects on other insects. The protein becomes active and toxic only in the alkaline environment of the intestine and the presence of the specific receptors.



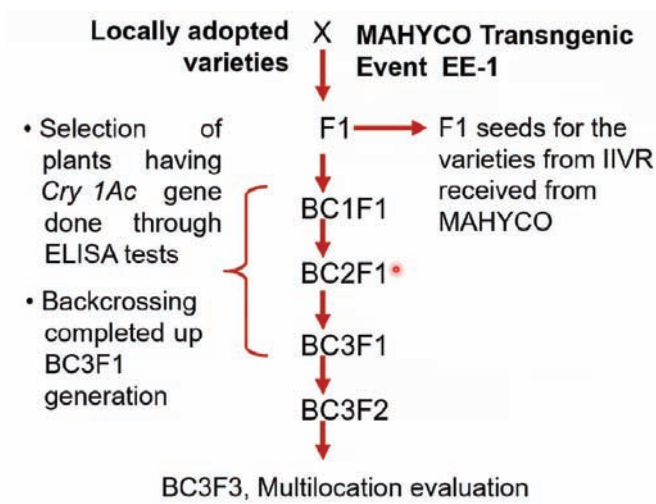
Mode of action of *cry 1Ac* protein within the insect

Transformation of IVBL -9 with *cry1 Ac*

In the direct transformation technique *cry1 Ac* was inserted to line IVBL -9.Transgenic plants developed were tested with PCR and the results confirmed the integration of the gene. ELISA, southern and segregation analysis were also completed. It was advanced up to T4 stage and completed RCGM event selection trials. Now other safety trials are due for this particular event. Bioassays were conducted in transformed and non-transformed plants to know the effectiveness of the gene in controlling the pest.

Indo –US Collabration for developing Bt-brijal

Indo –US programme for developing Bt- brinjal was a collaboration between University of Cornell, USA and Indian partners MAHYCO, IIVR, UAS Dharwad and TNAU and the project was funded by DBT. The gene from MAHYCO events was inserted to our cultivated varieties byusing backcross breeding method.Six varieties chosen for breeding were IVBL-9, Punjab Barsati, Uttara, VR -14, VR-5 and Pant Rituraj, into these varieties the genes were inserted. Selection of plants having *cry1Ac* gene was done by using ELISA.Bioassay of these particular varieties developed by backcross breeding were performed and the results indicate that larval mortality was 100 percent in Bt counterparts whereas it was less in non Bt counter parts of the same varieties. Thisshows that the gene was very effective in controlling fruit and shoot borer. Apart from this the effect of *cry1Ac* gene on shoots and fruits were also studied and the mortality rate was 100 percent and 90 percentrespectively in Bt plants, this was higher than the Bt counterparts.All these resultsadds to the effectiveness of the gene in controlling FSB.

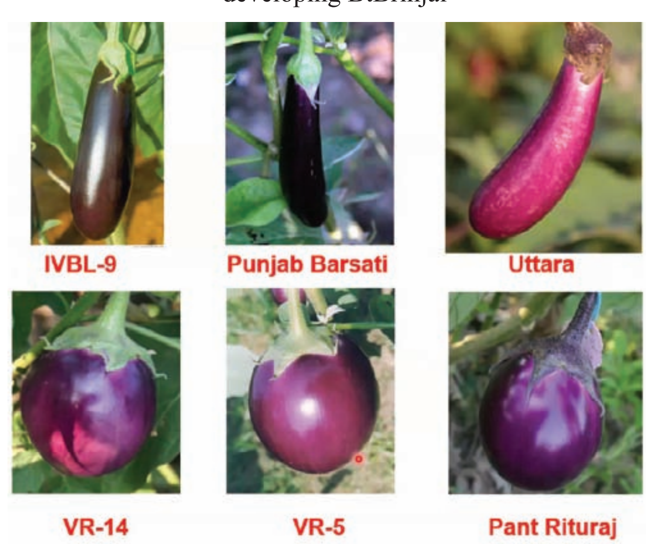


Schematic representation of backcross programme for developing BtBrinjal

LST trials were conducted in 11 locations for 2 years. The selected locations were Varanasi, Raipur, Coimbatore, Ludhiana, Hisar, Jabalpur, Dharwad, Ranchi, Anand, Parbhani and Rahuri. All over the locations shoot damages and fruit damages were very high in non Bt plants as compared to Bt plants. Cumulative fruit damage was also very high in non Bt plants. Marketable yield was very high in Bt plants all over the locations because damage was very low as compared to non Bt plants.

Development of Biosafety Information

IIVR and MAHYCO together generated biosafety information in all regards by conducting germination and weediness studies, aggressiveness studies, effect on non-target and beneficial insects, soil micro biota studies, substantial equivalence studies, acute oral toxicity studies in rats, mucous membrane irritation studies in female rabbit, primary skin irritation test in rabbits, sub chronic oral toxicity studies in Sprague Dawley rats, assessment of allergenicity of protein extract using Norway rats, response as a dietary ingredient for common carp growth performances, and protein expression studies. Further they have tested for food cooking safety, performance of broiler chicken. Conducted feeding studies in goat, dairy



Varieties identified for developing transgenics by IIVR cows,chicken,pollen flow studies,crossability studies, base line susceptibility and detailed compositional analysis. These studies were conducted in various laboratories across India.

Economic surplus studies were conducted to know what will happen if farmers adopt this technology and how much they can gain from this. If only 10 -15% adoption is there the economy is going to produce 27,000 crore rupees but if its above 50% the benefit will be enormous. So this particular technology is going to benefit consumers as well as producers both. Consumers will be more benefited because the prices will come down due to surplus production and farmers income will also increase because more production will be there with less use of insecticide this will in turnbenefit the environment.

Expected Outcome and benefits

Out come and benefits include providing seeds at low cost as all fifteen varieties taken upfor the programme were open pollinated varieties. So naturally farmers can save their own seeds. , availability of high quality seeds to resource constrained farmers, benefits through high adoption and organized seed distribution. This will also increase domestic consumption, cross country trade, help in poverty alleviation, consumer will gain from low cost due to surplus production andhealth benefits because of reduced use of pesticides.

Conclusion

Based on the biosafety data generated at different laboratories, reports of LST trials, pollen flow studies and crossability studies by IIVR, Varanasi. GEAC approved the event EE-1 environmentally safe on 14th October,2009. However this became the most controversial technology not only in India but across the world. There were lot of hue and cry by the NGOs, environmental activists, super stars, religious leaders and even a film was produced by the title “*Poison On a Platter”* featuring BtBrinjal. Due to these issues in 2010 former ministerJayaram Ramesh passed a moratorium on BtBrinjal and stated that “let us generate more data then we will go for release of BtBrinjal varieties”. After this moratorium, ten years have passed now we are in 2020, still the moratorium is imposed. So let’s hope someday the moratorium will be lifted and the varieties will be available for farmers and consumers for use.

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National Webinar
"Challenges and opportunities of vegetable production in warm humid tropics"

Session -5

Crop improvement in okra and tuber crops

Chair:
Dr. Pritam Kalia
Former Head
Division of Vegetable Crops
IARI, Delhi

Dr. M. Pitchaimuthu
Pricipal Scientist
ICAR, IIHR, Bengaluru

Dr. Palaniswami M.S.
Former Project Coordinator
(Tuber crops) ICAR
CTCRI

Dr. Susan John K.
Principal Scientist, ICAR
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Session -5

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13 YVMV resistance in Okra
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14 Challenges and opportunities in Cassava
- Dr. Palaniswami M.S., Former Project Coordinator, (Tuber crops) ICAR, CTCRI

15 Recent developments in nutritional management of tropical tuber crops
- Dr. Susan John K., Principal Scientist, ICAR, CTCRI

Breeding for Yellow Vein Mosaic Virus resistance in okra [(*Abelomoschus esculentus* (L.) Moench]

Pitchaimuthu, M.
Division of Vegetable Crops,CAR- Indian Institute of Horticultural Research
Hessaraghatta Lake Post, Bengaluru-560 089, Karnataka , Email m.pitchaimuthu@icar.gov.in

Abstract : Yellow Vein Mosaic Virus (YVMV) is the most distractive begomovirus and their satellites group causing severe to very severe critical yield losses due to it's the stage infection occurs 59-94 %. Begomovirus spreads widely in cultivated okra throughout the growing seasons of tropical, subtropical and warmer temperate regions of the world. Several methods were tried to control the viral diseases including chemical, but none of the methods found very effective . The only possible method to control practically and economically possible is use of virus resistant varieties or hybrids. So far more than 40 varieties, few land races and more than a dozen F_1 hybrids were released from both private and public institutions, few of them are very much popular in the farmer's field. However, at present none of the hybrids and varieties are totally resistant to begomorirus at specific agro ecological zones. There is no stable sources of resistance are available in the cultivated genotypes, only way to search the sources from untapped wild relatives of *Abelmoschus* spp and utilize it for resistant breeding program.

Okra [*Abelmoschus esculentus* (L.) Moench] is one of the most important and traditional, commercial vegetable crop grown across India. Okra fruits are rich in minerals, dietary fiber, vitamins, iron and iodine. The mucilaginous substance present in okra is reported to remove toxic substances and bad cholesterol from the human blood system and provide protection against cancer (Kumar *et al.,* 2010). Okra polysaccharide lowers the cholesterol level in blood and may prevent cancer by its ability to bind bile acids (Kahlon, Chapman & Smith, 2007).In India okra is cultivated in an area of 0.62 million ha with an annual production of 7.2 million tonnes, and a productivity of 11.7 tonnes ha^{-1}. The major production constraint which limits the productivity of okra are biotic and a biotic stresses (Table-1). YVMV, ELCV, fusarium wilt, nematodes, shoot & fruit borer and sucking pest are the major biotic stresses which cause yield reduction and fruit quality deterioration whereas drought and low temperature are the abiotic stress factors which limit okra productivity.

The major breeding objectives of okra are to develop varieties/hybrids with higher yield and better fruit quality, photo-thermo insensitivity and wider adoptability, resistance to biotic and abiotic stresses, long shelf life, better nutritional quality and seed producing ability.

Table 1. Yield loss due to biotic stresses in okra

Diseases/ Pest attack	% of loss	References
YVMV	50-94	Sastry and Singh 1974; Pun and Doriaswamy 1999
ELCV	83	Singh and Dutta 1986; Singh *et al.,* 2013
PM, Root rot, Cercospora	43.6	Singh *et al.,* 2013
Jassids and mite	40-56	Rawat and Sahu, 1973; Krishnaiah, 1980
Shoot and fruit borer	23-51	Reddy *et al.*, 2012

Diverse species of okra exist throughout the world. Genus *Abelmoschus* has 50 described species, out of which two are economically important cultivated species, *A. esculentus* and *A. caillei* (Patil *et al.*, 2015). Cultivated okra *A. esculentus* is an allopolyploid/ amphidiploid with 2n= 130. The chromosome number in the genus *Abelmoschus* varied from 2n = 56 in *A. angulosus* to the highest number around 200 in *A. caillei.*The true wild species in the genus are *A. tetraphyllus, A. tuberculatus, A. ficulneus, A. crinitus, A. enbeepeegearense, A. palianus, A. angulosus, A. cancellatus*, *A. pungence* sub sp *mezorensis*(Patil *et al.*, 2015). Charrier in 1984 divided okra into 3 types based on the ploidy level. Ploidy level 1includes species with chromosome number, 2n=56-72; ploidy level 2: 2n=108-144; and ploidy level 3: 2n=185-199. The presence of chromosomal differences or variability in the ploidy level makes the crossing between wild species and cultivated species difficult. The crossed seeds obtained by interspecific cross expressed sterility and unviable seeds in crosses between ploidy levels 1 and 2. There are significant variations in the chromosome numbers and ploidy levels of different species and biggest genome size make the breeding work more cumbersome process. Even if we perform interspecific hybridization in okra, embryo abortion is a major problem in the F_1 generation.Non availability of whole genome sequencing data and lack of appropriate transformation protocols limits experimentation related to transgenic okra. Absence of molecular genetic map and other molecular tools are the other limitations in okra breeding programme. Non-synchronous flowering pattern among wild, exotic and cultivated lines is a major problem during artificial cross pollination for successful establishment of crossed progenies.

In IBPGR, about 11,000 accessions of both cultivated and wild species of okra are available and are distributed over 46 institutes across the world. About 3,500 acessions of base collections are available in the National Gene Bank at NBPGR and regional stations at Akola and Thrissur. NAGC at ICAR-IIVR Varanasi is maintaining all the germplasm of okra. Apart from this, IIHR, Bangalore is also maintaining more than 450 working collections of okra. There are other institutes of ICAR as well as the State Agricultural Universities which hold more than 100 accessions of okra. More than 150-200 private seed industries were also involved in research and development programme of okra.

Okra breeding

Until 1950, there was no improved varieties of okra in India. Farmers were mostly cultivating local and available land races. Dr. Harbhajan Singh is the pioneer of okra breeding in India. He collected germplasm from India as well as Ghana and developed varieties; 'Pusa Makhmali in 1955 and Pusa Sawani in 1962. The former became susceptible to YVMV after sometime and the later was a symptomless carrier. N. D. Jambhale and Y. S. Nerkar developed the variety 'Parbhani Kranti' in 1986. From ICAR-IIHR, Bangaluru two varieties were released and notified, *i.e*., Arka Anamika and Arka Abhay during 1990.

Different breeding methods such as introduction, selection and hybridization are employed in okra. Apart from this, interspecific hybridization followed by backcross and selection in segregating population is the best method to produce interspecific hybrids in okra. Backcross method followed by pedigree selection, mutation breeding and combination of both conventional and marker assisted backcross breeding are also useful tools in okra breeding. For disease resistance breeding in okra, availability of suitable source of resistance within the cultivated species itself is desirable than using wild species to avoid difficulties in transferring the trait. The two wild species such as *A. angulosus* var. *grandiflorus* and *A. pungence* subsp. *mezorensis* are stable source of resistance to YVMV. Four wild species of okra, such as *A. caillei, A. manihot, A. manihot* subsp *manihot* and *A. manihot* subsp *tetraphyllus* var. *tetraphyllus* showed high degree of YVMV resistance and are utilized for interspecific hybridization followed by backcross breeding with cultivated *Abelmoschus esculentus.*

The major problem faced during interspecific hybridization in okra is sterility and development of subsequent generations. The sterility problem can be overcome by colchicine (0.1%) treatment on apical bud at two leaf stage and by irradiation with gamma rays.

Yellow vein mosaic disease in okra

Yellow vein mosaic disease is the major limitation in the production of okra. This disease is caused by a complex consisting of the bipartite begomovirus, *bhindi yellow vein mosaic virus* (BYVMV, family: Geminiviridae) and a small satellite DNA beta component, which is transmitted by the insect vector, white fly (*Bemisia tabaci*). This virus is neither sap-transmissible nor seed-transmitted, but can be transmitted through grafting. Among the 17 different begomoviruses which cause YVMV, 8 viruses are reported in India and out of which 4 are beta satellite and 3 are alpha satellite. (Venkataravanappa *et al* 2011)

Symptoms of YVMV

Under field condition, three types of YVMV symptoms are observed on okra plants. Leaves of the younger plants affected with the virus turn yellow and then completely dry up and yield loss will be 100 per cent. If infection starts after flowering, upper leaves, flowers and fruits become yellow, but the yield loss may not be 100 per cent. In the third case the plant continues to grow healthy and completes the life cycle, but at the end, young shoots appear in the basal portion shows vein clearing symptom *i.e.*, they are symptomless carriers.

Reason for the breakdown of resistance in the popular YVMV resistant varieties

The reason for the breakdown of resistance in the popular YVMV resistant varieties could be appearance of new strains of viruses or due to the mutation in the virus strain. Emergence of polyphagus biotype 'B' of *Bemisia tabaci*and wide host range of the virus (more than 600 plant species) are also reason for resistance breakdown in varieties.(Sanwal *et al.*, 2014a and Sanwal *et al*., 2016). The sources of resistant to YVMV identified from by different authors with okra germplasm as follows (Table 2)

Table 2. Okra germplasm tolerant or resistant to yellow vein mosaic virus

Species	Name of germplasm	Reference
A. esculentus (germplasm showing field tolerance to YVMV)	Parbhani Kranti, F-3, M-31, L-1, Bulk, AE 7, KS303, KS322, KS323, AS12, S-1-1, Baunia, P-7, 3(I), IC 9273, IC 23592, IC 282230, IC 006485, IC 469548, IC 541224, IC 028883, IC 128894, IC 043742, IC 045815, IC 043735, IC 045802, IC 045814, IC 541224, IC 218887, IC 069286, and EC 305619	Gunathilagraj*et al.* (1977), Singh and Singh (1986), Khan and Mukopadhyay (1986), Dhankar *et al.* (1989), Nizar *et al.* (2004).
A. Caillei (Resistant or symptomless carriers of YVMV)	African and a Japanese form of *A. manihot* subsp. *manihot* (2n = 194) from Ghana, EC 031830 (Asuntemkolo) from Ghana, Susthira, 18 accessions from Ivory Coast, 5 from Ghana and 1 from Liberia	Sandhu *et al.* (1974), Arumugam *et al.* (1975), Jambhale and Nerkar (1986) Sharama and Sharma (1981), Salehuzzaman (1985), Gopalakrishnan *et al.* (2004).
Wild species	*A. manihot, A. tetraphyllus* var. *pungens. A. enbeepeegearenses*	Ugale *et al.* (1976), Karuppaiyan (2006).

Genetics of resistance to YVMV

The genes governing the resistance to YVMV in different resistant parents are different. Resistance to YVMV in IC 1542 from Bengal is controlled by two complimentary recessive alleles, Yv1 Yv1, Yv2 Yv2 (Singh *et al.*, 1962). During the development of the variety Punjab Padmini, it was noted that the resistance to YVMV in *A. caillei* is controlled by two complementary dominant genes with additive effects (Thakur, 1976; Sharma and Dhillion, 1983). However, in *A. manihot*, resistance to YVMV is determined by a single dominant gene (Jambhale and Nerkar, 1981). Hence the overall picture pertaining to genetics of YVMV in okra is not convincing.

While working with the genetics of different species in okra, ploidy level should be considered. Breeder should classify segregating F_2 population based on not only the disease incidence but also disease intensity. Scoring for the disease reaction should also be done in F_3 and backcross progenies. While working out the genetics of resistance, physiological strain as well as the chemical strain of the virus should be considered. Molecular markers linked to the resistant/ tolerant genes need to be identified and this will help locating the number of the targeted gene present in the genome.

Resistance breeding in okra is mainly focused on;

A. Efficient screening technique
- Screening in hot spots/regions
- Artificial screening through whitefly
- Screening through grafting/ agroinoculation
- Screening seedling through agroinoculation followed by vector transmission

B. Resistance evaluation through sensitive assay
- Visual symptoms
- ELISA/Nucleic acid probe
- PCR assay

While screening for virus resistance in the open field, as a pre-requisite, breeder has to identify the hotspot areas. The recent hotspot areas identified for YVMV are given below;
- Vijayawada/ Guntur (Andhra Pradesh)/ Attur, Salem (Tamil Nadu)
- Raipur (Chattisgarh)
- Jabalpur (Madhya Pradesh)
- Kalyani (West Bengal)
- Anand (Gujarat)
- Haryana

Once the hotspot area is identified, design a field layout. In the boarder rows, grow susceptible varieties (YVMV or ELCV) and in the next five rows test material can be grown followed by susceptible varieties and continue so on. After sowing, from 5th day onwards start screening for symptom, and continue during 30-35 days, 60 days and finally 120 days after sowing. After screening virus disease indexing should be done according to the scale given below; (Table 3.)

Table 3. Virus diseases indexing scale

Reaction	% incidence	Probe/PCR
Immune	0	Negative
Highly resistant	1-10	+/-
Resistant	11-25	+
Susceptible	>25	++

Varieties released from pedigree method of breeding
- Pusa Makhmali (1955) (Singh *et al.*, 1962)
- Pusa Sawani: IC 1542 × PusaMakhmali – Tolerant to YVMV (Singh *et al.*, 1962)
- VarshaUphar: Lam selection 1 × Parbhani Kranti – (Dhankhar *et al.*, 1997)
- Hisar Unnat: Sel 2-2 × Parbhani Kranti – (Dhankhar *et al.*, 1999)
- VRO-6 (Kashi Pragati) – (B. Singh *et al.,* 2006)
- VRO-5 (Kashi Vibhuti) - (B. Singh *et al.*, 2007)
- IIVR-10 (Kashi Satdhari) - (B. Singh *et al.,* 2007)
- IIVR-11 (Kashi Lila) - (B. Singh *et al.*, 2010)
- VRO-3 (Kashi Mohini) - (B. Singh *et al.*, 2010)

Varieties released from mutation breeding

Anjitha and Manjima are high yielding varieties resistant to YVMV developed by Kerala Agricultural University, Thrissur. A few high yielding disease resistant plants resembling the cultivated plants were obtained from interspecific hybrids of okra between *A. esculentus* and *A. manihot*. F_1 seeds were irradiated with 300 Gy gamma radiation which suggested that 300 Gy could bethe ideal irradiation dose in okra (Manju and Gopimony, 2009). EMS 8 is a mutant carrying resistance to YVMV and tolerance to fruit borer released from Punjab Agricultural University, Ludhiana (Sharma and Arora, 1991).

Hybrids in okra

Hybrid vigour for yield and yield components has beenexploited from the available germplasm of okra. Nowadays hybrids are very popular in okra because of high yield, earliness, quality and no. fruits/ fruit length. Heterosis of okra is 30-36 %. Some of the hybrids developed by different ICAR- institutes and SAU's are given below;

F_1 hybrids resistant to YVMV

- Hyb- 7 & 8, COBTH (TNAU) - Yield
- GOH - 3&4 (Gujarat AU) - Yield
- DOH - 2, DOH – 6, IARI – Yield

Recently IIHR, Bangalore has released a F_1 hybrid, which is the first genic male sterility based hybrid in okra in the world, Arka Nikita. Since it is based on GMS, there is no need of hand emasculation of the female line and only pollination is needed.Arka Nikita is high yielding (21-24 t/ha) with good quality and tolerant to YVMV. The fruits are green, smooth, thin and tender. The plant has green stem and unique petal base (Purple colour in inside petal). It is suitable for both kharif and summer season. Seed production is easy in this hybrid and can save 70 % labour cost by avoiding emasculation. (Pitchaimuthu *et al.*, 2012)

Hybrids from Private sector

- Shakthi, Sonal, Sarika, Singam (Nunhems) – yield, quality and YVMV resistant
- No.10 & 64 (MAHYCO) - yield, quality and YVMV resistant
- Syngenta – 152 (Syngenta), Hyb – (Krishidhan) - yield, quality and YVMV resistant
- Hyb – 7315 (JK seeds Agri genetics) - yield, quality and YVMV resistant
- Avanthika (Bio-seed) - yield, quality and YVMV resistant
- Sahibha and Sahan (Rasi seeds)-Yield and tolerant to YVMV
- Janni, Navya and Radhika (Adventa seeds) - yield, quality and YVMV resistant
- NS 811, NS862, NS 7772 and NS 7778(Namdhari) - yield, quality and YVMV resistant

Varieties released from interspecific hybridization/ backcross breeding

- Punjab 7 – *A. esculentus* (Pusa Sawani) × *A. caillei* (Harbajan Singh, 1952)
- Punjab Padmini – *A. esculentus* (Reshmi) × *A. caillei* (Thakur and Arora, 1986)
- Parbhani Kranti - *A. esculentus*(PusaSawani) × *A. manihot* (Jambhale and Nerkar, 1986)
- Arka Anamika and Arka Abhay– *A. esculentus* (IIHR 20-31) × *A. tetraphyllus* var. *tetraphyllus* (Dutta and Singh, 1990)

Arka Anamika produces fruits with lush green colour and yield 20 t/ha. The variety is recommended for almost all zones of the country and the variety has occupied more than 42-45 % of the okra growing zones in the country. It was resistant when it bred, but now breakdown of resistance is observed in certain locations. It is used as national check variety for all India co-ordinated vegetable improvement project (AICVIP). ArkaAbhay is also tolerant to YVMV and has an yield potential of 18 t/ha. It is recommended for Southern and Eastern zones of the country. It is also used as all India national check variety for virus resistance.

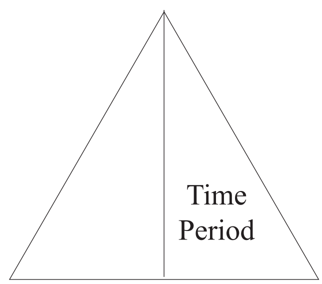
Biochemical basis of disease resistance

YVMV resistant wild species had maximum phenolics, peroxidase, polyphenol oxidase activity and seed soluble protein content, while cultivated okra had minimum of these whereas interspecific hybrids recorded in between their parents. Prabu and Warade (2013) revealed that, YVMV resistant plants infected with virus exhibited decreased phenol content whereas peroxidase and polyphenol activity, total nitrogen and sugar content increased when compared with YVMV resistant healthy plants. An exact opposite trend was observed in the YVMV susceptible healthy and infected plants. Higher amount of phenols and their oxidation products like quinines formed by increased peroxidase and polyphenol oxidase may be responsible for reduced virus multiplication which finally could have led to resistant reaction in wild species and their interspecific hybrids.

According to Ravi *et al.* (2005) sequencing analysis of the DNA-A component from various isolates collected from different places in India revealed that 80 % of the isolates aligned into a common cluster and virus isolates from Gujarat was highly distinct and aligned to two distinct clusters. Isolate with enation like symptoms were nearly identical (95.5%) with cotton leaf curl Gemini virus. Isolate with stem bending symptoms fall into distinct species and rest of the isolates were identical to common tomato leaf curl virus.

Elements of epidemics

Favourable environment: High temperature and low humidity



Susceptible host: Narrow genetic base, Virulent pathogen Monoculture (Dutta *et al.*, 2002)

Vector: (*Bemisia tabaci*) can carry different viruses for 6 days simultaneously

Tolerance at the cellular level may be achieved by the absence of toxins receptor sites from the host cells. Detoxifying the toxins produced by the pathogen and inactivating pathogen generated enzymes and compensation for irritants (Stress) (Dutta *et al.*, 2002).

Stability of resistance

Gemini virus has enormous potential in developing new virulent form and it out match the efforts of breeding. Once a resistant variety is released, it holds resistance for 4-5 years and after that they became slowly susceptible. The varieties such as Arka Anamika, Arka Abhay, Pusa Sawani and Parbhani Kranti remain stable for more than two decades. For a more permanent solution to this problem a team work of plant breeder, entomologist, virologist, and plant biotechnologist is needed to develop strains for non-specific resistant / tolerant varieties. Virologist should study the epidemiology and physiological strains of the virus prevalent in the country and develop strain specific probes for easier identification. Experts in molecular markers should identify specific markers linked with genes conferring resitance/ tolerance to the genotypes. Cytologist should assist the breeder ensuring normal meiotic behaviour of the genotype and biochemist should work out the mechanism of disease resistance or tolerance. Maintenance breeding work should be ensured and threat of new viral strains have to be tackled before they can cause excessive damage.

Enation leaf curl virus

ELCV was first identified by Singh and Dutta in 1986.The disease is caused by bacilliform virus and transmitted by insect vector, whitefly (*Bemisia tabaci*). It is not transmitted through seed or sap. The yield loss is about 30 – 100 %. The disease initially causes small pin-head enations on the under surface of leaves followed by a warty and rough texture of leaves, with later leaves curling upwards. Affected plants show a twisting of the stem and lateral branches with leaves becoming thick and leathery.

Different types of viruses
- Petiole bending/ stem bending – Begomo virus
- Tobacco streak virus – Ilar virus

YVMV breeding work done at IIHR, Bangalore

The germplasm collected were screened under natural epiphytic condition (hotspots). Screening is done at different hot spot areas such as;
- Salem, Attur (Tamil Nadu) – YVMV
- Guntur/ Vijayawada (Andhra Pradesh) – YVMV
- CHES, Bhubaneswar – YVMV + ELCV
- KVK, Sonipet and Sadalpur (Haryana) – ELCV
- BCKV, Kalyani – only hybrids
- Villupuram (Tamil Nadu)

Out of the 60 germplasm screened in the hot spot area Salem, Tamil Nadu, more than 6-7 lines are advanced lines which are highly resistant to YVMV. The clear cut difference between susceptible and resistant lines has been obtained because of conducive environmental conditions and virus growth in the hot spot areas,that made screening very easy. Symptoms start appearing 20 days after sowing, and after 120 days, screening was done and resistant material were selected, and selfed. While screening the germplasm in Guntur during 2016-17, two advanced lines which are highly resistant to YVMV and ELCV were selected, IIHR-385-5 and IIHR-386-7. Natural screening was done at hot spot during summer 2013 at Salem, Attur in Tamil Nadu and one advanced YVMV resistant line, 296-22-10-11-598 and one ELCV resistant line, IIHR-290-10-11-335 were selected. Among the germplasm screened for YVMV and ELCV resistance at Guntur during summer 2018, IIHR-374, IIHR-362, IIHR-383-2, IIHR-385-5-1 and IIHR-294 were advanced resistant lines. Open field screening is followed by artificial inoculation of the virus and then artificial screening with grafting.

Screening under artificially induced epiphytic condition (poly/ net house)

The procedure for artificial inoculation of white flies is given below;
- Release the virulent white flies carrying three viruses simultaneously (@10 white flies/ seedling)
- Cover the seedlings with plastic cup
- Allow the white flies to feed on the plant over night
- Take the observation 20-25 days after inoculation

Artificial screening with grafting

To test the transmissibility of YVMV through graft union, pencil thick scion of susceptible plant were grafted on to resistant plants, using approach grafting in the poly house. Graft union takes place after 21 days and then started taking observation. The new shoot formed on the bottom portion of the plant will not show the symptom if it is resistant. This is how the screening is done.

Out of the 13 accessions screened, two accessions, 10-11-344, and 10-11-444 were totally resistant to both YVMV and ELCV (Table-4). In the resistant plants the total phenol and total flavonoids will be more compared to the susceptible plants.

Hybrids screened at IIHR

From IIHR, Bangalore 40 hybrids were developed using GMS lines. Seven hybrids were short listed and screened at hot spot area of Guntur during summer 2016. Out of these hybrids, OKMSH-3, which showed less than 26.83 % YVMV incidence and less than 13.25 % ELCV incidence with an yield of 21.43 t/ ha is released as the F_1 hybrid Arka Nikita (Table 5). The hybrid Arka Nikita has been grown in almost 6 hot spot areas for YVMV and ELCV, such as BCKV, Kalyani (West Bengal), Kollar (Karnataka), Gowriwakam (Tamil Nadu),

Table 4. Artificial screening of okra advance lines and wild species for resistance against YVMV and ELCV under poly house using approach grafting during rabi season2013 at IIHR, Bangalore

Sl. No.	Name of the accessions	No. of plants grafted with susceptible scion	No. of plants successes	Reaction for YVMV	No. of plants grafted with susceptible scion	No. of plants successes	Reaction for ELCV
1	296-22-2-5 (G-10)	12	9	-	-	-	-
2	11-1-128	20	11	+4	-	-	-
3	10-11-335	20	15	+8	-	-	-
4	M-64	6	4	-	-	-	-
5	11-1-327	16	10	+3	-	-	-
6	10-11-340	36	9	+2	4	4	-
7	11-1-281	15	7	-	-	-	-
8	10-11-344	5	5	-	5	4	-
9	10-11-444	16	10	-	4	3	-
10	11-1-170	8	6	-	-	-	-
11	11-1-127	11	4	+1	-	-	-
12	285-4-11-55-1	10	8	-	-	-	-
13	*A. angulosus var. grandiflorus*	4	4	-	-	-	-

Table 5. Screening of okra F_1 hybrids at hot spot area of Guntur (A.P) during summer 2016

Hybrid	Fruit length (cm)	Fruit diameter (cm)	No. of branches	Fruit yield (t/ha)	YVMV incidence (%)	ELCV incidence (%)
OKMSH-3	12.93	1.70	4.33	21.43	26.83	13.25
OKMSH-2	13.76	1.66	3.00	15.76	33.32	44.79
OKMSH-1	13.53	1.86	2.33	18.25	33.61	21.75
OKMSH-4	15.13	1.23	2.66	15.65	30.86	17.66
OKMSH-7	13.20	1.73	3.00	15.15	23.90	16.50
OKMSH-9	13.86	1.9	3.66	20.85	23.33	33.33
Shakthi (C)	15.76	1.63	4.66	14.36	36.33	34.00
AC-1685	16.16	1.833	3.66	15.06	80.00	74.03
CD 5%	1.165	0.388	1.14	1.92	2.185	10.29
CV %	4.652	9.412	18.62	6.43	3.686	15.37

KVK, Sonipet (Haryana), CHES, Bhubaneswar and KVK, Guntur (Andhra Pradesh). At all the places the hybrid showed less than 10-12% incidence of YVMV and ECLV. Arka Nikita is screened for ELCV at hot spot area of KVK, Sadalpur, Haryana during 2019 and it exhibited resistance to ELCV compared to the susceptible check with zero per cent incidence along with commercial cultivar Radhika.

Interspecific cross between wild and cultivated lines

A. angulosus var. *grandiflorus* and *A. pungence* subsp. *mezorensis* are wild species which are stable source of resistance to YVMV and ELCV, could be exploited in future breeding programme to develop stable pre-breeding lines.

Interspecific hybrids were developed using the wild species *A. angulosus* var. grandiflorus, *A. pungence* subsp. *mezorensis*, *A. caillei,* and *A. tetraphyllus* var. *tetraphyllus.*Crosses were made using YVMV resistant lines IIHR-385-5-1, IIHR-386 and ACC 2288. Out of the crosses made, *A. caillei* ×IIHR-385-5-1 was success with seed set, but the F_1 interspecific hybrids of remaining 3 species were sterile. Hence by colchicine treatment stabilized amphidiploids were developed and they were backcrossed with cultivated type and BC_1F_2 seeds were collected. The research work is under progress.

Okra commercial industry requires okra ideotypes with

- Medium plant height with very shorter intermodal length
- Prolonged fruit harvest (45-95 days)
- Uniform filling of seeds of the marketable stage fruit
- Deeply lobed leaves
- Dark green fruits with resistance to begomo viruses
- Fruits starts bearing early nodes (2nd node) onwards
- Fruit colour, shape and shape based on market segment

Future plan of research

Identification of stable and reliable sources of resistance to viral diseases is an important step in future breeding programme. Collect, conserve and evaluate available land races, varieties and stable source of resistant material through out the country and screen them at hot spot and artificial condition. Go for reverse breeding and reconstitute the parental lines. Identification of virus specific resistance and introgression of resistance gene from unexploited wild species will help to broaden the resistance breeding. Identification of source of resistance to white fly is also important.

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Challenges and opportunities in cassava In India

Dr. M.S. Palaniswami
Former Project Coordinator,
ICAR - Central Tuber Crops Research Institute, Thiruvanathapuram 695017, Kerala
Email: palaniswamims@gmail.com

Burgeoning population, food shortage, ever increasing need to explore new frontiers in order to alleviate hunger and poverty, alternate sources for bio diesel etc., beckons support of root and tuber crops as a source of food and bioenergy especially cassava (*Manihot esculenta* Crantz). Cassava is the third largest source of food carbohydrates in the tropics, after rice and maize and is known as the energy bank of nature serving as food to meet the caloric needs; and has a higher biological efficiency as food producers with higher dry matter production per unit area per unit time. It is a crop of food security for the millions of people especially in the developing countries. The international community is committed to ending hunger and all forms of malnutrition worldwide by 2030.This crop has the potential to produce more food per unit area, capacity to withstand adverse biotic and abiotic stresses and adaptability to the conditions of drought and marginal lands. It is a climate resilient crop.

Biochemical constituents:
Cassava tubers on fresh weight basis contain -Moisture 60.0-66.2 %, Energy 528-611 kJ/100g, dry matter 40%, starch 28.0-33.2%, total sugar 0.34 - 1.14%, protein 0.8%, dietary fibre 1.43 - 1.57%, Crude fibre 0.9 -2.0%, fat 0.2%, ash 1%, calcium 0.05%, phosphorous 0.04%, and Vitamins (mg/100g) -Vitamin A 0.01-0.04, Thiamine 0.03-0.28, Nicotinic Acid 0.6, Vitamin C 14.9 - 36.0; and minerals (ppm - DW)- Fe 127, Mn 10-15 and Zn 15-16 and cyanoglucoside 25-400 ìg cyanide/g. Cassava leaf on fresh weight basis has- 22% dry matter, 8% starch, 8% protein, 2% fibre, 1.7% fat, 1.5% ash, 0.125% calcium, 0.08% phosphorous, 0.25% vitamin C and cyanoglucoside 350-600 ìg cyanide/g. Some genotypes are rich in b carotene. The rind of the tuber and seed extract were found to have biopesticidal properties especially for nematodes and insect pests.

Area and Production:
Cassava is grown in 104 countries with 61% production concentrated in Africa and 29% in Asia. Nigeria alone contributes 21% of world cassava production. Ten countries contribute 75% of the total world production and Nigeria (59.48 m tons), Thailand (31.67), DR Congo (29.95), Ghana (20.85), Brazil (17.64), Indonesia (16.12), Vietnam (9.85), Angola (8.66), Mozambique (8.53) and Cambodia (7.65). It is very interesting to note that the productivity of cassava ranges from 1.02 t/ha in Guatemala to 32.09 t/ha in Lao PDR with a global average productivity of 11.30 t/ha, and even the highest productivity is still far below its potential up to 80-100 t/ha (FAO, 2013; http://www.fao.org/ag/save-and-grow/cassava/index_en.html). During the 2014–16 period the production in Africa was about 72%, followed by Asia 18%, and 10% from South America). Average yield of cassava worldwide is 11.8 t/ha, with productivity in Asia being markedly higher (21.6 t/ha). The highest productivity in the world is recorded in India (FAO, 2018). Sub-Saharan African countries, in general, are the most dependent on cassava in terms of food security, but cassava also plays an important food security role in Latin America and the Caribbean. In SE Asia, Indonesia in particular, cassava in being used in animal feed, starch and ethanol industries.

The crop has been cultivated in India for more than a century. Cassava was introduced into Kerala, India from Brazil by the Portuguese. In 1943 entrepreneurs from Salem, Tamil Nadu found cassava flour as a good substitute for American corn flour and marketed at Chennai. They also commenced sago production from cassava in Tamil Nadu with the technical know-how from Malaysia. Factors like suitable climate for drying of starch, low labour costs in Tamil Nadu prompted the development of cassava based industries and making it as a commercial crop today.

In India, cassava is cultivated in Kerala, Tamil Nadu and Andhra Pradesh. It is spreading to Maharashtra, Gujarat, Chhattisgarh, Jharkhand and North Eastern States. Cassava is a major industrial crop in Tamil Nadu and Andhra Pradesh and used as a secondary staple in Kerala and north – eastern states. It is grown over an area of 2.55 lakh ha with a production of 82.32 lakh tonnes. The productivity of cassava is the highest in the world. Kerala, Tamil Nadu and Andhra Pradesh contribute major share in the total area and production of cassava.

Though the area of cassava is decreasing, the productivity is increasing (Fig 1). The area during 1970 was 3.5 lakh ha decreased to 2.5 lakh ha during 2007, while the production increased from 5.0 mt during 1970 to 7.5 mt during 2007. During 2011-2012 the area was 2.27 lakh ha andit was more or less same as on 2018. There was decreasing trend in production (from 8.14 to 4.65 million tonnes) and in productivity (from to 20 kg/ha) during 2013 to 2018 (Fig 2) (FAOstat_data_11-19-2020;https://www.statista.com/statistics/874047/india-area-harvested-for-cassava-production/).

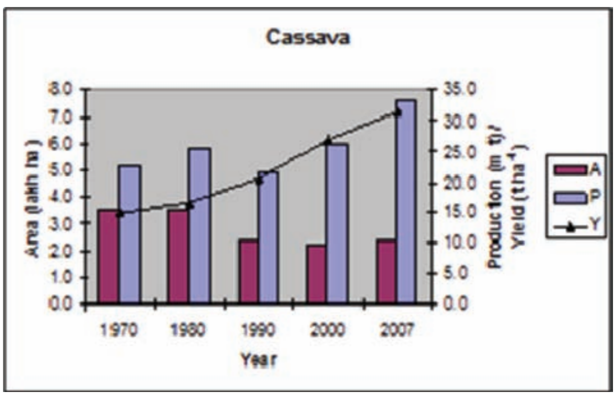

Figure 1. Cassava area, production and productivity in India during 1970 – 2007 (Palaniswami and Peter, 2008)

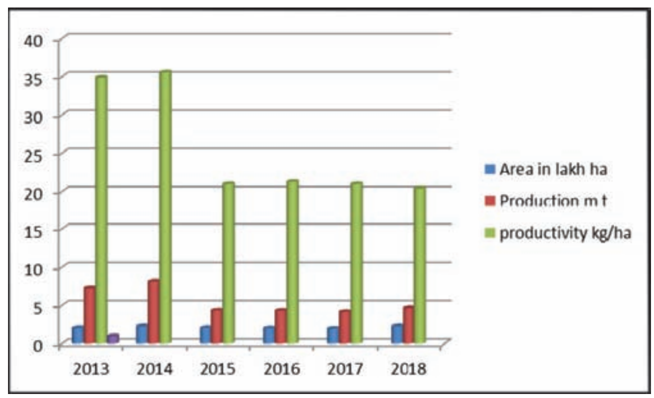

Figure 2. Cassava area, production and productivity in India during 2013 -2018(FAOSTAT_data_ 11- 19-2020)

Cassava Varieties:

Many varieties have been identified for different states like Andhra Pradesh, Assam, Kerala, Chhattisgarh, Gujarat, Jharkhand, Maharashtra and Tamil Nadu. CO (TP)-4, CO-3, H-119, H-165 and H-226 are popular in Tamil Nadu and last two in Andhra Pradesh. Sree Prakash, Sree Jaya and SreeVijaya are being adopted in Andhra Pradesh, Assam and Jharkhand. IGT-2 for Chhattisgarh and CI-590 for Gujarat are suitable. H-740/92 is performing well in Andhra Pradesh, Assam, Jharkhand and Bihar. Sree Padmanabha has been found to be resistant to cassava mosaic disease in Andhra Pradesh and Tamil Nadu. M 4 a selection first identified variety is still a preferred table variety in Kerala.

ICAR – CTCRI Improved varieties: H 97, H 165, H 226, Sree Visakam, Sree Sahya, Sree Jaya, Sree Vijaya, Sree Prakash, Sree Rekha, Sree Prabha, Sree Harsha, Sree Padmanabha, Sree Athulya, Sree Apoorva, Sree Swarna, Sree Pavithra, Sree Reksha, Sree Sakthi and Sree Suvarna. Sree Reksha was identified to be drought tolerant with high WUE based on assessment through various physiological parameters and C12/C13 ratio.

AICRPTC Improved varieties for different states: CO 1, CO 2, CO 3, H-119, MVD-1 and CO (TP)-4 (Tamil Nadu), TCa13-1 (Manipur),TCa13-7 (Kerala, Manipur, Chhattisgarh), TCa13-4 (Chhattisgarh), Sree Suvarna (Early Bulking, CMD resistant for Kerala, Tamil Nadu, Andhra Pradesh), PDP-9 (TCa 12-9) (Early Bulking,CMD resistant; high starch 28-30 % for Andhra Pradesh), TCMS-5 (PDP-CMR-1)(CMD resistant; starch 25% for Andhra Pradesh), Sree Reksha (CMD tolerant for Kerala), Chhattisgarh cassava-1(Resistant to CMD, Starch 30% for Chhattisgarh).

Kerala Agricultural University Improved varieties: Kalpaka (suited as an intercrop of coconut), Nidhi (tolerant to mosaic and moisture stress) and Vellayani Hraswa (cannot tolerate drought; cooking quality very good).

Challenges and Threats:

- Decline in area- It has been observed that there is a considerable decline in the area of cassava
- Bulkiness of planting materials and availability of good quality planting materials
- Weak linkage among stakeholders
- Domestic cassava starch facing stiff competition from cheaper starch of south-east Asian countries
- Perishability and Post-harvest physiological deterioration Rapid deterioration of cassava tubers is an important problem. An effective shelf life of less than three days significantly limits farmers' ability to supply high quality tubers to local markets and processing factories
- Effective old storage techniques for the harvested tubers so as to render the tubers to the factories as and when needed
- Duration of the cassava for good quality of starch. High yielding and short duration varieties with higher starch
- Cassava lines are rich in starch but very low or negligible in protein, vitamins and minerals. We need varieties with high â-carotene and (1000 to 2000 ìg/100 g) content, low cyanogens and good culinary quality. Cassava roots contain an average of only 2 to 3% dry weight protein. Enhancing protein content in cassava (7-9%) with balanced amino acid ratios would have significant impact.
- Varieties that can tolerate abiotic and biotic constraints with higher yields.
- Cassava mosaic disease is perennial problem causing yield loss and depletion of the yield and genetic potential. Cassava Mosaic Disease is important and need to be tackled. Production of virus free planting material in vector free areasand Use of healthy planting materials. Necessity of CMD-resistant varieties with higher starch yield with (more than 30%)for industrial utilization and low cyanogens to prevent soil pollution
- International - Plant quarantine. There are many economically important exotic diseases and pests (invasive alien species)not so far gained entry into India *viz.*, African Cassava Mosaic disease (ACMV), Cassava Brown Streak Virus disease (CBSV), Cassava Common Mosaic Virus disease (CCMV), Cassava Green Mottle Virus disease (CGMV), Cassava Vein Mosaic Virus disease (CVMV), Cassava American Latent Virus (CALV), Frogskin disease (FSD), Cassava Witches' Broom, Cassava bacterial blight (CBB) - *Xanthomonas campestris,* Dry root stem rot - *Diplodia manihotis,* Superelongation disease – *Sphaceloma manihoticola,* East African cassava mosaic virus and South African cassava mosaic virus and pests - coreid bugs - *Amblypelta* spp., mealy bugs - *Phenacoccus manihoti; P. herreni,* Green Mites- *Mononychellus tanajoa,* Scale insect-*Pseudaulacaspis pentagona,* Stem borers - *Coelosternus maniho; Lagochirus clarkei, t*hrips - *Frankliniella williamsi; Euthrips manihoti* and hornworm - *Erynnisello* need to be vigilant. It requires coordination at regional, national and international levels.
- Mechanization of cassava cultivation and harvestingto rescue of farmers woes.

Strength and Opportunities:

Cassava has vast production and processing potentialities and this could be translated into opportunities in spite of many odds faced by it. Good scope for area expansion - Meeting the challenge of additional production, could be achieved by extending to non-traditional areas as high calorie foods.

Biological advantages like thriving well in marginal and rainfed conditions come in its favour for area expansion in other parts of India especially Maharashtra, Gujarat, Orissa and Karnataka and it has a great role in food security.

We have rich biodiversity of cassava and their closely related species utilization for developing varieties with desired traits. Cassava lines with High â-carotene (1000 to 2000 ìg/100 g), Low cyanogens, Good culinary quality and High yield can be derived from gene pool for development and recombinant breeding.

Fresh roots and leaves contain two different cyanogenic glucosides, linamarinnd lotaustralin at levels that may be toxic, but if properly treated (in a process that may include roasting, soaking, or fermentation), the cyanide content is negligible.

Adaptation and Mitigation to Climate Change- Climate smart agriculture practices which include nutrient (liming, SSNM, neem coated urea and green manuring), water (drip irrigation), energy and carbon (sequential cropping, QPM and ridge and furrow) and smart practices. Cassava responds well to micronutrients (Micro nutrients MgSO4 @ 20 kg, ZnSO4@ 12.5 kg, Borax @ 10 kg for increasing the tuber yield). Cassava variety drought tolerant with high WUE (based on physiological parameters and C12/C13 ratio) an be developed like – Sree Reksha.

CMD management through diagnostic kit, resistant varietiesandrestricting the movement of diseased planting materials from diseased areas to non-prevalent region. Quarantine – Intra / International - Plant quarantine is the first line of defense against emerging pests, diseases and weeds due to climate change and introduction of invasive alien species.

Product diversification: Ample scope for diversification and value addition; value-added foods, animal feed formulation and production of starch, sago as well as commodity chemicals like citric acid, high fructose syrup etc.We can exploit its opportunities in the area of convenience food for which greater demands are ahead in view of self-employment in various sectors. Demand for starch and sago is increasing corresponding to population growth which put the requirement of these as 6 lakh tonnes by the end of 2025. SAGOSERVE is the only organised set up to help and protect the cassava processors in Tamil Nadu. SAGOSERVE helps the cassava farmers and entrepreneurs by eliminating middlemen in sago and starch trade in the country.

- The process of sago and starch extraction put cassava in good position than other sources which could be exploited for setting up units in areas like Gujarat, Maharashtra and North eastern states.
- Potential for developing environment friendly biodegradable plastics and allied materials like biofilms, packaging materials etc.
- Govt. of India has declared Biofuel policy by including cassava as one of the potential crops for industrial biofuel production.
- Cost effective method for biochar (soil ameliorant) production from cassava stem waste.
- Bioethanol production from cassava and develop biodegradable plastics for packaging and also for making cups, plates, cassava bags etc.
- Biodegradable films can be prepared from chemically modified cassava starch.
- Hydrogels can be prepared from native cassava starch.
- Cassava stem based Particle boards from dried and powdered cassava stems with different types of synthetic resins as binding.
- In Thailand, cassava starch is extensively used for monosodium glutamate and plywood production.
- Native and modified starches can find use in tablet and capsule making in pharmaceuticals.
- Cold water miscible starch from cassava tubers, besides textile use, can also find application as a food thickener, in cosmetics etc.
- Cassava varieties for leaf protein- an import substitute product for pet feed and cattle feed. Cassava leaves have high protein content (14-20 per cent) though the roots are low in protein (1-2 per cent). The leaves, after processing are used for protein enrichment of different feeds and have been found cheaper than the imported Alfalfa leaf protein. This is being utilized commercially in feed industry in Thailand and other Asian countries growing cassava for commercial use.
- Cassava flour (even without processing into pure starch) can be a substitute to agar and improve the growth of plant shoots in tissue. If cassava flour can provide both the gelling and carbon source requirements in the tissue culture medium then it can substantially reduce the medium cost.

- Eri silk worm rearing on cassava leaves is promising and has been encouraging in Assam. In Andhra Pradesh and Tamil Nadu ericulture has been found rewarding indicating there is lot of scope in the rural employment.
- Cassava is a gluten free natural starch. It is used in Western cuisine as a wheat alternative for patients with Celiac disease (a chronic digestive disorder resulting from an immune reaction to gliadin, a gluten protein found in wheat, barley, rye, and sometimes oats).
- By-product utilization: Thippi is a solid fibrous waste from the cassava starch factories. Being a starchy low cost product, can be used for production of ethanol, liquid glucose, high fructose syrup, industrial enzymes like amylase, amyloglucosidase, glucose isomerase and in incorporation of thippi in feed. Thippi can be used for particle boards.

Cassava has gained importance not only as food crops but also for its scope for food, feed and agro based industries. The versatility of cassava will remain on enduring attraction for producers and end users.There is tremendous scope for its expansion in non-food, non-feed *viz.*, sago, textile starch, gelling agent, particle boards, hydrogels, gums for paper/cardboard industry, carry bags, pharmaceutical fillers/capsules, biodegradable plastics/ films, alcohol production, feed industries etc. Cassava a 21st century crop is a multipurpose crop and responds to the challenge of climate change. Adaptation to climate change - of the major staple crops, cassava is expected to be the least affected by climatic conditions predicted in 2030.

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Recent advances in the soil-plant nutrition management of tropical tuber crops

Dr. K. Susan John[1], Dr. P. S. Anju[2], Dr. S. Chithra[2], Dr. S. U. Shanida Beegum[2], Dr. I. P. Anjana Devi[3], G. Suja[4], Dr. M. N. Sheela[5] and Dr. V. Ravi[6]

[1]Principal Scientist, Division of Crop Production, [2]Former Research Scholars, Division of Crop Production, [3]Former Research Scholar, Division of Crop Protection, [4] Former Project Assistant, Division of Crop Production, [5] Principal Scientist & Head, Division of Crop Improvement, [6] Principal Scientist & Head, Division of Crop Production

ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, 695017, Kerala, India

Corresponding Author:susanctcri@gmail.com

Root and tuber crops (RTC) like cassava, sweet potato, yams, potato, cocoyams and other minor root crops are important in the agriculture and food security regime of many countries, as it apparently forms a component of the diet for about 2.2 billion people in addition to contributing to the animal feed and other industries. The annual world production of root and tuber crops is about 765 million tonnes (MT) consisting of potatoes (333 MT), cassava (237 MT), sweet potatoes (130 MT), yams (53 MT) and taro and other aroids (12 MT) (WCRTC, 2016). Out of the total world production of RTC, about 45% are consumed as food and the rest being converted as animal feed or industrial products (FAO, 2017).The global consumption of tropical root and tuber crops is around 110 kg/capita/year (CTCRI, 2016). With this global per capita consumption, these crops occupy a significant place in the food basket of developing nations. Tropical tuber crops such as cassava, sweet potato, yams, elephant foot yam and cocoyams contributed 4.2 per cent of the human dietary intake and meet the food and energy requirement of millions of farm families in the developing countries (The Hindu, 2000).

Though tropical tuber can be grown in marginal environmental conditions especially poor soil, our experience over the past three decades clearly showed their high and positive response to the application of manures and fertilizers (Susan John *et al.*, 2005). Moreover, during the early years, though these crops were less susceptible to pests and diseases, with global environmental change, there observed many emerging pests and diseases affecting the existence of the crop globally adversely influencing the growth and yield of the crop. The poor shelf life and keeping quality of the tubers necessitated the use of these tubers to be used in many different value added forms like various food and industrial products which are fetching markets to a great extent providing income and employment opportunities to the growers.

Taking into account the present and future prospects of these groups of crops, there is a need to maximize or enhance the production and productivity. Among the different factors affecting the tuber yield and quality of tubers, soil fertility and plant nutrition management deserves paramount significance. According to Henry and Gottret (1996), low soil fertility is one of the constraints in production where the management of soil fertility can increase cassava yield by 32%.

I. Significance and unique attributes of tropical tuber crops

Tuber crops are the third most important food crops of man after cereals and grain legumes. Under this group of tuber crops, tropical tuber crops like cassava, sweet potato, elephant foot yam, yams, taro, tannia, arrow root and Chinese potato deserve special significance due to many of its unique attributes especially biological efficiency, climate resilience, ability to thrive in marginal soil and other environmental conditions, less pest and disease incidence and good quality starch which have good potential in making many value added food and industrial products. As regards to the harnessing of solar energy and conversion into chemical energy as starch, the yield potential can go up to 100 t ha^{-1} in the case of crops like cassava, *Amorphophallus* and yams.The good adaptability of crops to extreme drought in the case of crops like cassava and yams are worth mentioning. Cassava owing to its high leaf dry matter production to the tune of 2-4 t ha^{-1} and its innate physiological character of leaf shedding marked the crop as a good carbon sequestering crop and hence can mitigate the global warming through reduction in atmospheric CO_2. Yams specifically white yam (*Dioscorea rotundata)* domesticated and grown as a major crop in African countries are being better adapted to extreme drought due to its polished cuticle in the leaves which prevent excess loss of moisture from the leaves through transpiration.

II. Characteristics of tuber crops growing soils

Tuber crops are generally grown in inherently low fertile soils like laterite soils (Ultisols), red soils (Alfisols) and coastal sandy loam (Entisols) soils which in turn are poor in native fertility, low in cation exchange capacity (CEC) (12-15 me $100g^{-1}$) with low organic matter content (0.5-0.75%), low pH (<5.5), low basic cations especially K, Ca, Mg, high P fixation, kaolinitic clay nature, lower nutrient retention with very high content of iron and aluminium oxides particularly in the red and laterite soils.

III. Need for nutrient management in tropical tuber crops

Compared to field crops like rice, wheat, maize while producing grains to the tune of 3-6 t ha^{-1}, the tuber yield from these groups of crops is many fold ranging from 20-50 t ha^{-1} clearly revealing the nutrient extraction from the soil (Table 1)

Table 1. Nutrient uptake by various crops

Crop	Yield (t ha^{-1})	N (kg ha^{-1})	P	K	Ca	Mg
Rice	4.2	91	46	142	32	20
Wheat	2.4	70	30	60	-	-
Maize	3.4	81	21	68	15	-
Cassava	36.0	106	54	241	108	55
Potato	20.0	110	40	180	-	-
Coconut	7000 nuts	56	27	85	47	21

Source: Thampan (1979)

The requirement for nutrients can be met by different methods *viz.*, Integrated nutrient management (INM) involving the application of organic manures, chemical fertilizers and bio fertilizers, organic management focusing on organic manures alone for crop nutrition.

IV. INM in tropical tuber crops

Integrated nutrient management (INM) involves the conjoint application of organic manures, chemical fertilizers and bio fertilizers.

a. Organic manures in INM

1. Comparison of farmyard manure (FYM) with commonly used organic manures

The first component in INM is organic manure sources. The common organic manure used is farm yard manure (FYM). Since the economic produce (tuber) of tuber crops are formed inside the soil, the improvement of soil physical properties of the soil is very important with respect to tuber initiation, tuber development and tuber bulking.

As FYM being a scare resource due to lack of sufficient cattle rearing, we have tried different organic manures like green manuring *in situ* with cowpea (GM), crop residue (CR), vermicompost (VC) and coir pith compost (CPC) to substitute FYM. The data over a decade indicated all these organic sources are best alternatives to FYM. Considering the BC ratio, green manuring *in situ* with cowpea can be found as the best (Susan John *et al.*, 2019)

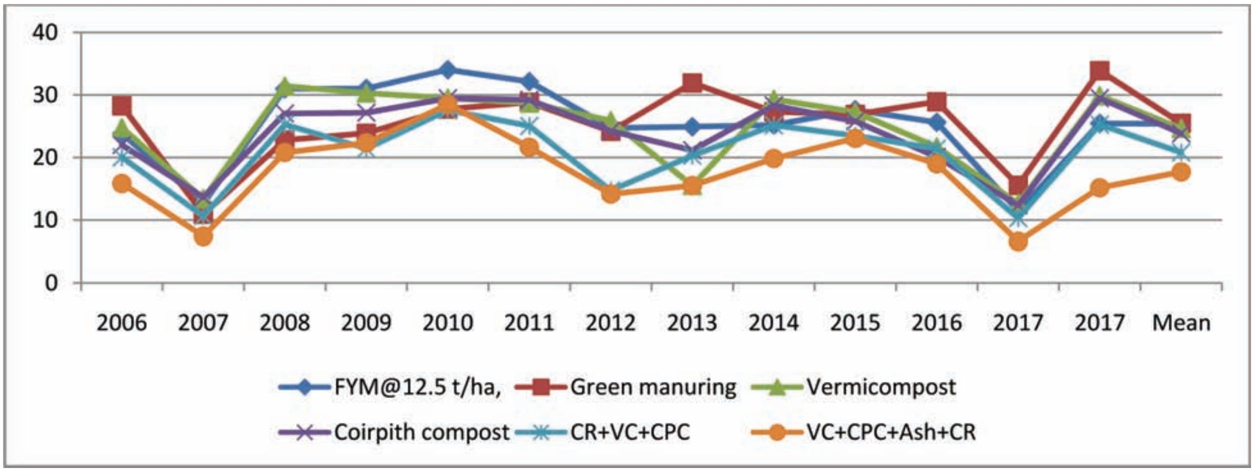

Figure1. Tuber yield(t ha^{-1}) with different organic manures under LTFE during 2006-2018

2. Thippi (cassava starch factory solid waste) compost as an alternative to FYM

In Kerala, while the cassava tubers are mainly used for human consumption, in Tamil Nadu, it is for the production of industrial starch and sago. During the extraction of starch from tubers, both small scale and large starch and sago factories are generating on an average about 40-60 tonnes of solid waste (thippi) per annum creating serious environmental pollution.

The physico-chemical, biochemical and microbiological analysis of thippi indicated that, it has high water holding capacity (89%) and porosity (95%) and low bulk density (0.58g cm^{-3}).It is acidic in nature (pH:3.6) with very poor plant nutrient contents *viz.*, N, P, K, Ca, Mg, Fe, Cu, Mn and Zn to the tune of 0.38 %, 0.07 %, 0.05 %, 0.04, 0.06 %, 60, 4.3, 7.8 and 7.5 ppm respectively with very high C:N ratio (82:1) and high percentage of starch (60 %). Microbiological characterization revealed very few bacterial colonies (3×10^6 CFU ml^{-1}) and there was no evidence of actino bacteria and fungi (Chithra *et al.*, 2017).

Considering the voluminous quantity of thippi discharged from these industries, possibility of making some value added organic manures from thippi was explored. Among the various protocols tried, the cheap and traditional way of composting using earthworms for a period of 45-60 days gave better result in making it in to a nutrient rich organic manure. The nutritional evaluation of thippi compost revealed that, among the nine different treatment combinations tried for making thippi compost, high nutrient content with respect to primary, secondary and micronutrients was seen in the case of thippi enriched with organic materials *viz.*, FYM, *Gyricidia*/ cassava leaves, Mussoriphos and rock powder and composted with earthworm. It had the highest plant nutrient content with low C:N ratio (8:1). The mean N, P, K, Ca and Mg, Fe, Mn, Cu and Zn content in thippi compost was 1.32, 3.82, 0.40, 2.18, 0.96, 1.11, 0.08 %, 11.23 and 89.93 ppm respectively which is 3.5, 49,7, 32.5, 8, 185, 100, 2.5 and 12 times compared to raw thippi.

A study on the mineralization (nutrient release) pattern of nutrients from thippi compost under pot incubation study for a period of one year indicated the maximum release of almost all nutrients from thippi compost was during 5-7th month.

Field experiments conducted for two seasons to study the effect of thippi compost as a substitute to commonly used organic manures and fertilizers including secondary and micronutrients revealed thippi compost (24.662 t ha^{-1}) as an alternative to FYM (26.638 t ha^{-1}), green manuring *in situ* with cowpea (27.183 t ha^{-1}), crop residue incorporation (25.028 t ha^{-1}), vermi compost (22.153 t ha^{-1}), coir pith compost (21.781 t ha^{-1}), NPK up to 50% (26.549 t ha^{-1}), $MgSO_4$ @ 2.5 kg ha^{-1} (27.937 t ha^{-1}) and $ZnSO_4$ @ 2.5 kg ha^{-1} (24.436 t ha^{-1}) (Chithra *et al.*, 2017, 2019, Susan John *et al.*, 2019).

The tuber quality parameters such as tuber starch were increased with thippi compost and the HCN content of the tubers was also reduced with thippi compost both alone and along with chemical fertilizers.

b. Chemical fertilizers in INM (Major, secondary and micronutrients)

If we see the nutrient management strategy of crops during early 50-70's, it can be seen that, the nutrient need of the crop was met purely through organic manures in the form of farm yard manure (FYM), green manuring *in situ* with leguminous plants like cowpea, sunhemp etc., green leaf manuring with plants like *Glyricidia* to supply mainly N. Similarly bone meal was the other commonly used organic source to supply P and wood ash to supply nutrients like K, Ca, Mg. With the advent of time and with the introduction of HYV's of crops coupled with irrigation to these crops resulted in high yield causing drastic nutrient removal manifesting the depletion of nutrients especially N, P, K necessitating the use of chemical fertilizers containing these nutrients to replenish the soil of the depleted nutrients.

In this regard, the first approach was blanket recommendation without seeing either the soil nutrient status or the crop need/requirement. Later, after recognizing the adverse impact of blanket / PoP recommendation on soil health as continuous application of these nutrients influenced the physico-chemical and biological properties of the soil badly, the significance of soil test based application of nutrients became pertinent. After these two approaches, it is felt that, other than soil status, the crop requirement too needs to be taken care to arrive at a precise nutrient recommendation comprising of major, secondary and micronutrients. In other words, it is actually a designing of fertilizer mixtures meeting the crop requirement with adequate thrust on the available status of nutrients in the soil.

1. Blanket Recommendation

Blanket recommendation comprising mainly of organic manures and chemical fertilizers containing basically of primary nutrients like N, P, K was arrived based on fertilizer rate/level experiments. Fertilizer rate/level trials include in laying out field experiments with different levels of N,P,K in replicated trials, estimating the yield and BC ratio under each level and finally coming out with the best level of N, P, K giving the optimum yield fetching the best BC ratio. The blanket recommendation for major tuber crops are given below:

Table 2: Blanket fertilizer recommendation for tropical tuber crops

Crop	FYM (t ha^{-1})	N	P_2O_5(kg ha^{-1})	K_2O
Cassava	12.5	100	50	100
Sweet potato	5.00	50	25	50
Taro	12.5	80	25	100
Tannia	25.0	80	50	150
Lesser yam	10.0	80	60	80
Greater yam	10.0	80	60	80
Elephant foot yam	25.0	100	50	150
Chinese potato	10.0	60	60	100
Arrowroot	10.0	50	25	75

2. Soil test based fertilizer cum manurial recommendation

i. Primary Nutrients

The basic principle involved in arriving at the recommendation for major nutrients like N, P, K was based on a nine class system where the N recommendation was arrived based on soil organic carbon (SOC) content. The recommendation is based on the blanket or PoP recommendation depending upon the soil status of N, P, K. Table 3 gives the details of soil test values and the corresponding N, P, K recommendation as percentage of general recommendation (PoP/blanket recommendation).

Table 3. Soil test ratings and fertilizer recommendation

Soil fertility class	% of organic carbon		N as % of general recommendation	Available P (kg ha^{-1})	Available K (kg ha^{-1})	P and K as % of general recommendation
	Sandy	Clayey/ loamy				
0	0.00 – 0.10	0.00-0.16	128	0.0 – 3.0	0 - 35	128
1	0.11 – 0.20	0.17-0.33	117	3.1 – 6.5	36 -75	117
2	0.21 - 0.30	0.34-0.50	106	6.6 – 10.0	76 -115	106
3	0.31 - 0.45	0.51-0.75	97	10.1- 13.5	116-155	94
4	0.45 - 0.60	0.76-1.00	91	13.6 -17.0	156-195	83
5	0.61 - 0.75	1.01-1.25	84	17.1 -20.5	196 -235	71
6	0.71 - 0.90	1.26-1.50	78	20.6- 24.0	236 -275	60
7	0.91 - 1.10	1.51-1.83	71	24.1- 27.5	276 -315	48
8	1.11 - 1.30	1.81-2.16	63	27.6 – 31.0	316 -355	37
9	1.31 - 1.50	2.17-2.50	54	31.1- 34.5	356- 395	25

Source: Aiyer and Nair (1985)

At, ICAR-CTCRI, the long term fertilizer experiment (LTFE) initiated during 1977, during its third phase in 2005 had a treatment on soil test based application of FYM and NPK. The soil test data during these years and the recommendation evolved based on the soil data on organic carbon, available P and K is given below (Table 4).

Table 4. Soil test values (organic carbon, available P and K) during the experimental period (2005 - 2018)

Planting Years	Soil test values				Recommendation		
	OC (%)	P (kg ha$^{-1)}$	K (kg ha^{-1})	FYM (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
2005	0.71	56.3	145.6	10.0	91	0	94
2006	0.90	158.1	206.1	10.0	91	0	71
2007	0.92	139.9	233.0	7.5	91	0	71
2008	0.78	80.8	192.6	7.5	91	0	83
2009	0.94	56.5	267.7	7.5	91	0	60
2010	0.93	82.4	400.3	7.5	78	0	25
2011	1.01	53.9	93.5	5.0	84	0	106
2012	2.20	94.0	278.0	5.0	60	0	54
2013	1.30	130.9	288.4	5.0	78	0	48
2014	1.39	145.4	132.0	5.0	78	0	94
2015	1.18	187.4	97.7	5.0	84	0	106
2016	1.60	98.6	105.6	5.0	71	0	71
2017	1.80	142.95	242.82	5.0	71	0	60
2018	1.56	255.14	275.30	5.0	75	0	54
Mean	1.23	120.16	211.33	6.43	81	0	71

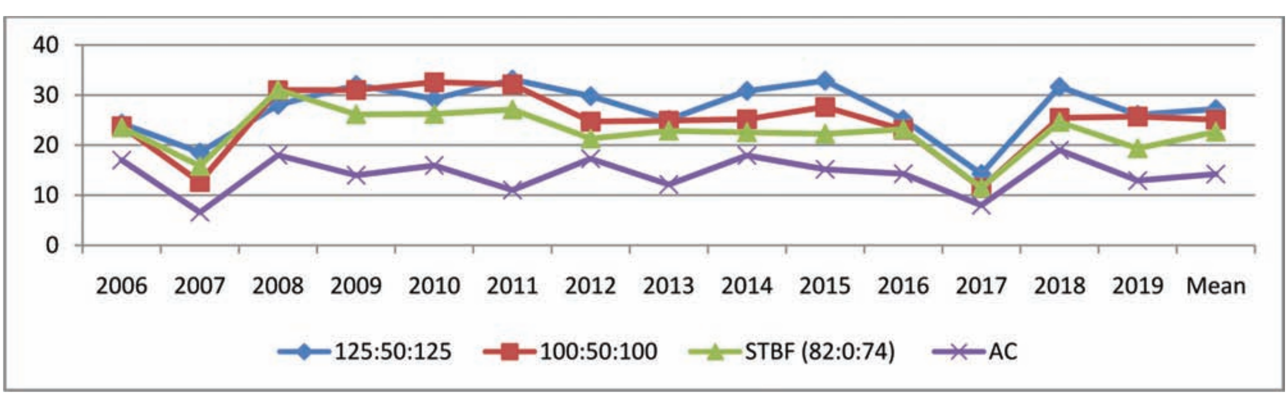

Figure 2. Tuber yield of cassava (t ha^{-1}) under different fertilizer levels over a period of 3 years of continuous cultivation

The data clearly reveals a lower nutrient dose with respect to N and K in place of 100 kg ha^{-1} each and complete avoidance of P during all these years. The mean recommendation of N:P:K was seen as 81:0:71 indicating a saving of 19 kg N, 50 kg P_2O_5 and 29 kg K_2O. The tuber yield data based on this recommendation along with PoP, a higher dose (NPK @125:50:125 kg ha^{-1}) and absolute control (without any organic manures and chemical fertilizers) is depicted in Fig.2.

ii. Secondary and micronutrients

In the case of secondary nutrient Mg and micronutrients *viz.*, Zn and B, there is blanket recommendation as $MgSO_4$ @ 20 kg ha^{-1}, ZnSO4 @ 12.5 kg ha^{-1} and borax @ 10 kg ha^{-1}. Continuous application of these nutrients at the rates since 1990 in the case of Mg and Zn and B since 2005 resulted in non response on tuber yield after 5-7 years. Hence, we have developed a criteria on the recommendation of these nutrients based on soil test and is given in Table 5.

Table 5: Soil test based recommendation of FYM, Mg, Zn and B for cassava

Soil Mg status (meq $100g^{-1}$)	Rate of application of $MgSO_4$ (kg ha^{-1})	Soil Zn status (ppm)	Rate of application of $ZnSO_4$ (kg ha^{-1})	Soil B Status (ppm)	Rate of application of borax (kg ha^{-1})	Organic carbon (%)	Rate of application of FYM (t ha^{-1})
0–0.25	20	<0.2	12.5	<0.2	10	<0.50	12.50
0.25–0.50	15	0.2–0.3	10	0.2–0.5	7.5	0.5-0.75	10.00
0.50–0.75	10	0.3–0.4	7.5	0.5–1.0	5 .0	0.75-1.00	7.50
0.75–1.00	5	0.4–0.6	5	1–2	2.5	1.00-1.50	5.00
>1.00	2.5	>0.6	2.5	>2	0	>1.50	2.50

Susan John *et al.*, (2010), PoP (2011)

Under the LTFE, the soil test values of Mg, Zn and B and the corresponding recommendation of $MgSO_4$, $ZnSO_4$, borax are given in Table 6. The tuber yield data with blanket and soil test based recommendation of these nutrients are presented in Fig. 3 and 4 respectively.

Table 6. Soil test values of Mg, Zn and B under LTFE (2005-2017)

	Soil test values			Recommendation		
Planting Years	Mg (meq $100g^{-1}$)	Zn (ppm)	B (ppm)	$MgSO_4$ (kg ha^{-1})	$ZnSO_4$ (kg ha^{-1})	Borax (kg ha^{-1})
2005	1.510	5.281	-	20	12.5	10
2006	-	1.563	-	20	12.5	10
2007	1.438	2.223		20	12.5	10
2008	1.548	4.825	-	20	12.5	10
2009	1.640	5.06	-	20	12.5	10
2010	1.393	0.860	-	20	12.5	10
2011	1.307	0.940	-	20	12.5	10
2012	0.520	9.060	0.49	10	2.5	2.5
2013	0.660	5.530	0.748	10	2.5	5
2014	0.508	3.892	0.852	10	2.5	5
2015	0.270	2.830	2.083	15	2.5	2.5
2016	0.538	4.467	0.849	10	2.5	5.0
2017	0.788	4.660	0.414	5	2.5	7.5
2018	0.788	5.600	0.312	5	2.5	7.5

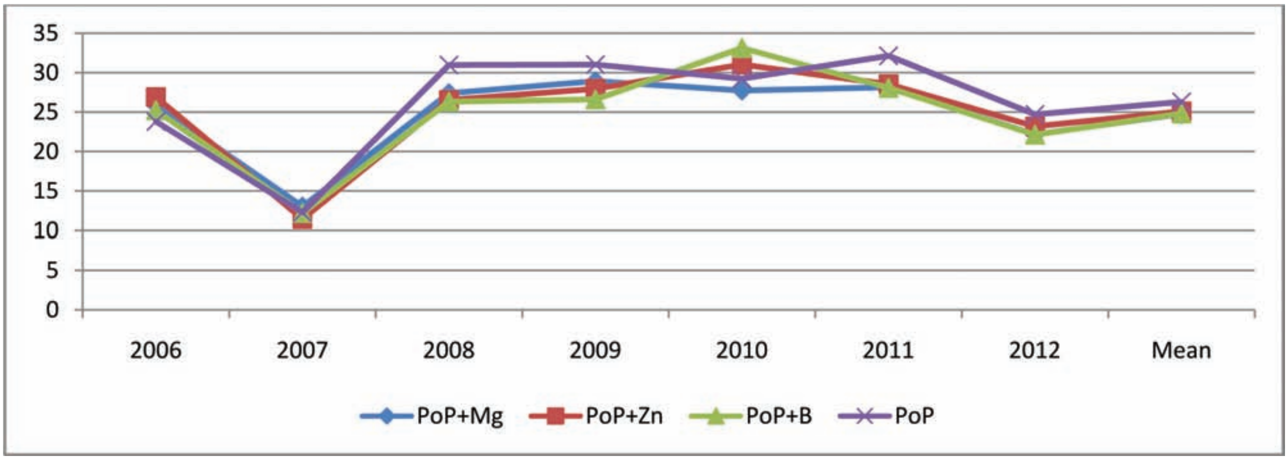

*Figure 3***.** Tuber yield (t ha^{-1}) under blanket application of Mg, Zn and B application under LTFE (2005-2011)

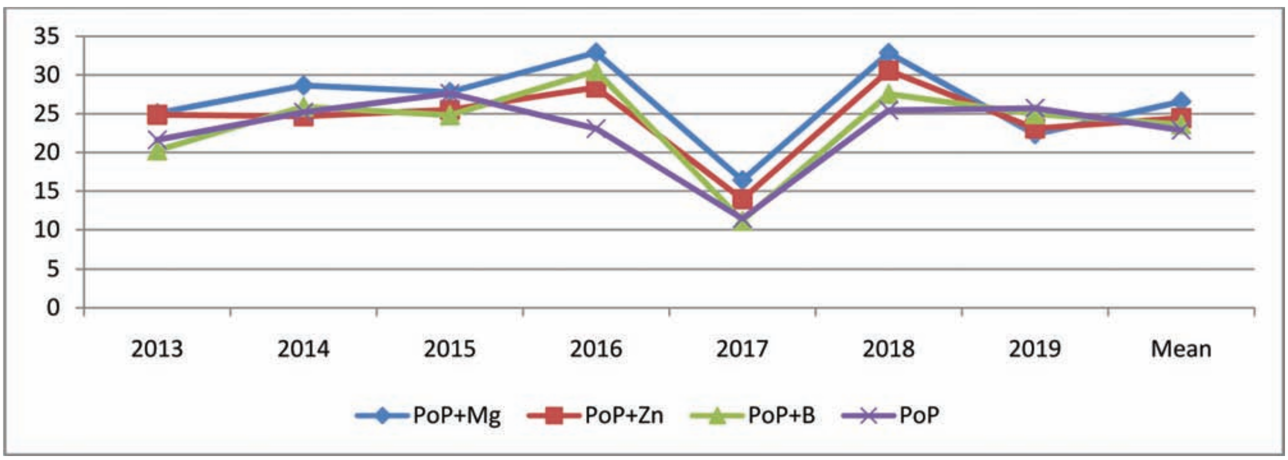

Figure 4. Tuber yield (t ha^{-1}) under soil test based application of Mg, Zn and B (2013-2019)

3. Customized fertilizer mixtures in elephant foot yam

As indicated earlier, they are designed fertilizers based on crop need and soil nutrient status specific to crops and soils. In this regard, we have developed three customized fertilizer grades comprising of nutrients *viz.*, N, P, K, Mg, Zn and B containing 20 % N and 70 % K for the two agro ecological units of Kerala *viz.*, AEU3 and AEU 9. The protocol for the development of these grades include arriving at the weighted average data of the soil chemical parameter of each AEU based on the average chemical parameter of each panchayat with respect to the area of the panchayats under the AEU. A theoretical optimum of the nutrients was evolved based on the weighted average data following Aiyer and Nair (1985). From this theoretical optimum, the practical optimum for NPK was arrived based on nutrient omission plot experiment (NOP) and that of soil amendment (Mg) secondary nutrient (Mg) and micronutrients (Z, B) were arrived based on nutrient level experiments (NL). Basic data like nutrient requirement, innate nutrient supplying capacity of the soil, fertilizer use efficiency were computed from the above two experiments to arrive at the grades of the CF following soil test crop response (STCR) and response curve (RC) approaches. The details for evolving the grades of CF for EFY under intercropping in coconut gardens of Kerala in AEU3 and AEU 9 are presented below:

In the present research, the mean weighted average data of AEU 3 comprising of 40 and AEU 9 comprising of 135 panchayats with respect to soil chemical parameters like pH, electrical conductivity, organic carbon, available P, exchangeable K, Ca, Mg, available S, Zn, Cu, Fe, Mn and B was 5.7, 0.29 dSm^{-1}, 0.937 %, 60.47 kg ha^{-1}, 209 kg ha^{-1}, 109.3 ppm, 36.8 ppm, 4.68 ppm, 3.74 ppm, 1.76 ppm, 99 ppm, 18.7 ppm and 0.683 ppm for AEU 3 and 5.5, 0.28 dSm^{-1}, 1.386%, 64.6 kg ha^{-1}, 271kg ha^{-1}, 555 kg ha^{-1}, 105 ppm, 20.2 ppm, 5.3 ppm, 3.43 ppm, 60.83

ppm, 35.02 ppm and 0.78 ppm AEU 9 respectively. The soil test based fertilizer cum manurial recommendation arrived based on weighted average data of the soil chemical properties were N, P, K, Mg, Zn, B, Dolomite @ 71:12.5:106.5:12.8:4.2:1.31:1000 kg ha^{-1} for AEU 3and 78:12.5:90:12.8:4.2:1.31:1000 kg ha^{-1} for AEU 9. Based on NOP and NL experiments, the optimum nutrient doses for nutrients *viz.*, N, P, K, Mg, Zn, B and dolomite, taking into account the tuber yield data was N: P: K: Mg: Zn: B: Dolomite @ 140 : 20 : 225 : 19.2 : 4.2 : 1.575 : 1500 kg $ha^{-1}$for AEU 3 and 160 : 12.5 : 180 : 19.2: 6.3: 1.975 :1500 kg ha^{-1} for AEU 9 respectively.

Nutrient requirement (NR) computed to arrivethe grades of CF formulations based on STCR and RC approaches were 3.68, 0.70 and 4.47 kg N, P, K respectively per ton of tuber for the two AEU's. The innate nutrient supplying power of the soil computed to arrive at the grades were 55.6, 33.3, 44.3 and 32.8, 33.3 and 48.5 per cent N, P, K respectively for AEU 3 and AEU 9. The fertilizer use efficiency of N, P, K for AEU 3 and AEU 9 respectively were 27.1, 48.5, 90 and 54, 40, 48 per cent. The grades of the CF evolved based on STCR approach was N: P_2O_5: K_2O: Mg: Zn: B is 8:11:21:3.5:1:0.3 for AEU 3 (CF1) and 7: 12: 24: 4:1.25: 0.4 for AEU 9 (CF2). Based on the RC approach, the level of nutrients at which the maximum tuber yield obtained was under the grade as N : P_2O_5: K_2O : Mg : Zn : B is 6 : 3 : 30 : 3.5 : 1: 0.3 for AEU 3 (not selected for field trial) and 7 : 3:25 : 4 : 1.25 : 0.4 for AEU 9 (CF3) (Anju, 2020; Anju *et al.*, 2020; Susan John *et al.*, 2019).

Evaluation of the two rates *viz.*, 500 kg ha^{-1} and 625 kg ha^{-1} of the three CF's in three locations of the two AEU's along with PoP and farmers' practice (FP) indicated all CF's @ 625 kg ha^{-1} as the best with respect to tuber yield and B:C ratio.

Based on the results of the previous year, trials were conducted in five locations of the five major EFY growing districts of Kerala to screen the best CF out of the three CF's. It is seen that, the CF developed for AEU 9 through STCR approach having the grade as N: P_2O_5: K_2O : Mg : Zn : B @ 7: 12: 24: 4:1.25: 0.4 as the best in terms of tuber yield (67.56 t ha^{-1}), BC ratio (5.44), tuber quality and soil quality indices (SQI) (Table 8). Hence, for EFY under intercropping in coconut gardens of Kerala, CF formulation with the above grade was selected for popularizing among farmers.

Table 7. Effect of treatments on economic parameters including B:C ratio

TreatDescription	Tuber yield (t ha^{-1})	Gross Income (Rs. ha^{-1})	Net Income (Rs ha^{-1})	B:C ratio	SQI
FP	51.645	1549350	1221100	4.19	1.39
PoP	47.36	1420800	1092550	4.01	1.16
CF1 @625 kg ha^{-1}	58.708	1761240	1432990	4.73	1.38
CF2@625 kg ha^{-1}	67.561	2026830	1698580	5.44	1.31
CF3@625 kg ha^{-1}	62.623	1878690	1550440	5.06	1.32
SEm ±	5.8390				0.0799
CD	12.378				-
p-Value	0.021				0.2452
CV (%)	21.8				13.07

Testing of these CF's in cassava under intercropping in coconut showed CF1 and CF2@ 500 kg ha^{-1} as good. In sweet potato, and EFY under sole cropping, CF1 and CF3 @ 500 kg $ha^{-1}$and CF1 and CF2 @ 625 kg $ha^{-1}$was found good for yams. These CF's were tested through KVK's of Kerala for cassava (KVK, Alapuzha, Idukki), EFY (KVK, Kollam, Idukki) and yams (KVK, Alapuzha) and indicated yield increase of up to 30 % and BC ratio of 1.6-2.3 for these crops over PoP.

c. Bio fertilizers in INM

The bio fertilizers commonly recommended for cassava is N fixer (*Azospirillum)* @ 3-5 kg ha^{-1} there by the chemical fertilizer N dose can be reduced to half (Suja *et al.*, 2005). In sweet potato, *Enterobacter* sp. could substitute chemical fertilizer P upto 75 %the N fixer (*Acaligenes feacalis*) could substitute N fertilizer up to

25 % (Susan John *et al.*, 2010a). In EFY, under independent application, there was possibility of substituting N @ 50 % with N fixer (*Bacillus cereus*), full P with P solubilizer (*B. megaterium*) and K could reduce from 150 kg ha^{-1} to 100 kg ha^{-1}under the K solubilizer (*B. subtilis*). Conjoint use of the above NUE microbes as a component of the INM practice in EFY resulted in saving of 25 % each of N and K and P up to 50-75 %, thereby reducing the use of chemical fertilizers (Susan John *et al.*, 2019d, Anjana Devi *et al.*, 2015; Anjana Devi, 2014).

V. **Secondary and micronutrient management in sweet potato and elephant foot yam (EFY)**

1.Sweet potato

In the recent years, the most important problems encountered with respect to nutrient management in this crop include

a. Lack of better tuberization in acid laterite soils (Ultisols).
c. In sufficiency of nutrients as per the present blanket recommendation: For sweet potato, the present PoP recommendation is FYM @ 5 t ha^{-1} along with N:P:K @ 50:25:50 kg $ha^{-1,}$ if calculate for more than 83,300 plants in a hectare as per spacing, based on its nutrient uptake is not a sufficient quantity.
c. Occurrence of tuber splitting/cracking resulting in the reduction in marketable tuber yield

These issues were taken care during the last five years and the results are summarised below.

a. Liming materials for sweet potato

As soil acidity was found to be one of the constraints for tuberization in sweet potato in the acid laterite soils having low pH to the tune of 4-4.5, experiments were conducted with liming materials *viz*., lime, dolomite, gypsum and calcium nitrate at lower and higher doses as 0.5, 1.0, 1.5, 2 t ha^{-1} and higher rates as 4, 8, 12, 16 t ha^{-1} both under controlled and field conditions for more than five seasons. Tuber yield data indicated lime followed by gypsum and dolomite @ 8 t ha^{-1} are effective in resulting good yield. It was clearly understood that, raising the soil pH of acidic soils like laterite soils is a must for good tuberisation and since the number of plants in one hectare as per the spacing accounts to nearly 85,000, liming with any of the above liming materials @ 8 t ha^{-1} can improve tuberisation (CTCRI, 2017, 2019).

b. Soil application of secondary and micronutrients

Laterite (Ultisols) and sandy soils (Entisols) where tuber crops are mostly grown are deficient in Ca, Mg, Zn and B. The nutrient level experiment conducted with different levels of Mg, Zn and B based on a theoretical optimum fixed for the major tuber crops growing soils indicated the practical optimum as per the tuber yield obtained from the experiment was soil application of Mg, Zn and B @ 19.2, 6.3 and 3 kg ha^{-1} which is 120, 30 and 28.5 kg ha^{-1} $MgSO_4$, $ZnSO_4$ and borax/solubor respectively. Among the different secondary and micronutrients tried through soil, the best result was obtained with independent application of Mg SO_4 @ 80 kg ha^{-1}, $ZnSO_4$ @ 20 kg ha^{-1} and borax @ 10 kg ha^{-1} giving an interval of 5-10 days between application. Application of these nutrients can be started after one week of top dressing with NPK (after 45 days of planting). Moreover, need based application can be resorted to depending upon the soil status. If the soil test values of these nutrients are above the soil critical level, the rate can be limited to one half or one fourth as a maintenance dose. (CTCRI, 2017, 2018)

c. Foliar application of secondary and micronutrients

The major objectives of applying nutrients through leaf is either to rectify any nutrient disorder affecting the crop growth and yield or to enhance the crop growth and incidentally the yield.

The response of sweet potato to soil and foliar application of both secondary nutrients (Ca and Mg) and micronutrients (Zn and B) were studied since 2016. Among the different combination of these nutrients tried as foliar, better tuberization was resulted with 0.1 % solubor, 0.1 % Zn EDTA and 0.5 % $MgSO_4$ @ 500-750 g ha^{-1} independently depending upon the requirement as per soil test or on the occurrence of the symptom manifestation. Two sprays at an interval of 20 days during the peak vegetative growth stage of the crop and two sprays at an interval of 20 days during the tuber bulking stage was found giving good results.

As regards to combined application along with major nutrients, foliar application of 19:19:19 (1%) + Zn EDTA (1%) @ 625 litres ha^{-1} during the peak vegetative growth stage and 1 % KNO_3 along with 0.1 % solubor (together @ 625 litres ha^{-1}) at tuber bulking stage at an interval of 15-20 days is giving better growth and yield (CTCRI, 2018, 2019)

d. Critical vegetative growth stage of sweet potato for foliar nutrition

Foliar nutrition is really intended during the peak vegetative growth stage and tuber bulking stage. To demarcate the peak vegetative growth stage (stage with the highest uptake of nutrients), the total plant uptake determined through destructive sampling from 22 days after planting (DAP) till 124 DAP at an interval of 20 days indicated the maximum uptake between 64 and 84 DAP and hence the foliar application of secondary and micronutrients can be initiated from 2 months after planting (MAP) and can be continued till 3 MAP (CTCRI, 2019).

e. Management of tuber cracking and related problems

Among the essential nutrients required for growth and yield in sweet potato, B plays a significant role. Moreover, laterite soils are very poor in B. In this regard, there is a need to restore/replenish the B status of the soil through external supply. Recently, deficiency symptoms in the form of tuber cracking is very common in major tuber crops growing soils. As indicated earlier, in order to prevent the symptoms as well as to enhance yield in low B soils, the adhoc recommendation evolved is as follows:

Liming the soil either with lime or dolomite @ 2 t/ha twice at an interval of 15 days prior to land preparation so as to raise the soil pH and increase Ca content of the soil (Lime rate can go up to 8 t ha^{-1} depending upon the soil pH). Follow balanced application of NPK as per recommendation. Solubor @ 5 kg/ha can be given in the ridge/mount at planting with irrigation. After top dressing, apply solubor 5 kg/ha in the soil at 50-60 DAP. Apply solubor 0.1% as foliar spray @ 650 litres/ha at maximum vegetative growth stage (55-60 DAP), tuber bulking stage at 70-80 DAP and 80-90 DAP (CTCRI, 2019).

2. Elephant foot yam

a. Liming materials

As in the case of sweet potato, the response of EFY to secondary nutrients *viz.*, Ca and Mg and micronutrients *viz.*, Zn and B were studied since 2016 and the results indicated dolomite @ 2 t ha^{-1} as the best liming material (CTCRI, 2018).

b. Secondary and micronutrients

The nutrient level experiment conducted under open situation indicated the optimum rate of Mg, Zn and B as 14.4, 4.73 and 1.48 kg ha^{-1}respectively which in turn was 90, 22.5 and 14 kg $MgSO_4$, $ZnSO_4$ and borax/solubor respectively. Among the secondary nutrients, soil application of $MgSO_4$@ 60 kg ha^{-1} and Zn SO_4 @ 30 kg ha^{-1} depending uponthe soil status and foliar application of Zn EDTA (0.5%), Solubor (0.1%) and $MgSO_4$ (1%) depending upon its requirement twice at an interval of one month during peak vegetative growth stage and tuber bulking stage is found as the best. Hence, the integrated package on secondary and micronutrients developed for EFY include application of dolomite @2 t ha^{-1} as basal dose. Soil application of $MgSO_4$, $ZnSO_4$ and borax/solubor @ 60-90, 20-30, 10-15 kg ha^{-1} respectively depending upon the soil status and soil critical level of these nutrients. Foliar application of Zn EDTA (0.5%), Solubor (0.1%) and $MgSO_4$ (1%) depending upon its requirement twice at an interval of one month during peak vegetative growth stage and tuber bulking stage can also be adopted depending upon the crop condition to rectify the disorder due to these nutrients or to enhance growth and yield of the crop (CTCRI, 2017, 2018).

c. Critical growth stage for foliar nutrition

Destructive sampling done in EFY at five intervals since 2.5 months after planting (MAP) at an interval of 1.5 months till 7 MAP to delineate the maximum vegetative growth for foliar nutrition indicated it as 4-5.5 MAP (CTCRI, 2019) .

VI. INM in Tannia

Being one of the nutritious tuberous vegetable grown locally and regionally, many experiments were undertaken at CTCRI to standardize the nutritional requirement of this crop. But these were hindered due to some soil and plant nutritional problems affecting the growth and yield of the crop. In all these cases, it was seen that, the crop will be having luxuriant vegetative growth up to 3 MAP, if other growth conditions like soil moisture, sunlight, relative humidity etc. are adequate. After that, the crop start showing clear and distinguishable symptoms in the foliage which appears as interveinal chlorosis of the older leaves followed by cupping inward and drying (characteristic of Mg deficiency). In severe cases, the entire foliage will dry resulting in complete devastation of the crop (Susan John and Suja, 2012).

Studies were conducted at CTCRI to find out the possible reasons of the above problem and was identified as sub soil acidity induced multi nutrient disorder involving Ca, Mg and K which is manifested in the form of Mg deficiency.

A series of experiments under pots and field resulted in the identification of dolomite containing CaO (33.2%) MgO (12.2%) @ 1 t ha^{-1} (80 g / plant) as a good soil ameliorant to rectify the problem (Susan John *et al.*, 2013). In addition, the INM strategy also was standardized which included the application of NPK @ 80:50:150 kg ha^{-1} +25 t ha^{-1} farm yard manure (FYM) with 50 % N as organic and the rest as inorganic. The organic sources used were FYM, neem cake, green manuring *in situ* with cowpea and N_2 fixer and inorganic N was urea. The strategy was standardised as an application of dolomite as soil amendment @ 1 t ha^{-1} (80 g/plant) during ploughing and keeps the land as such for 10-15 days, application of FYM @ 25 t ha^{-1} in pits and P @ 50 kg ha^{-1} as basal, plant the *Pseudomonas* treated cormel/corm, sow green manure cowpea immediately after planting tannia, apply N fixer within 1 month of planting tannia, apply neem cake in pits after 1 month of N fixer application, apply 1/3 fertilizer N and 1/3 fertilizer K within 2 months after planting (MAP), apply 1/3 fertilizer N and 1/3 fertilizer K within 4 MAP, apply the rest of 1/3 fertilizer N and 1/3 fertilizer K within 6 MAP (Susan John *et al.*, 2013a).This was validated through KVK's and included in the PoP of KAU (Crops' 2016) (PoP, 2016) .

VII. NUE genotypes as a feasible option to reduce the use of chemical fertilizers

The present scenario of fertilizer markets with respect to its price and availability at times of need are not that encouraging. Taking into account some factors which are hindering to some extent the fertilizer use as mentioned above, it is known that, there are some ways to reduce the use of commercial fertilizers through use of genotypes which can explore the soil nutrients from deeper soil layers due to its unique root system referred as nutrient use efficient (NUE) genotypes. Though NUE cultivars is a new concept as an alternative to reducing or substituting chemical fertilizers, Graham (1984) defined nutrient use efficiency of genotypes as the ability to produce high yield in a soil which is limiting in that particular nutrient. According to Blair (1993), NUE is the ability of a genotype or cultivar to acquire nutrients from growth medium and to incorporate or utilize them in the production of root or shoot biomass or utilizable plant material.

In the case of tuber crops especially cassava, K is considered as the 'key nutrient' with respect to yield and quality (Susan John *et al.*, 2010b). K plays a significant role in enhancing the tuber productivity and in reducing the cyanogenic glucoside content of tubers and increasing the starch synthesis. The research work initiated to identify K use efficient cassava cultivars resulted in the release of the first K efficient genotype by name 'Sree Pavithra' in 2015 for Kerala State.

To identify the same, a total of 100 elite genotypes from the germplasm collection of ICAR-CTCRI was evaluated for their inherent NUE (physiological efficiency) by growing them in a row trial without any fertilizers and manures. In addition to this, other required attributes like plant stature, tuber yield, mosaic tolerance, tuber yield, tuber quality also were considered and selected six genotypes (Table 8). These were further evaluated under a split plot design with four levels of K *viz.*, 0,50,100 and 150 kg ha^{-1} for three years. Among the genotypes, CI-1100 (locally called Aniyoor) which is a local selection from a place called Aniyoor near Sreekariyam in Thiruvananthapuram district responded well to zero K by giving very good yield on par with that of K at higher levels (Table 8).

Table 8:Effect of levels of K on tuber yield of selected cassava genotypes (Pooled Mean of 3 years)

Sl. No.	Genotypes	Levels of K (kg ha^{-1}) 0	50	100	150	Mean(G)
1	Aniyoor	32.030	35.313	38.217	37.750	35.828
2	W-19	29.547	30.973	39.207	34.200	33.482
3	7 Sahya 2	27.400	40.933	44.160	26.283	34.694
4	6—6	29.343	32.090	33.563	30.560	31.389
5	CR 43-8	36.407	37.430	43.150	45.300	40.572
6	7 III E3-5	30.993	41.050	40.880	40.627	38.388
	Mean K levels	30.953	36.298	39.863	35.787	
	CD(G)	4.943				
	CD(K)	5.071				
	CD(GXK)	8.010				

Along with Aniyoor, 7 III E3-5 was also found as very good with respect to its pink rind (as in the case of Aniyoor) better yield under low levels of K including other NUE and physiologic parameters, mosaic tolerance, tuber quality and cooking quality and plant stature.

In addition, we have studied all the NUE parameters like agronomic efficiency (AE), physiological efficiency (PE), agro physiological efficiency (APE), utilization efficiency (UE), K uptake ratio (KUpR), apparent recovery efficiency (ARE), harvest index (HI), K harvest index (KHI), K utilization for biomass (KUtB) and K utilization for tuber (KUtT) and physiological parameters like crop growth rate (CGR), relative growth rate (RGR), tuber bulking rate (TBR) and leaf area index (LAI) to justify its innate nutrient utilization character for biomass especially tuber. The unique inherent nature of this variety was further explained by studying the root architecture where in this genotype had the maximum number of thin/white roots responsible for nutrient and water absorption (Susan John *et al.*, 2016, Susan John *et al.*, 2017).

Again, these genotypes were tested for two seasons in farmers' fields of the three districts of Kerala *viz.*, Thiruvananthapuram, Pathanamthitta and Kollam under the aegis of Krishi Vignan Kendras (KVK's) of these districts. Ultimately, based on farmers' preference as regards to yield and very good cooking quality, CI-1100 was released under the name 'Sree Pavithra'. Experiments conducted in different soil types *viz.*, laterites (Ultisols: AEU 9) and sandy plains (Entisols : AEU 3) of Kerala State using Sree Pavithra as intercrops in coconut gardens indicated its suitability in such situation too.

The N efficiency potential of K efficient cultivars were tested for three years at four levels of N *viz.*, 25, 50,75, 100 kg ha^{-1} and identified W-19 and CR43-8 as N efficient which can save N up to 50%. Since the plant stature, tuber quality and tuber shape was not much farmer acceptable, it was not field validated under on farm trials and intended for registration as N efficient genotypes.

Again, we have identified 16 NUE genotypes of cassava through the screening of another set of 300 elite genotypes which in turn included some physiologically NPK efficient lines too. In addition, tuber yield, tuber quality attributes including cooking quality, plant stature and mosaic tolerance also were considered. Among these 16 genotypes, in addition to Sree Pavithra, 7 III E3-5, CI-905 and CI-906 were tested for NPK use efficiency under four levels of NPK *viz.*, 25, 50, 75 and 100 % of PoP for three seasons continuously to see the extent to which chemical fertilizers can be reduced by using these NUE genotypes.

It is seen that, though all these four genotypes were not influenced by levels fertilizers (Table 9), significant effect of genotypes were seen in the case of tuber yield (Table 10). During all the three seasons, the tuber yield realized under all the four levels of NPK were on par indicating the level of application of NPK fertilizers can be reduced up to 25 % (saving of 75 % NPK fertilizers) when the NUE genotypes are used.

Table 9. Tuber yield at Levels of NPK (I,II &III seasons)

	Tuber yield (t/ha)			
	25%	50%	75%	100%
I Year	39.767	41.575	44.342	46.199
II Year	19.850	21.150	17.837	21.290
III Year	36.479	36.347	40.698	41.032
CD(0.05)	NS			
Mean	32.032	33.024	34.292	36.174

Since these were having good cooking quality, low in HCN and mosaic tolerant, they were tested in 24 farmers fields across the 23 agro ecological units of Kerala with 25 % of the PoP recommendation and found very much farmer acceptable with respect to high yield, good tuber quality in terms of better cooking quality, low cyanogen and good starch content, low dose of NPK requirement, pink rind (7 III E3-5) and dark yellow colour of the flesh (CI 905) (Table 10). Hence, they are in pipeline for release/genotypes registration (Susan John *et al.*, 2019).

Table 10. Effect of NUE genotypes on cassava tuber yield and tuber quality

Genotypes	IYear	IIYear	IIIYear	Mean	HCN(ppm)	Starch(%)
S. Pavithra	39.466	23.897	35.299	32.887	36.43	19.69
7 III E3-5	49.444	22.101	43.893	38.479	60.17	20.20
CI-905	43.099	25.202	41.073	36.458	63.20	17.99
CI-906	39.874	18.771	34.291	30.979	75.93	21.90
CD	6.446	4.063	6.435	5.648	19.871	1.551

VIII. Low input management strategy in cassava

The basic concept behind this approach was the potential productivity of a crop is the integrated effect of genetic potential of the crop, environment under which it is grown, management practices and the developed technology adopted for its cultivation. Cassava is generally grown by resource poor farmers as a subsistence crop in diverse range of agricultural and food systems due to its ability to sustain under poor soil and harsh climatic conditions. It also responds well to manures and fertilizers. Since the resource poor famers prefer to have a low input management strategy which in turn needs to be economically feasible and environmentally sustainable, the present research programme was taken up with the objective of evolving the same using low cost involving inputs *viz.*, nutrient use efficient cultivars, cheap organic manure source like green manuring *in situ* with cowpea, soil test based application of primary, secondary and micronutrients and nutrient use efficient bio inoculants like N fixers, P and K solubilizers.

The first and foremost low input component considered was the nutrient use efficient cassava genotypes which were of better significance from the point of view of escalating fertilizer cost, hazardous effect due to under use and over use on soil and plant health and the monetary implications with respect to excess application. As regards to the second criteria *viz.*, environment, cassava is considered as a climate resilient crop owing to its unique character of leaf shedding at times of drought which in turn is designated as a crop having high carbon sequestration potential. Hence, the potential of cassava as a carbon sequestering crop owes to its high leaf dry matter production coupled with leaf shedding due to environmental impact resulting in mitigating the rising temperature. Under the management factor, an integrated nutrient management (INM) practice involving organic manures, chemical fertilizers and bio fertilizers based on soil test data has already proven best for cassava. The technologies developed with respect to the various components of the INM are taken care in the present programme. As organic manure being the primary component, greenmanuring *in situ* with cowpea which was already evolved as a low cost alternate practice to application of farm yard manure @ 12.5 t ha^{-1} was adopted. The second component being the chemical fertilizers, the already proven technology of soil test based application of fertilizers including the secondary (Mg) and micronutrients (Zn) was adopted. As the third component of INM being the bio fertilizers, application of nutrient use efficient bio inoculants *viz.*, N fixers, P and K solubilizers were done under the low input management strategy (Susan John *et al.*, 2018, Susan John *et al.*, 2019).

Field experiments conducted for 2 seasons with three NPK efficient genotypes under four nutrient management practices showed the genotypes *viz.*, CI 905 and CI 906 as promising under low input management in terms of tuber yield to the tune of 33.68 and 34.72 t ha^{-1} respectively with a B:C ratio of 4.43 and 4.57 respectively (Fig. 8). All the practices tried were similar revealing the beneficial effect of low input management strategy involving nutrient efficient genotypes *viz.*, CI 905 and CI 906 coupled with integrated nutrient management practice involving green manuring *in situ* with cowpea as source of organic manure and soil test based application of N, P, K, $MgSO_4$ and $ZnSO_4$ @ 106:0:83:20:2.5 kg ha^{-1} during first year and 106: 0: 94: 10:2.5 kg ha^{-1}during the second year along with nutrient efficient bio fertilizers containing N fixer, P and K solubilizing bacteria as a better option for cassava (Table 11).

Table 11. Tuber yield as affected by genotypes and nutrient management practices (Mean of 2 years)

Genotypes	POP	STBF	POP+BF	Low input	Mean (Genotypes)
Acc. No. 766	29.721 ^{bcd}	20.695^{gh}	24.398 ^{efg}	18.165^{h}	23.245^{b}
Acc. No. 905	29.442^{bcd}	24.073^{efg}	25.807^{e}	32.195^{b}	27.879^{a}
Acc. No. 906	26.943^{de}	30.343 ^{bc}	30.040^{bcd}	36.457^{a}	30.944^{a}
H-1687	27.331^{cd}	23.283^{fg}	24.504^{ef}	22.056 ^{fg}	24.294^{b}
Mean (Nutrient management)	28.509	27.879	30.946	29.443	

The low input management strategy could save P, K, Mg and Zn to the tune of 100, 11.5, 62.5 and 80 % respectively and the percentage increase in cost of inputs under the other practices over the low input practice varied significantly up to 55 %.The field experimentsindicated that, the genotype *viz.*, CI 906 had the highest starch content (25.61 %) and lowest cyanogenic glucoside content (31.74 ppm) (Shanida *et al.*, 2013; 2015; Shanida, 2016).

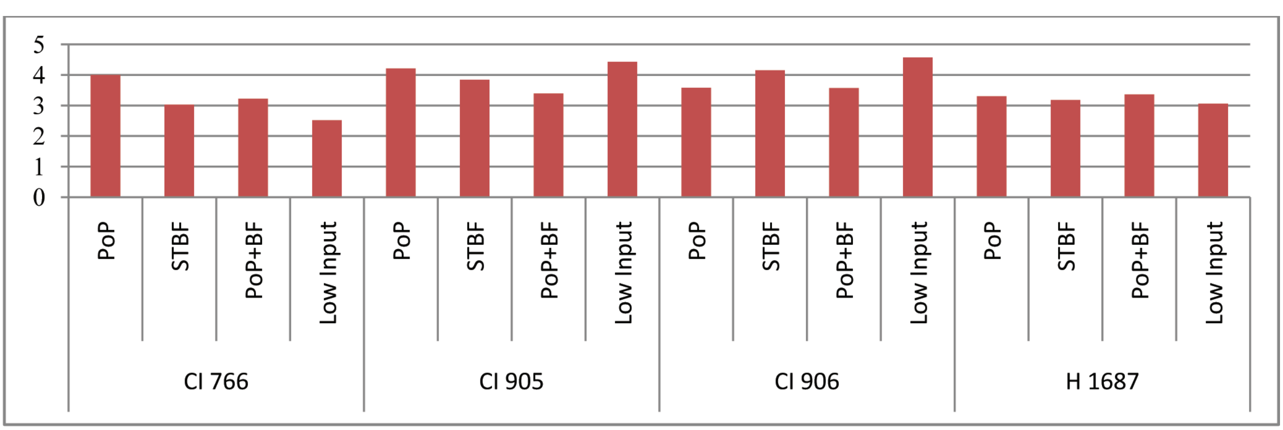

Figure 8. B:C ratio under low input management strategy in cassava

IX. Carbon sequestration potential of cassava in climate resilience

Climate resilience of a crop denotes the ability of the crop to adapt and adjust to the adversities of climate change. Increasing CO_2 concentration of the atmosphere is considered as the predominant cause of global warming and this indirectly indicates that, by decreasing the CO_2 concentration of the air, global warming can be reduced. C sequestration is the removal of atmospheric CO_2 by plants and storage of fixed carbon as soil organic matter. If the crop can absorb more CO_2 from the atmosphere and if the absorbed CO_2 can be converted to soil organic carbon, it can be designated as a high C sequestering crop and thereby reduce the atmospheric CO_2 and hence global warming (Susan John *et al.*, 2019).

Cassava because of its high leaf dry matter production (average 2.5-3 t ha^{-1}) absorbs more CO_2 from the atmosphere to produce more leaf dry matter and due to the innate physiological mechanism of leaf shedding especially during drought will result in incorporating the leaf dry matter into the soil and get converted into soil organic matter. The comparison made between recommended fertilizer practice (PoP) and an absolute control (AC) with respect to change in soil organic carbon (SOC) through leaf dry matter addition were calculated for 1990-2009 and 2005-2017 separately which in turn highlighted the C sequestering efficiency of cassava. This theoretical assessment was based on the finding of Jian Ni (2004) that, 1 g leaf dry matter contains 0.45g carbon and Singh *et al.*, (2007) that, to produce 1g leaf dry matter, 1.69g CO_2 is absorbed from the atmosphere, thus the atmospheric CO_2 utilized to produce the leaf dry matter was arrived. The atmospheric CO_2 concentration during 1990 is taken as 360 ppm (Ramakrishna *et al.*, 2006) and is increasing at the rate of 1.5 ppm per year. Hence, the reduction in CO_2 content of the air through leaf production was calculated. The atmospheric carbon sequestered was calculated by deducting the initial SOC of 8000 and 6700 ppm under PoP and AC respectively from the mean SOC after 20 years (Susan John *et al.*, 2014).

In the absolute control, the CO_2 acquisition and concomitant increase in SOC (soil organic carbon) ranged from 25-50 % of POP only. The ultimate effect of sequestering the atmospheric CO_2 through reduction in atmospheric CO_2 and increase in SOC was manifested as increase in tuber yield. Hence, it can be inferred that, cassava can sequester atmospheric CO_2 into SOC and mitigate global warming to a great extent. These findings under the LTFE

established the fact that, cassava has high potential for C sequestration where in carbon present in the atmosphere as CO_2 through photosynthesis resulted in leaf carbon which in turn is converted to SOC, reducing the atmospheric CO_2 content .

X. Conclusion

Tropical tuber crops are now designated as the 'climate smart future crops' of this millennium. The unique attributes of these groups of crops in combating the present day environmental challenges especially drought , the high yield potential as well as the scope to evolve many nutritive as well as industrial value added products can be taken as specific features to be considered in promoting these crops among the tuber crops growers throughout the globe. In augmenting the production to meet the global challenge of satisfying the commodity demand, among the different primary factors affecting its growth and yield, soil fertility and plant nutrient management can be considered as very important. This chapter gives a vivid picture of the different soil and plant nutrient management strategies in making the crop as well as the soil healthy in addition to enhancing the crop yield and tuber quality. Most of these tuber crops, though are high input demanding, but grown with low inputs, the development of some important farmer acceptable and eco-friendly technologies like low input management strategy and nutrient use efficient genotypes deserve special mention. Nutrient recycling through composting of starch factory solid waste (thippi) and thippi compost can be well recommended for the industrial cassava belts of Tamil Nadu as a nutritious organic manure. Green manuring *in situ* with cowpea was a very possible and economically feasible alternative to the commonly use organic manure *viz.*, FYM in all situations for all tuber crops. In the case of very high nutrient demanding crops like EFY, the latest concept of designing fertilizer mixtures containing primary, secondary and micronutrients based on soil nutrient status and crop need found attention from the point of view realizing high yield, better soil and tuber qualities. With advent of time, due to the imbalanced nutrient management especially chemical fertilizers resulted in many different types of nutritional disorders. The scientific diagnosis and management measures advocated are of very practical benefit to the farming community. Hence, it can be concluded that, tropical tuber crops having very significant potential in moulding the industrial economy of the different tuber crops growing countries in coming years owing to the very cheap and quality starch as the active principle of the crop needs scientific soil and plant nutrient management to overcome the challenges in productivity to meet the industrial demand of tubers.

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Dr. Pradeepkumar T., born on 31. 05.1965 at Tellicherry, Kerala, obtained his PhD degree in Horticulture from IARI, New Delhi in 1994 and undergone overseas training at University of Wisconsin, USA. He is now working as Professor and Director of Planning, Kerala Agricultural University. Dr Pradeepkumar.T has experience of more than 26 years in horticultural research, UG and PG teaching and extension as state and national level expert. He has developed six hybrids of different crops like water melon (Seedless types), salad cucumber (Parthenocarpic type) and ridge gourd. He has supervised 11 M.Sc. and 6 PhD students. He is the recipient of Krishi vijnan award for the best agricultural scientist instituted by Govt. of Kerala and Harbhajan Singh Award by ISVS. He has published 70 research papers, 11 books, 16 book chapters and 45 popular article . He received ISVS fellowship from, Indian Society of Vegetable Science in year 2016, IAHS fellowship from Indian Academy of Horticultural Science in the year 2019 and ISS fellowship from Indian Society for Spices in the year 2021.