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भारतीय कृषि अनुसंधान परिषद

Agrisearch with a human touch

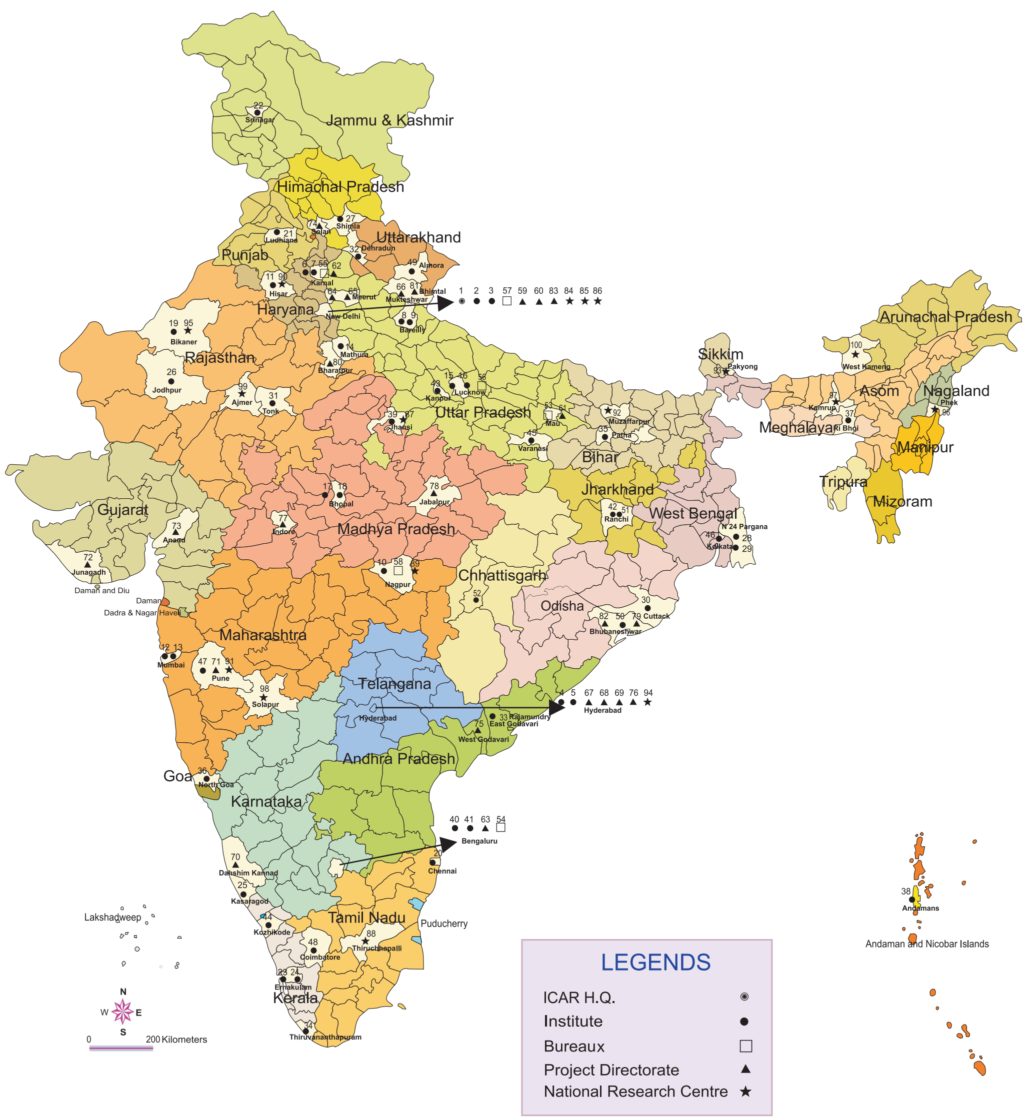
Vision 2050

Central Citrus Research Institute

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



• 64 Research Institutes • 6 Bureaux • 15 National Research Centres • 15 Project Directorates

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Agricultural Universities

LEGENDS

- State Agricultural Universities ○
- Central Universities with Agricultural faculties ■
- Central Agricultural Universities ☆
- Deemed Universities ●

Vision 2050

Central Citrus Research Institute
(Indian Council of Agricultural Research)
Amravati Road
Nagpur

www.nrccitrus.nic.in

Printed : July 2015

संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Central Citrus Research Institute (CCRI), Nagpur has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

(S. AYYAPPAN)
Secretary, Department of Agricultural Research & Education (DARE)
and Director-General, Indian Council of Agricultural Research (ICAR)
Krishi Bhavan, Dr Rajendra Prasad Road,
New Delhi 110 001

Preface

Citrus is the third most important fruit crop of India with production of 10.48 million tonnes (2013-14) from 1.07 million hectares. Thus, the average productivity is 9.78 tonnes/ha, although 20-25 tonnes/ha yields have also been recorded by some progressive growers. In other citrus growing countries, these figures stand at 40-50 tonnes coupled with a much higher orchard productive life. High density planting with automated fertigation has contributed immensely in revolutionizing commercial citriculture in many countries. Citrus decline has been rampant and virtually plagued Indian citrus plantations which warrants for a massive rejuvenation programme. Many citrus growers in the country are still not fully aware of the available technological options for improving and sustaining productivity. Technological support in post-harvest handling aimed at enhancement of shelf life for off-season availability of fruits and price stability in the market is the need of the hour. Processing is other field gaining importance and need to be addressed. Development, dissemination and impact assessment of viable technologies for sustainable citrus production during next 35 years is the key to meet the requirements of citrus industry in future. An envisaged two fold increased productivity will be achieved by increase in productivity of water, labour and energy.

Central Citrus Research Institute at Nagpur has witnessed significant growth in development of infrastructure and initiating the prioritized research projects. As the institute has completed three decades of its existence, the challenges have been well identified with the clear cut objectives and goals while formulating the future strategies. The strengths are to be consolidated further and weaknesses to be minimized, so that new emerging opportunities are favorably responded. Therefore, more concerted research efforts need to be focused to address the problems of Indian citrus industry in coming years up to 2050.

'VISION-2050' covers brief background of citrus research at CCRI and its achievements which take into account the overall scenario of citrus cultivation in India *vis-à-vis* other citrus producing countries. The road-map of research with immediate and long term programmes has been outlined along with guiding principles, human resource development, linkages required and constraints to overcome in future. This perspective plan document has been prepared on the basis of

'Knowledge Meet' guidelines provided by the Council along with suggestions of RACs and QRTs.

I am at loss of words to express my deep sense of gratitude to Dr S. Ayyappan, Secretary, DARE and Director General, ICAR who has been a guiding force in bringing out this document. I sincerely thank Dr. N.K. Krishna Kumar, DDG (Hort. Sci.) for his untiring efforts and valuable advice in finalization of this Vision document. I am especially thankful to Dr. S. K. Malhotra, ADG (Hort. Sci.) for his guidance. I sincerely acknowledge hard work of Drs. A.K. Srivastava, A.D. Huchche, I.P. Singh, Lallan Ram, A.K. Das, C.N. Rao and P.S. Shiragure in drafting this document. I am thankful to Miss Lily Verghese, ACTO, PME Cell for compiling required information for this document.

(M. S. Ladaniya)
Director
CCRI, Nagpur

Contents

Context

Citrus is grown in 114 countries around the world. Out of these, 53 countries grow citrus commercially with a total production of more than 115 million tonnes. On production basis, China tops the list with 22.9 million tonnes followed by Brazil with 22.7 million tonnes and USA with 10.4 million tones. India with 10.48 million tonnes is at 4th position. Mexico with 6.7 million tonnes and Spain with 6.5 million tonnes are rank at 5th and 6th position. Commertial Citrus fruits of the trade include sweet orange (*Citrus sinensis* Osbeck), Mandarin (*Citrus reticulata* Blanco), limes (*Citrus aurantifolia* Swingle), lemon (*Citrus limon* (L) Burm.f), grapefruit (*Citrus paradise* Macf.) and pummelo (*Citrus grandis* (L.) Osbeck).The world citrus is dominated by sweet orange with a 64% contribution followed by mandarins with 20%, limes and lemons 10% and rest of the 6% contributed by grapefruit and other citrus fruits. In India, the area under citrus is 1.07 million ha with a production of 10.48 million tonnes and average productivity of 9.78 tonnes/ha. Total mandarin production in India is 3.25 million tonnes with 0.32 million ha area and 10.16 tonnes/ha as productivity while limes/lemons have occupied an area of 0.21 million ha with 2.10 million tonnes production and 9.62 tonnes/ha productivity. Over the last 20 years, expansion has been recorded at an annual rate of 5.95% in area and 6.2% in production.

Indian citrus industry has certain unique features and unlike China and Japan where citrus is grown mainly in humid subtropical climate,in India, both mandarins and sweet oranges are grown under tropical climatic conditions except Kinnow and Khasi mandarin. The famous Nagpur orange (mandarin) is grown in humid tropical Vidarbha region of Maharashtra where summer temperature reaches as high as 45-46^{0}C. Both Maharashtra with 278,000 ha area under citrus in Central India and Andhra Pradesh with 1,28,000 ha in South India enjoy a distinct tropical climate where there is no well defined winter season with low temperature regime. The Kinnow mandarin, however, is showing good promise and is commercially successful in north Indian states like Punjab, Haryana and Rajasthan falling under subtropical climate with distinct winter season. Similarly, the traditional mandarin growing areas of north-eastern hill states experience humid subtropical climate with high rainfall in monsoon (summer) and low temperature during winter months.

At present, citrus production is 10.48 million tonnes, with maximum share of mandarins (3.25 million tonnes) followed by acid lime & lemons (2.10 million tons) and sweet orange (1.36 million tons). The production trend during 1992-93 to 2010-11 clearly established increased production of citrus fruits. During last 50 years (1961- 2011), citrus production and area expanded more than nine fold (Table 1).

Table 1 Growth of citrus industry in India

Year	Area ('000 ha)	Production('000 tones)
1961	90.7	823.7
1968	105.4	1211.9
1988	279.4	2282.2
2004	563.0	5680.0
2009	923.0	8608.0
2010-11	846.5	7463.6
(50 yrs)	925% increase since 1961	945 % increase since 1961
Per capita per year availability of citrus fruits in India : 6.16 kg (2010-11)		

Problems and Prospects

As citrus is being widely grown across the country, its cultivation faces variety of problems. Yields are far below the full orchard potential with inferior fruit quality. The problems include:

- Unavailability of quality planting material.
- Threats of insect pests and diseases and nutrient deficiencies.
- Scarcity of water in some areas.
- Lack of post-harvest handling along with processing infrastructure.

In India, there are 26 states involved in citrus production but 9 states cover more than 70 % of area and 89% of production. In Maharashtra, there was almost four fold increase in area under citrus during 1968-69 to 1991-92. The high market price and steady increase in demand in the domestic market keeps citrus cultivation a highly remunerative venture. Large area of citrus has been planted in Maharashtra during the recent past which is yet to come to bearing. Productivity is maximum in Punjab due to prolific bearing of Kinnow mandarin.

Utilization of trait specific germplasm in hybridization programmes and marker aided clonal selection are focused approaches in crop improvement. Molecular characterization of citrus genetic diversity, development of *in-vitro* regeneration (somatic embryogenesis/ organogenesis) and genetic transformation protocols and ploidy manipulation needs to be emphasized. Large scale production of disease-free planting material, decision support based fertilizer recommendation, refining INM module, organic citrus, dwarfing rootstocks, high density planting, crop regulation, drainage in problematic soils, fertigation, watershed management, rejuvenation of declining orchards, precision citriculture and citrus-based cropping systems are some of the approaches to achieve expected production targets. Use of bioagents/semio-chemicals and new molecules for effective control of pests and diseases, developing disease diagnostics and forecasting models would receive attention in the field of plant health management. Screening of new safe/eco-friendly chemicals treatments including antagonists to reduce post-harvest fruit losses and new product development will be the focus areas in postharvest management. In technology transfer, adoption aspects including constraints and impact will be given priority.

Central Citrus Research Institute

The task force team appointed by the Ministry of Agriculture, Government of India, suggested urgent need of strengthening research on citrus in Central India after their survey of declining citrus orchards during 24th to 26th April, 1980. Further, Dr. D.J. Hutchison, an UNDP consultant on citrus, recommended establishment of Citrus Research Station at Nagpur to investigate problems concerning citrus fruits in Central India. Similarly Quinquennial review team of IIHR, Bengaluru, also recommended that the citrus research work conducted at Nagpur will be more useful and applicable. As a result, the Centre started functioning from 29th November, 1985 and on 1st April 1986 it was upgraded to National Research Centre for Citrus. In October 2014, the centre was upgraded to Central Citrus Research Institute.

Mandate

The mandate of CCRI is to undertake basic and strategic research on major citrus cultivars *viz.,* Nagpur mandarin, sweet orange and acid lime to increase the sustainable productivity through developing better varieties, standardizing appropriate citrus production technologies, integrated pest and disease management and developing technologies for improved storage, packing, processing, waste utilization and technology dissemination.

In the light of future projections and citrus research network, the mandate proposal is given below -

- To undertake basic and applied research for developing technologies for improvement and increased productivity in citrus.
- To act as a repository for genetic resources and scientific information relating to citrus.

- To undertake research to develop technologies for better shelf life and utilization of citrus fruits considering domestic and export needs.
- To act as a Centre for training in advanced research methodologies and technology upgradation in citrus.
- To collaborate with relevant national and international organizations/ Govt. agencies for citrus research and technology dissemination.
- To provide consultancy services and undertake contract research to solve the problems of citrus industry.

Buildings and Infrastructure

The Institute has made overall progress in developing the research farm, creating requisite infrastructure and research facilities available in the laboratories and field. Rapport has been established not only with the State Hort./Agriculture Department and SAUs but also with the farmers due to which it is being acknowledged by all the concerned.

The Institute has two storied Administrative-cum-Laboratory building at Amravati Road, Nagpur. A farmhouse and a tractor shed are also constructed at the farm premises. A residential complex of 24 quarters including six quarters of type I, II, III and IV each, two quarters of type V and one Director's bungalow are also available in the premises and allotted to staff.

During the past 30 years, the Institute has procured several sophisticated equipments like HPLC, GC, Plant canopy analyser, Photosynthesis analyser, ELISA reader, PCR, Real time PCR, Atomic Absorption Spectrophotometer, Nitrogen analyser, Particle size analyzer etc. and also constructed several screen houses, green houses to bring about the qualitative change in the research outcomes. The Institute has well developed computer facilities for research and other activities. This serves for data processing, analysis, interpretation, maintenance and cataloguing information, developing expert systems, information systems, database creation and forecasting models etc. besides auditing and accounting. Internet facility links the Centre with ICAR headquarters and other ICAR institutes. Provision has been made to expand the existing facilities of computers to all the scientists,laboratories, and administrative sections through Local Area Network (LAN). All purpose working web portal for global connectivity has been developed.

The Institute is richest source of literature on citrus in India. It subscribes number of citrus periodicals published all over the world. As of now it possesses 1809 books, 1042 journals/periodicals; 28 Indian journals (current subscription); 6 Foreign journals and 1320 research reports. The Institute is having 10 CD's of Horticulture abstracts (1975 onwards). It also publishes its Annual Report and Newsletters timely. Centre has published 5 books, 2 manuals, 1 handbook, 15 technical bulletins, 1 monograph, 37 extension bulletins, 1 interactive compact disc (CD) and 26 extension folders on various aspects of citrus.

Experimental Farm

CCRI has 250 acres of land out of which about 180 acres is available for citrus plantation and the rest has been earmarked for screen and green houses, glass and cagehouses, roads, water-bodies etc. By now most of the cultivable land (about 170 acres) has been brought under plantation mandate crops besides nursery sheds, foundation blocks, vermicompost and other fruit crops. The entire farm area has been now protected by the compound wall and is served by the well maintained roads. For drip irrigation purposes above ground and underground water storage tanks have been constructed which are fed with the underground pipe line from the Ambazari lake located 1.5 km away from the farm site. Entire plantation is irrigated with drip system.

Budget

Sr. No.	Plan Period	Plan	Non-Plan	PHT on F&V	NARP Project on Bio. Tech.	Total
1.	VII Plan (1985-90)	102.25	-	29.54	-	131.79
2.	VIII Plan (1992-97)	440.00	192.27	29.65	61.00	722.92
3.	IX Plan (1997-2002)	724.00	565.00	-	-	1288.00
4.	X Plan (2002-07)	961.67	1087.00	-	-	2048.67
5.	XI Plan (2007-12)	1303.00	1052.00	-	-	2355.00
6.	XII Plan (2012-17)	2800.00	3557.07	-	-	6357.07
Increase from 1 to 6 (Per cent)		2738.39	1850.04			4823.63

Manpower

	Plan Period	Scientific	Technical	Adminis-trative	Supporting	Tech. (Workshop)
1.	VII Plan	20	12	8	-	3
2.	VIII Plan	-	11	7	12	1
3.	IX Plan *	-	4	3	27	2
4.	X Plan *	-	4	3	27	2
5.	XI Plan	-	-	-	-	-
6.	XII PLan	-	-	-	-	-
Increase from 1 to 6 (Per cent)		0 %	33.33%	37.5%	-	66.66%

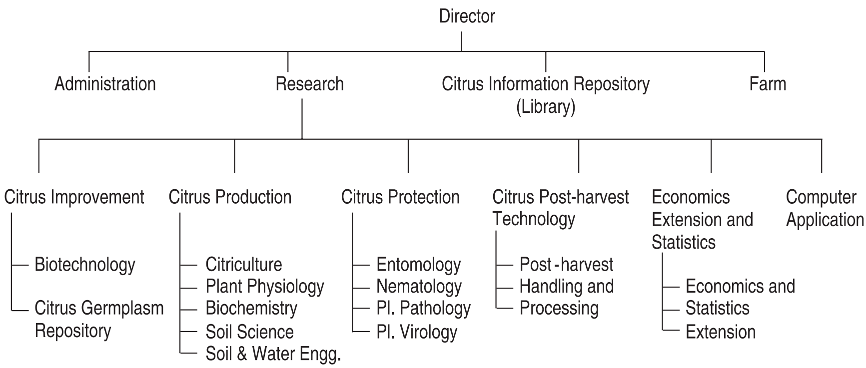
(*) Posts sanctioned but not created.

Staff

Staff position as on date at Central Citrus Research Institute, Nagpur

Sr. No.	Category	Post sanctioned	In position
1	Director (RMP)	1	1
2	Scientific	20	16
3.	Technical	20	20
4.	Administration	11	9
5.	Supporting	17*	11
TOTAL		69	57

*(11+6 ADRP)



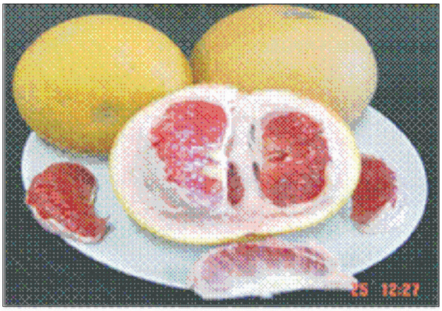
Research Contributions of the Institute

Germplasm and Improvement

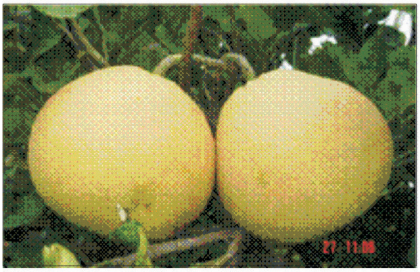
- The germplasm repository of Institute has a total of 614 accessions of citrus including 23 rootstocks from exotic sources (from U.S.A. and Australia), 552 from indigenous sources and 39 scion cultivars (mandarin, sweet orange, grapefruit and pummelo from U.S.A., France, Japan and Niger).
- Two clones-one with less seeds and another with early maturing traits have been identified and are being further evaluated under AICRP. Besides, 55 superior clones of Nagpur mandarin, 12 of Acid lime, 5 of 'Mosambi' sweet orange and 6 of pummelo have been identified.
- Shoot tip grafting (STG) method has been standardized for cleaning the scion mother plants of virus for utilization in production of disease free planting material.

- A technique of micro budding on young citrus root stock measuring 3mm has been standardized.
- *In-vitro* regeneration protocol has been standardized for *Citrus limonia* Osbeck and Rangpur lime (Gonicoppal and Brazilian) with 50% survival in sterilized soil mixture (soil, sand and cocopeat).
- Protocols for production of disease-free quality planting material of Nagpur mandarin, acid lime and Mosambi orange and distribution of the material have been standardized.

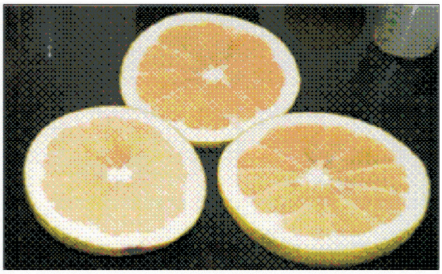
NRCC Pummelo - 1



NRCC Pummelo - 2



NRCC Pummelo - 3



NRCC Pummelo - 4

Promising clones of Pummelo selected by CCRI, Nagpur

Crop and Resource Management

- Rejuvenation technology for declining orchards of citrus standardized through multidisciplinary approach. Severely affected (>80%) private orchards were rejuvenated successfully within two years with yield of 13 t/ha in the 2nd year itself.
- Leaf sampling techniques were developed for Nagpur mandarin and acid lime. Using the same technique, cultivar specific database was generated across citrus belts. Leaf nutrient standards for major citrus cultivars viz; 'Nagpur', 'Khasi' and Kinnow mandarins; Mosambi, Malta and Sathgudi sweet oranges and acid lime were developed.
- Comprehensive soil suitability guidelines were developed for major citrus cultivars grown in the country.

- A comprehensive fertilizer schedule from pre-bearing to bearing Nagpur mandarin and acid lime orchards was developed for higher fertilizer use efficiency. These studies were further fine-turned through site specific nutrient management using geospatial tools.
- Citrus rhizosphere specific microbial consortium developed and evaluated under nursery as well as pre-bearing orchard. The results were highly responsive in terms of fruit yield, quality and soil carbon accreditation.
- Two pre-emergence applications of Diuron at an interval of 120 days controlled the weeds upto 300 days besides effective studies on post-emergence weed control.
- Technology for fruit drop control and fruit size improvement were standardized.
- The soil factors causing irregular flowering were identified and reversal mechanism using growth retardant were worked out for Nagpur mandarin.
- The root CEC was observed as an effective parameter as a marker for evaluation of vigour of different citrus rootstocks for pre-evaluation at nursery stage. The root CEC further acted as an index for ranking the salinity tolerance.
- The rootstock Alemow was identified as most promising rootstock for Nagpur mandarin as well as acid lime for improved quality production.
- Fertigation scheduling based on pan evaporation and available water capacity of soil were developed for Nagpur mandarin and acid lime which helped in reducing the fertilizer doses. Effective K-source through K-fertigation were also identified.
- Drip arrangement system (emitters on single lateral in octagonal arrangement followed by 4 lph inline emitters at 0.60 meter spacing on the lateral and double lateral arrangement 3 feet apart from trunk) under the tree canopy was worked out with best result through micro-jet irrigation system.

Soil application of Microbial Consortium (MC) Control

Soil application of MC+Foliar application of Vm Control

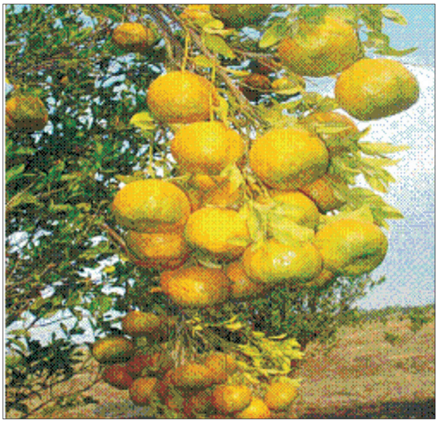
Containerized citrus nursery for disease-free planting material with five–star accreditation rating at CCRI, Nagpur

STG derived disease free planting material ready for release

Declined orchard of Nagpur mandarin

The same orchard after rejuvenation

Smooth Bud Union of Nagpur mandrin on Alemow (*C. macrophyllo*)



Fruiting behaviour of Nagpur mandarin on Alemow rootstock

- Automatic irrigation schedule for Nagpur mandarin was developed.
- An effective method of soil water conservation through black polythene mulch (100 micron thickness) was worked out in mandarin and acid lime.
- An effective method of drainage as surface bedding drainage system

(broad bed furrow) was worked out to avoid water logging in citrus orchards.

- Critical growth stages in Nagpur mandarin were worked out with regard to both nutrient and water use efficiency.

Plant Health Management

- Population dynamics, seasonal incidence, losses caused etc. studied with regards to citrus blackfly, psylla, leaf miner, aphids, thrips and mites.
- Chemical control schedules for major insect pests standardized.
- Biological control identified in case of blackfly, psylla and leaf miner and multiplication techniques developed in some cases.
- Standardized mass multiplication technique of a chrysopid predator, *Mallada boninensis* Okamoto and its field release @30 larvae/tree twice in each season effectively reduced citrus blackfly, psylla and leaf miner.
- Surveyed and the major pest complexes identified Central India, Kinnow, Khasi mandarin and sweet orange areas of Marathwada (Maharashtra) and Andhra Pradesh.
- A pest management module comprising of clean cultivation + release of *M. boninensis* @30 larvae/tree followed by foliar sprays of sweet flag (3%), *Verticillium lecanii* @5g/l water at weekly intervals + trap crop – *Murraya koenigii* on border lines reduced psylla and blackfly population.
- Citrus nematode, *Tylenchulus semipenetrans* was observed to be the most prominent in 73.7% Nagpur mandarin orchards and the occurrence of maximum nematode population in January and February months at 20cm soil depth vertically and 100 cm radially from trunk.
- Molecular diagnosis technique has been developed for *Phytophthora nicotianae* and *P. palmivora* causing root rot, foot rot and gummosis disease.
- Two sprays + drench treatment either by Fosetyl (Aluminium) (2.5g/l of water) or Mefenoxam MZ (2.5 g/l of water) covering the whole plant canopy and basin of affected plant at 40 days interval from onset of monsoon provided significant control to root rot and gummosis disease.
- Pruning and destruction of infected twigs followed by three to four sprays with copper oxychloride (COC) 0.3% + streptocycline 100ppm at monthly intervals after the onset of monsoon effectively reduced citrus canker in acid lime.

Eggs

Feeding on leaf miner lava

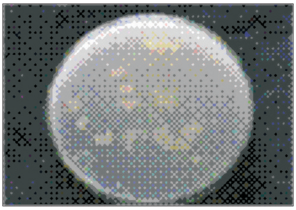
Feeding on psylla mymphs

Feeding on mealyoug

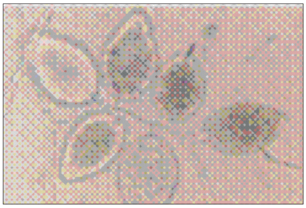
Mallada desjardinsi (Navas)

Diagnostics

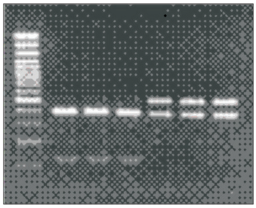
Phytophthora



Isolation



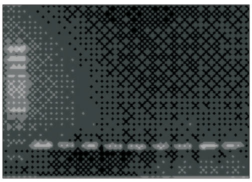
Marphology



Molecular

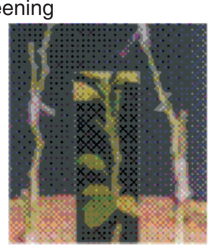
Canker

Isolation

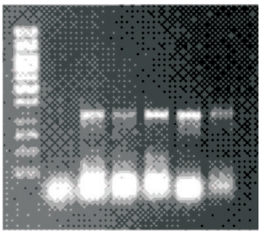


Molecular

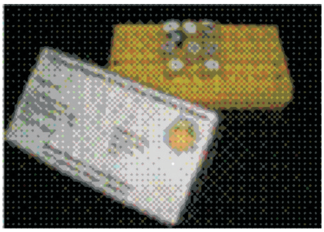
Greening



Bio-indexing



PCR



Diagnostic Kit

- A PCR-based rapid molecular indexing technology has been developed to screen mother plants and nursery plants for the presence of graft-transmissible pathogens (*viz.*, CTV, greening, ring spot and mosaic) for "Production of disease free planting material".

Post-harvest Management, Processing and Value Addition

- Post-harvest losses can be reduced substantially three pre harvest spray of Carbendazim @ 1000 ppm at 15 days interval before harvest.
- Nagpur mandarin fruits having minimum TSS of 10% and TSS/ acidity ratio of more than 14 can be harvested with desired quality.
- Designed a 1 ton capacity de-greening chamber. Nagpur mandarin fruits could be de-greened with 5 ppm ethylene and Mosambi fruits requires 5-10 ppm ethylene up to 48 hrs to get de-greened at 26-28°C and 90-95% RH.
- Standardized the mechanized processes of sorting, washing, wax coating and size grading on 1 t/hr capacity packing line for mandarins, Mosambi orange and acid lime.
- Packaging containers of corrugated fibre board (50x30x30 cm size) were designed and packaging method standardized in vented polyethylene substituting conventional wooden packing for long distance transport.
- Coatings with Carnauba wax (10%) gave desired shine and decay control up 3 weeks in Nagpur mandarin fruits at ambient condition.
- Pre-cooling at 6-7°C with 90-95% RH reduce the losses during refrigerated storage using vented corrugated boxes. Pre-cooling unit

Corrugated fibre board container designed at CCRI, Nagpur for Nagpur mandarin

Nagpur mandarin juice powder developed at CCRI, Nagpur

with 1/2 ton fruit holding capacity has been developed for forced-air cooling.

- The wrapping (individual fruit as well as tray over-wrap) of Nagpur mandarin and Mosambi orange in "Cryovac" (D955 and BDF 2001) and polyethylene heat shrinkable film resulted in retention of natural freshness and flavour up to 3 weeks at 30-35^{0}C under ambient conditions.
- Refrigerated storage conditions at 6-7^{0}C temperature and 90-95% RH were found most suitable for Nagpur mandarin and Mosambi orange without any chilling injury.
- The low cost evaporative cool chamber (7.5 feet length x 6 feet width x 7 feet height, inside) with 1.5 ton fruit storage capacity has been developed to store citrus fruit up to 3 weeks.
- Beverage by blending carrot and Nagpur mandarin juice has been developed for better nutritional value.
- Nagpur mandarin juice concentration technique under vacuum has been standardized at 45°C temperature. Concentrate at the brix of 60°, 70° and 80° (6 to 8 times higher than 10°brix) were stored under ambient condition up to 90 days with desired sugar content and colour of the product.
- Dehydrated product of segments of Nagpur mandarin has been developed. Vacuum packed product could be stored for 6 months in poly and silver paper packing.

- Protocol for preparing juice powder from citrus fruits has been standardized.
- The recovery of pectin (jelly grade 200) peel with Aluminum precipitate method was 2.66% on fresh weight basis the peel oil recovery was 0.6% on fresh weight basis. The peel oil of Mosambi and acid lime was better in respect of aldehyde content.
- Feed prepared from de-oiled Nagpur mandarin processing waste contained nearly 8% protein, 20.57% sugar and 7.8% fiber. Feed mixed in broilers diet @ 10% by replacing maize with and without pellets cost without affecting broilers weight.

Extension Education

- The principle force of technology adoption was found to be rationale of technology. Innovative traditional practices in citrus being economical, easy to adopt and locally perfected made it more acceptable than the modern recommended practices.
- In view of marginal and small land holding and the financial crunch, farmers were seriously constrained to adopt the recommended technology package.
- CCRI developed technologies such as Rejuvenation of declining orchards, fertilizer (stage wise) schedules, leaf and soil testing methods, fruit drop control and fruit size enhancement, insect pest and diseases management, post harvest technologies e.g. packing line, cardboard telescopic boxes for fruit for distant market etc.

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Challenges

Climate Change

India is one of the 27 countries which are more likely to be affected by the impact of climate change with citriculture being no exception experiencing serious consequences in all aspects of its crop production, protection, fruit quality and processing.

Climate change is not local but global, however, the variability in climate change in different citrus growing belts is of different magnitude. Hence, the issues of climate change on citriculture need to be handled at local level in order to harness an ensured sustainability in quality production. However, it is not easy for a citrus orchardists to respond promptly in order to change crop, species or variety under climate change situation. This needs a thorough understanding of the future patterns of climate change at a regional level and act accordingly. While the future climate change will dictate the choice of different combat technologies, the present day situation is to be handled carefully for meeting the current demand of citrus fruits. This not only demands for deeper study on climate change scenario but also on its impact on factor productivity. Therefore, the challenges ahead are to have sustainability and competitiveness in addition to achieve targeted production in the environment of declining land and water resources coupled with climate change.

Rise in Temperature

Inter-Governmental Panel on Climate Change (IPCC) in its recently released report has reconfirmed that the global atmospheric concentrations of carbon dioxide, methane and nitrous oxide, greenhouse gases (GHGs), have increased markedly as a result of human activities since 1750. Increase in GHGs have resulted in warming of the climate system by 0.74°C between 1906 and 2005. Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the record of global surface temperature (since 1850). IPCC has projected that temperature increase by the end of this century is likely to be in the range of 2 to 4.5°C. It is projected that rainfall over India will increase by 15-40%, and the mean annual temperature will increase by 3-6°C by the end of 21st century. Such changes in climate will affect citriculture through direct and indirect effects.

Rise in CO_2 Level

Increase in CO_2 up to 550 ppm is expected to enhance the yields of most of the field crops. However, it is postulated that in the long run, including citrus there will be decrease in the yield levels with rise in temperature and CO_2. Tree fruit crops are expected to perform well even in the rising CO_2 and temperature levels to a greater extent. Scientific evidence suggests positive effect of increase in atmospheric CO_2 in citrus having C3 photosynthetic pathway promoting their growth and productivity. Increased CO_2 may increase photosynthesis efficiency and thus increase water use efficiency. However, the positive effects will be counteracted by increase in temperature. Rise in temperature will reduce the crop duration, increase in respiration rate, alter photosynthate partitioning to economic product, alter phenology of flowering, fruiting, hasten senescence, fruit ripening and maturing besides altering the population dynamics of pest diversity. However, measures to adapt to these climate change-induced variations are critical for sustainable production.

Rising carbon dioxide levels due to anthropogenic greenhouse gases, may have both, detrimental and beneficial effect. The overall effects of climate change on citrus will depend on balance of these effects. In this background, vertical growth in citrus production will have to be achieved through efficient nutrient and water management. Effective plant canopy management and plant health management are the approaches to develop climate resilient production management strategies. Nonetheless depleting rainfall pattern in some regions will dwindle the storage in water reservoirs necessitating the need for adoption of modern methods of micro-irrigation as well as developing new technologies for water conservation and sustaining the production levels.

Erratic Precipitation

For more than a decade now, rains have been playing truant during most of the monsoon seasons resulting into complete/partial loss of the crop. Although there may not be the reduced precipitation but its uneven distributions is a matter of concern. Maximum rainfall in shorter span of time leads to flooding, heavier run off and lesser percolation. Similarly delayed monsoon or its early withdrawal pose a serious threat to the crop. It would also offer more opportunity for rain water harvesting due to high intensity rainfall but greater loss of top soil due to erosion would be a fallout.

On the other hand, prolonged winter followed by abrupt rise in temperature to 38-40°C right in the first week of March leads to heavy flower and fruit drop. 'Off season' hailstorm during March – April has been observed in several seasons during past decade. These climatic changes have already started showing explicit adverse effect due to incidence of insect pests and diseases. Thrips, mites and mealy bugs have taken centre stage whereas, the problem of Phytophthora has increased.

Ecological Diversity

The characteristic feature of citrus industry is that it is spread across the diverse ecological conditions. Hence, there is a need to increase research efforts as per the changing requirements of different citrus growing regions.

Deteriorated Ecosystem

Degraded, nutrient deficient, marshy or submerged lands along the canal system, salinity problems, higher levels of CO_2, poor organic matter content, regular and excessive use of pesticides may add to the environmental pollution, health hazards and can disrupt ecological balance of insect pests and their natural enemies. Excessive use of fertilizers in coarse textured soils may result into ground water pollution particularly through nitrate leaching.

Shrinking Land and Water Resources

Citrus plantations in central India are suffering on account deepening ground water table. Government was compelled to declare newer areas as 'dark zones' in the recent years. Continuously deficit precipitation for three to four years has been mainly responsible for large scale wilting of citrus orchards in Central India during the first few years of this century. Recently, in Marathwada region, Mosambi orchards have dried on a large scale due to water shortage.

Theoretical and climate model studies suggest that, in a climate that is warming due to increasing greenhouse gases, a greater increase is expected in extreme precipitation. This is because extreme precipitation is controlled by the availability of water vapour, while mean precipitation is controlled by the ability of the atmosphere to radiate long-wave energy to space, and the latter is restricted by increase in greenhouse gases. Land area is shrinking due to rapid industrialization and urbanization. Thus, soil and water conservation and maintenance of soil fertility for sustainable production are major challenges.

Loss of Biodiversity

Global concern about loss of valuable citrus genetic resources prompted international action. The reasons for this loss include deforestation, developmental activities such as hydroelectric projects, urbanization, changes in agricultural practices coupled with introduction of new uniform varieties and zoom cultivation in NEH region. This situation has led to a more systematic, globally coordinated approach for collecting germplasm and effective, long-term conservation of plant genetic resources. Programs for conservation of plant genetic resources were initiated and gene banks established in many countries. Monitoring of storage and viability of seeds in gene banks have been initiated as the plant breeders and crop curaters frequently use the gremplasm for breeding. The main objective was to develop linkage between conservation and use of genetic diversity to ensure its continued availability.

Surveys have indicated that most of the plantations of sweet orange are infected with greening bacterium while the same pathogen has been found in some orchards of Nagpur mandarin in Central India also. Similarly, *Phytophthora*, citrus canker and Citrus Tristeza Virus are major diseases in nursery and fields. While leaf miner, fruit sucking moths, thrips and mites remain to be serious pests throughout the country, trunk borer, fruit fly and citrus psylla are specific for 'Khasi' mandarin. All these factors may be responsible for causing citrus decline and loss of biodiversity.

Pest and Disease Complex

Altered rainfall patterns cause drier regions in conventionally humid areas and ecosystem shifts could bring about biome changes. Outbreak of pest like caterpillars could become overwhelming in unconventional areas. It has been projected that termites and white grubs could become more serious due to changes in soil moisture and temperature. It is likely that changes may occur in the temperature dependent insect behavior and population dynamics leading to escalation of populations and the pest activities of many insect groups. Changes in host plant phenology, flowering and growth patterns of host plants will create serious imbalance in the insect-host-plant relationships and their tri-trophic interactions. These changes are projected to alter the bionomics of insect pests; the impending changes in the abiotic factors and consequent impacts on the biotic factors could create cascading effects.

Trade and Competitiveness

Value addition in fresh fruits is achieved by extraction of juice and preserving it in various forms including concentrate/semi-concentrate and juice powder without loss of natural flavour and nutritive value. Utilization of processing waste from citrus industry for manufacture of quality products like pulp and peel fiber, essential oil and essences, pectin, flavonoids and bioconversion products (alcohol and methane) would not only ease the problem of waste disposal but also provide monetary returns. The unique geographical location and cropping systems in India make European, Gulf and South East Asian markets accessible to Indian citrus. Climatic conditions to grow fruits almost year round offer very good opportunity to tap overseas markets in changing world scenario. Citrus growing countries of southern hemisphere can produce citrus during March to September when it is summer in India, however, these countries mainly grow sweet oranges. Therefore, export oriented production of popular mandarin varieties would be a boon to citrus industry in the country. There is a tremendous scope for export of Kinnow from Punjab due to its demand in Gulf countries, Mauritius and South East Asian countries. Since Pakistan has exported more than 1.5 lakh tonnes of Kinnow to Gulf and south-east Asian countries during 2006-07, there are good export opportunities for India in these markets. Export quality Indian mandarin production is hardly around 8-11% of total citrus fruits which can be increased to 30% by adoption of new technologies.

Absence of organized and regulated marketing system and conventional handling of citrus fruit are other drawbacks which result in poor returns to the growers and therefore, insufficient investments. Poor processing and lack of storage infrastructure is a deterrent for farmers to increase production because prices crash in glut season.

In the coming years Intellectual Property Rights (IPR) and Sanitary and Phytosanitary (SPS) issues would come to the fore. Therefore, precision farming, refinement of technologies to the level of registration would be in demand. It will ensure and improve commercialization of technologies.

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Goals/Targets

India with growing population is a big market for all types of products including industrial, agricultural and other natural products. Improving economy, better health awareness and changing food habits and lifestyle of the people will push-up the demand for fruits. Citrus fruits have major role in the human diet due to high vitamin 'C' content, vitamin 'B' viz. niacin, pantothenic acid, antioxidants, flavonoids and limonoids thereby providing nutritional security. Demand for by-products such as pectin, fiber, flavonoids is likely to increase which would fetch handsome price.

During last fifty years, although citrus production increased due to expansion in area, the further increase in area of that magnitude may not be possible in coming 35 years (up to 2050) due to shrinkage in critical natural resources like land and water. But the technologies for increased nutrient and water use efficiency will be developed, transferred and adopted by the growers. Input costs are going to be higher and hence increased input use efficiency will be the key for increasing production at lower costs.

With annual growth rate of 6-7% during 1992-93 to 2010-11, it appears that estimated growth rate of 5per cent can be easily achieved with the help of strong technological support emanating from research programmes in the country. This is likely to enhance citrus production by 175% in next 35 years which would be sufficient enough to meet the domestic demand and exports requirement. The citrus yield is projected to be 20.59 million tonnes (Table 2) with productivity of 15-16 tonnes/ha by 2050. Accordingly, the per capita availability of citrus fruit will be 12.65 kg.

Table 2 Projected area and production of citrus in India

Citrus type	Area (Lakh ha)			Production (Lakh tonnes)		
	1992-93	2010-11	2050	1992-93	2010-11	2050
Mandarin	1.66	3.24	4.80	13.40	32.55	72.00
Sweet orange	1.10	1.57	4.00	8.93	13.16	60.00
Acid lime and lemon	0.93	2.19	3.80	7.46	21.08	57.00
Other citrus fruits	0.17	1.46	1.70	3.90	7.90	16.90
Total	3.86	8.46	14.30	33.69	74.69	205.90

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Operating Environment

Citrus research and growth of citrus industry in the country will have to sustain in variety of operational environments in the years to come.Therefore, multiple demands will have to be fulfilled through linkages, collaborations, strong public relations and research strategies for targeted outcomes. A better linkage of researchers-entrepreneurs-growers-funding agencies is anticipated to address demand driven researchable issuesfor the progress of Indian Citrus Industry.

Exploiting rich biodiversity of citrus is one of the prime options in citrus improvement. CCRI through its long term approach has been able to possess core collection of citrus germplasm including those of cultivated, wild and semi-wild types from all parts of India which are otherwise threatened and some are at the verge of extinction. Such core collection of germplasm will serve as an important resource for exchange of promising germplasm with other citrus growing countries. Molecular characterization of these accessions and genomic studies will be useful in quantitative trait loci (QTL) analysis and further marker aided selection (MAS). Genomic studies will also be useful in development of transgenic citrus resistant to biotic and abiotic stresses. Similarly, diversity in insect bioagents, microbial antagonists and plant growth promoting rhizosphere microorganisms could also display promise, much to the benefit of citrus industry. To accomplish these mega objectives, operational support need to be planned through national as well as international linkages for better commercial competitiveness.

Loss of aerable land and water resources owing to urbanization and infrastructure development is a major cause of concern. Growing population and intensive agricultural practices are leading to contamination and pollution of land, water and air thus threatening human and animal health. Climatic changes especially droughts and floods are further worsening the situation.

Intellectual property rights need also to be protected in coming years. Active collaboration between academicians, researchers and industrial community backed by sound operational environment would find an amicable solution of the related problems.

The various components of operational environment in the future are highlighted as below:

Political

At present there are hardly any political issues to be addressed involving institute's mandate. On the other hand, this institute over the years has developed a close linkages/relationship with most of citrus growers, their associations and societies, public representatives and bureaucracy to address issues faced by them. All concerned appreciate the work done by the institute to tackle problems related to citrus cultivation, handling and marketing. Regional problems of Kinnow, Coorg and Khasi mandarin cultivation or Mosambi and Sathgudi cultivation and utilization may become local political issues and the institute is expected to address them. Better funding and manpower provision to the institute would definitely improve its presence in all citrus growing areas of the country. Apart from this, eco-friendly less polluting technologies with better input-use efficiency for reduced cost of cultivation may attract attention of politicians and growers in general. Adaptation and mitigation technologies to counter challenges posed by climate change need to be developed to avoid them becoming a major political issues.

Economical

- Greater investments with respect to funding and manpower to achieve research objectives is imperative keeping in view need of biotechnological, physiological, biochemical and sensor based high–tech research in coming years.
- Introduction of germplasm from outside sources would become all the more expensive and difficult with protected varieties and rules of IPR and WTO regimes.
- Developing cost-effective technologies suiting to small citrus orchardists is a major economic issue for sustainability and economic feasibility of citrus cultivation. Low cost technologies which are simple and easy to adopt would go a long way in sustaining citrus production and wider technology adaptation and implementation.

Socio-cultural

- Citrus is grown in tribal areas of north-eastern region since centuries and it is a part of their community culture and source of living. Citrus germplasm is threatened with modernization and urbanization. There is a greater need to conserve and utilize citrus for better economic return and nutrition of tribals.
- Citrus fruit have many nutritional and health promoting properties. For nutritional security of growing population in the country, citrus

would play important role if proper promotion campaigns of citrus processed products are carried out and popularization/publicity of fruits like grapefruit and pummelos is undertaken.

Technological

- Expertise in important areas like biotechnology, bioinformatics, genomics, plant physiology, biochemistry, Geoinformatics, genetics and breeding, food processing, engineering, and chemistry would go a long way in developing need based technologies through multi-disciplinary research. This will usher in sustainable quality production with desired precision.
- Technological developments in areas of nano-technology, ultra high density planting with sensor-based pulse irrigation/fertigation, in-vitro conservation and cryo-preservation in-vivo conservation of germplasm, development of seedless/late/early maturing and processing varieties, synthesis of semio-chemicals/pheromones/ kairomones, distribution of bioagents for field release, use of microbial consortium for soil health/resilience, microbial antagonists for combating soil borne pathogens (especially *Phytophthora* induced foot and root rot disease) would meet needs of the citrus industry in the future.

Environmental

- Sustaining citriculture in the context of climate change will be the major challenge in coming years.
- Resurgence of insect-pests and diseases will involve grater effort in increasing citrus production and productivity.
- Acceptance and field evaluation of bioengineered citrus particularly that has toxin producing gene for resistance could become debatable issue.
- Use of chemical fertilizers, toxic chemicals and pesticides in intensive citrus production and post-harvest management may lead to controversies and hence cautious approach will have to be adopted while developing technologies.
- Quarantine issues such as introduction of alien pathogen and insect-pests through fruit or planting material and their threat to citrus industry in the country would have to be handled carefully.

Stakeholders

- Various stakeholders who will be active partners in citrus industry will consist of ICAR institutes, State Agricultural Universities, Internationally renowned organisations involved in citrus research, Industries dealing with Fertilizers/pesticides and other inputs, growers associations, private nurseries, NGOs, individuals, KVKs and private companies. They will either individually or collectively influence the operational environment.

- The conducive operating environment could be established with updated infrastructural facilities well backed up by competent scientific and technical manpower, better affiliation with farming community, congenial working atmosphere to maximise output, establishment of state of art referral laboratories, bringing funds from outside sources through consultancy/contract research projects and introducing the concept of awarding best technical staff award at institute level to encourage quality research work.

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New Opportunities

Biotechnology, Genetics and Breeding

- Functional genomics and phenomics based gene identification for specific trait and gene pyramiding to have cultivar of multiple resistance on one hand and identifying genes for some negative traits like genes leading rootstock vulnerability to *Phytophthora*, drought tolerance, nutrient deficiency etc. on the other.
- Exploiting biodiversity via extreme biotic and abiotic conditions, subjecting the promising landraces to whole genome sequence and newer genes. Marker aided selection out of existing diversity for useful traits.
- More number of seeds in citrus fruits are a really limiting factor for consumers and bottleneck in export. Existing citrus cultivars in the country are unsuitable for processing. Hence, seedlessness is an important breeding objective of most of the scion cultivar improvement programmes, but production of quality seedless triploid citrus via interploid crosses has historically been limited by low quality of available tetraploid parents. Production of tetraploid hybrid parents from elite diploid scion cultivars via protoplast fusion is now a practical strategy and numerous hybrids can be produced on a timely basis from a wide range of interploid crosses. In this context, autotetraploid breeding parents through colchicine induced chromosome doubling and allotetraploid somatic hybrid breeding parents via somatic hybridization could open new opportunities.
- Anti-oxidant and neutraceutical profiling of citrus germplasm could be new objectives in citrus breeding programme.
- An engineered rootstock capable of withstanding both biotic as well as abiotic stresses, besides fitting well into high density planting will improve factor productivity of citrus orchards.

Canopy Management and Crop Regulation

In citrus, growth and development are complex processes that are controlled by various factors in time and space including internal and external factors. Optimum yield is a function of planting density, canopy size, potential for reproductive growth, intensity of flowering, fruit set, size and harvest at maturity. Planting density is optimized with tree size control which can be achieved by genetic manipulation and also with horticultural techniques like tree architecture management using pruning and plant bio-regulators. Regulation of flowering and fruit development can be achieved by understanding endogenous factors like carbohydrate reserve, hormonal balance and exogenous manipulations. Interaction of environmental and hormonal factors is likely to play important role in citrus flowering, fruiting and fruit quality in coming years. Higher planting density and crop regulation management and understanding of tree physiology could be key issues in increasing productivity to desired level.

Natural Resource Management

- The growing importance of natural resource management in citriculture requires a reversal of current resources degradation in key areas. Exploiting natural resources both horizontally and vertically will be an urgent need through citrus based multi-tier cropping in areas where this crop is grown as mixed cropping. In addition, floor management will be the core agenda with emphasis on off-site resource movement and zero tillage. Turnover of soil carbon, nutrient and microbial load in such system will be a true challenging task as a climate resilient technological option.
- Considering the complexity involved with the analysis of microbial diversity in soil, there is a need to understand the freshwater microbial diversity. Culture independent methods of assessing soil microbial diversity such as PCR-based methods, alternative methods to PCR approaches (examining physiological or metabolic characteristics of microbial communities) are yet to be worked out. Studies are yet to be initiated focusing on the rhizosphere microbial diversity versus plant nutrition or fruit quality issues. Microarray technology will soon enable us to assess the community diversity in soils by directly exposing and hybridizing oligonucleuotides fixed on membranesin addition to relating community structure with community function using messenger RNA combined PCR amplification.
- Studies on gene expression in the rhizosphere soil can permit a better understanding of processes such as biological control, stimulation of microbial activity by root exudates, competition between microorganisms and roots for nutrients, molecular colloquia, between microorganisms, between roots, and between roots and microorganisms. Techniques for extracting and characterizing mRNA from soil are now available whereas soil proteomics is still in its

infancy. An advancement in linking between functional activity to community structure has been obtained by applying stable isotope probe to soil. Reporter technology has been used to assess several functions in the rhizosphere soil including gene expression even at the single cell level. The ever increasing knowledge of the promoter and regulator gene along with the refinement of reporter gene insertion techniques will allow using the reporter gene technique for monitoring induction, expression and regulation of virtually any gene in the rhizosphere.

These studies will lead to understand:

- Induction of shifts in microbial communities by altering the micro-environment,
- Isolation of specific microorganisms or group of micro-organisms for signature markers and then detecting the signatures after induction,
- Detection of shifts in microbial community nutritional status with alteration in the environment,
- Detection of specific micro-organisms and their activity and,
- Consequences of specific predation on the composition and diversity (community structure) in soil microbial communities.
- Mechanisms need to be explored to inject micronutrients straightway into the transpiration stream via process called " Trunk Nutrition" or some biomolecules which act as complexation agent that can add enhanced mobility to otherwise immobile micronutrients within the plant.

Nutriomics and Nutrient Use Efficiency

- Development of nutriomics in relation to functional food is becoming an imperative issue for human health. Role of functional genomics to understand metabolic pathways and regulatory mechanisms of related genes in various biomolecules of citrus fruits will offer newer opportunities of developing nutrient rich citrus based products.
- The currentbreeding efforts are mainly implemented through simple selection of biomass or yield in the field. Biomass or yield selections in the field are not only costly but also subject to confounding environmental interactions and spatial heterogeneity. Therefore, it would be preferable to identify and select specific traits that are directly related to a specific nutrient efficiency. Once clearly identified, these traits could be used for more efficient screening in controlled environments, or tagged with molecular markers and improved through markerassisted selection or gene transformation. Useful traits for nutrient efficiency may be associated with altered

physiological and biochemical pathways in adaptation to nutrient stress. Specific nutrient-signalling pathways, such as Pi-signalling and their regulatory systems in plants have been revealed, making it feasible to modify some key regulator(s) to enhance the uptake and use efficiency of the nutrient through genetic engineering. However, systemic mechanisms might be involved in adaptation to nutrient stress at the whole plant level. The fact that many of the molecular and biochemical changes in response to nutrient deficiency occur in synchrony suggests that the genes involved are coordinately expressed and share a common regulatory system. Therefore, systematic studies are needed to understand the genomic, transcriptomic, proteomic and metabolomic aspects of nutrient efficiency. This area of study is termed 'plant nutriomics', a new frontier of plant biology that is attracting more and more attention by the researchers worldover.

- Sensor–based Decision Support Systemusing the soil fertility variograms vis-a-vis major production zone is another opportunity towards improved nutrient use efficiency. The steps involved will consist of :
  - i) Development of spatial soil fertility variogram (by using GPS and GIS database) as decision support tool for precision fertilizer recommendation
  - ii) Development of SSNM strategy and evaluation through long term field experiments
  - iii) Development of logical relationship between canopy volume and fertilizer requirement and
  - iv) Identification and evaluation of variable rate fertilization for possible improvements in fertilizer use efficiency through field experimentation.Non-destructive method of identifying nutrient constraints using hyper-spectral analysis will further perch the citrus fertilization programme, a way forward and more importantly, it will address the constraints in a standing crop.

Improved Plant Nutrition Verses Changes in Antioxidant Profile

Fruit anti-oxidant content may depend on plant nutrition.This is another potential area which will involve:

i) Field identification of different soil and plant nutrient deficiencies and their profiling for different antioxidants.
ii) Evaluation of changes in anti-oxidants in response to different nutrients in a progressive nutrient field experiment and
iii) Establishment of relation between antioxidant system with indices of drought tolerance.

- *In-situ* conservation of rain water through watershed based citriculture backed up with zero tillage in order to minimize the burgeoning load on ground water.

Stress Physiology

- Alternative to water stress through studies involving intermediary metabolites.
- Development of climatic analogues in relation to stress induced physiology of flowering.
- Identification of physiological processes involved in low temperature induced stress versus water deficit stress.

Plant Health Management

Insect Pest Management

Thrust will be given on use of semiochemicals (Pheromone and repellants for insect pests; attractants for bioagents), induced resistance, Insect Growth regulators (IGR's) and bio-control agents including entomopathogens against major citrus insect pests, Development of semi synthetic diets for the mass multiplication of chrysopids and coccinellids, conservation of bio-agents, digital documentation of insect pests and bioagents and insecticide resistance management. Development of pest management modules using above mentioned tactics may lead to eco-friendly and cost-effective better management opportunities.

Combating *Phytophthora*

- Effective, rapid and user friendly diagnosis and detection of Phytophthorapathogens which infect citrus
- *In-silico* Mining: Exploiting the available molecular and Genomic resources of Citrus through *in-silico* mining of *Phytophthora* resistance specific QTLs and identification of putative markers linked to *Phytophthora* resistance.
- Association Mapping: Implementing WGAS (whole genome association system) with the available molecular resources to trace out putative marker-trait associations with respect to *Phytophthora* resistance.
- Identification of Avr genes from *Phytophthora* and R genes from citrus rootstocks.
- Understanding the infection process and disease development in relation to key variables (e.g. host, inoculum production and climate change).

- Comprehending the mechanism employed by bio-control agent Trichoderma to control *Phytophthora* in citrus.
- Improvement of efficacy of *Trichoderma* strains by genetic transformation
- Use of Hypovirulent strain of *Phytophthora* for disease control.

Post Harvest Management

- Automation and robotics in fruit harvesting.
- Development of quality standards for processed or value added products to ensure consumer safety against microbial contamination and environmental safeguard. In this regard, establishment of quality testing laboratory for citrus-based processed and value added products is important.
- Development of comprehensive information system on post-harvest management.
- Development of protocol based on advanced methods of storage like controlled atmosphere (CA) storage, modified atmosphere(MA) storage, ice bank coolers, hypobaric storage etc.
- Studies on pectin de-esterification and fruit softening with emphasis on comparing polyphenolic composition and antioxidant activity of fruit juice.
- Non-destructive analysis of fruit quality.
- Use of nano-technology (nano particles having cellulose-silver hybrid) for improved shelf life of packaged products.
- Role of phosphites (also termed as phosphonates, the salt of H_3PO_3) has been perceived as a new approach of extending fruit self life.

Strategy

In order to increase and sustainthe productivity of citrus orchards, a multi-pronged strategy consisting of research, infrastructure and human resource development, technology dissemination and industry/ stakeholder linkages is essential for holistic development of citrus industry in India.

Research Priorities

Development of high yielding cultivars (scion and rootstock) with desirable horticultural characters and resistance to biotic and abiotic stresses using frontier areas of biotechnology and molecular biology coupled with conventional improvement programme needs to be accentuated. Development of cultivar/region specific precision citriculture using high density planting, canopy architecture management, sensor based fertigation,nutrient and disease diagnostic kits, push-pull strategy based pest management modules etc coupled with soil health and organic carbon management will collectively lead to desired citrus production spurt across citrus growing belts of India. Focus on integrated pest and disease management by using eco-friendly control measures involving development of digital distribution maps, use of bio-agents, antagonists, botanicals, need-based chemicals, pheromone, pest and disease forecasting models etc would help in effective management of insect pests and diseases. Development of farmer- friendly diagnostic kits for timely prevention viral diseases, identification of exotic pests and accordingly, sanitary and phyto-sanitary (SPS) measures based on international standards to be made mandatory for boosting Indian citrus trade and industry. Development of package of practices for export of citrus fruits and exploitation of nanotechnology in reducing post-harvest losses and its effective use in processing and value addition coupled with farmer-friendly marketing and transportation bye-networking, market survey and surveillance could improve the net farm income substantially.

Research funding in line with commodity based box tax of USA to deal withcurrent problems being faced by orchardists may give a clue to the Indian policy makers for ways and means of fund collection and prioritizing research projects in association with growers. Research projects based on time frame and linked with on-farm technology demonstration after project completion will further enhance the quality of research and accountability.

Infrastructure and HRD

Establishment of Referral Laboratory equipped with provision for diagnosis of cultivars/varieties, nutritional constraints, insect pests and diseases (especially graft -transmissible viral and bacterial diseases) in each citrus growing region for facilitating early diagnosis of problems with effective remediation strategy is a need of the day. Quarantine issues with respect to diseases and pests and chemical residues in export and import material, genetic purity of scions, rootstock and planting material can be effectively addressed from such well equipped laboratory. Further, establishing facilities in each citrus growing belt for implementation of citrus bud-wood certification programme would result in production of healthy certified planting material across India.

Undergoing trainings in the cutting edge areas of research at world renowned research institutionswill help the scientists of the institute not only to improve their skills and knowledge but also improve the standard of research. Subsequently, it would help in the overall strengthening of the research programs which will be at par with the advanced research Centre's of the world and finally results in the growth and development of citrus industry in India.

Technology Dissemination

Organizing Researcher-Grower interface as annual feature to take stock of the progress and problems faced by the growers is further warranted in finding suitable practical remedies to emerging issues time to time. At the same time, it would highlight some useful researchable issues to the citrus researchers in terms of real practical application.

On-farm demonstration of developed technologies with cost-benefit ratio results in effective dissemination and adoption of technologies by growers with the help of researchers and extension personnel. Kiosk with touch screen expert system in the local language and website-based information along with 'Kisanmela', 'Orange Day', on-spot advisory service etc. will further boost the process of dissemination of developed technologies. Development of mobile phone based network between growers and researchers for sending disease symptoms from field would help in taking timely and effective management decisions.

Establishment of Model Citrus Nursery utilizing the elite mother stock, biological and molecular indexing, containerization, solarized potting mixture and high budding in each district is necessary so that concept of commercial nursery on scientific footing percolates down to end users. This will lay the sound base of healthy citrus industry of tomorrow. Establishment of Model Citrus Orchard in each district, preferably at Govt.'s premises would motivate citrus growers at large scale about the ideal citrus cultivation. Establishment of Demonstration Trial on Rejuvenation of Declining Citrus Orchards on the lines of latest available technologies in at least 2 locations (1 each at Govt. farm and progressive citrus grower) in each district in order to demonstrate the longevity of citrus orchard with best management practices (BMP) will instill the confidence among citrus growers about the technology intervention.

Linkages with Industries/growers

Development of area-wide projects in Public-Private Partnership mode involving researchers, private firms and growers would help in the faster development of Indian citrus Industry. As Indian growers have a small land holdings and farming is monsoon dependent, contract farming of citrus orchards over a large area involving private firms with buy-back arrangement may be given emphasis to increase the farm income.

Conducting contract research for testing products of private firms and providing consultancy services to the private industrial units engaged in citrus handling, storage, export would help in not only generating the resource for the institute but also benefit the concerned laboratory/ discipline and the staff in generation of information.

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Vision 2050

Mission

The mission is to increase overall citrus production of quality fruit and per hectare productivity with intervention of innovative and high-tech citriculture technologies. Sustainability, environmental protection and risk management are the key safeguarding factors for future growth of citrus industry.

The inter-institutional collaborations and networks for research and development in citriculture will continue and further strengthened. The major focus will be on following aspects:

i) Genetic Resources and Crop Improvement

- Characterization and cataloguing of citrus germplasms using microsatellite molecular markers.
- Marker-aided-selection of citrus germplasm for useful traits e.g. less seeded, suitable for processing, tolerance to drought, floods, salinity and diseases.
- Rootstock improvement through protoplast fusion.
- Clonal selection for better yield and quality and ploidy manipulation for seedlessness
- Evaluation and barcoding of citrus germplasm.
- Hybridization for scion and rootstock improvement.
- Identification of germplasm tolerant to water stress (drought and flood).
- Evaluation of cultivars for increased CO_2 level and higher temperatures.

ii) Crop and Resource Management and Environment

- Evaluation of new rootstock and scion combination for biotic and abiotic stress management especially tolerance to drought, floods and Phytophthora root rots.
- Studies on crop phenology under changed climatic conditions, induction of flowering, crop regulation for assured Mrig crop of Nagpur mandarin and fruit quality management.
- Development of agro-techniques for high density planting in major citrus cultivars with emphasis on plant canopy management.

- Development of non-destructive hyper spectral sensor-based technology for nutrient stress sensing as an early nutrient deficiency detection technique.
- Substrate development and nutrient dynamics for rhizospheric changes in nutrient pool and their integration under INM module for nutrient turn over soil carbon accreditation.
- Expansion of DRIS indices and their validation to other commercial citrus cultivars and development of fertility diagnostics as per soil type.
- Development of SSNM into sensor-based DSS (Decision Support System) using variable rate fertilization (VRT) and improved fertilizer use efficiency.
- Development of protocol for organic citrus.
- Plant nutrition with respect to antioxidant system and drought tolerance.
- Irrigation scheduling with Infrared thermometry, pulse irrigation and regulated deficit irrigation and their integration under automated fertigation.
- Evaluation of new drip and micro-jet irrigation systems.
- Development of mitigation/adaptation techniques by addressing the issues of climate change from various biotic and abiotic factors influencing quality production.

iii) Integrated Pest and Disease Management

a) Entomology

- Development of Insecticide Resistance Management (IRM) based IPM for major pests of citrus.
- Refinement of chemical control using new insecticides and methods of application.
- Studies on the frugivorous pests of Nagpur mandarins and its management using push-pull strategy.
- Use of semio-chemicals particularly pheromones for insect pests and kairomones for bio-agents.
- Digital distribution maps of the major pests and bio-agents of citrus in India.
- Conservation of bio-agents in citrus ecosystems and their use in crop protection.
- Refinement of bio-agent multiplication methods.
- Use of botanicals/plant products for the management of citrus insect pests.

- Development of cultivar/region specific IPM modules for major citrus pests.
- Impact of climate change on insect pests dynamics of citrus.
- Development of forecasting system for citrus insect pests.
- Insecticide resistance management.
- Development of expert system for Citrus IPM.
- Field evaluation of bio-control agents for insect and nematode pests.
- Molecular characterization of important pests of citrus.

b) Plant Pathology

- Complete genome sequencing of citrus tristeza virus, citrus mosaic badna virus and *Phytophthora* nicotianae and citrus greening bacterium.
- Developement of rapid diagnostic kits for field identification of diseases.
- Developing VIGS and RNA-i mediated disease resistance against citrus viruses like CTV and CMBV
- Diagnostic method to detect multiple *Phytophthora* spp. in environmental samples & developing farmer-friendly ready-to-use on-site simple diagnostic tools.
- Species/strain specific detection and quantification of *Phytophthora* in host tissue and soil.
- Complete/whole genome sequencing of *Phytophthora* nicotianae for effective management of root rot, foot rot and gummosis in citrus
- Identification and molecular characterization of *Phytophthora* species and variants/strains pathogenic to citrus
- Diversity analysis by MLST using ITS, COX-I or II, elongation factor-1α, ß-tubulin and virulence genes in *Phytophthora* isolates.
- Search for efficient biocontrol agent and to frame an integrated management strategy for citrus *Phytophthora* diseases
- Molecular differentiation and genetic diversity studies of *Xanthomonas citri* pv. citri strains and searching for acid lime clone resistant to canker.
- Culturing citrus greening bacterium and development of diagnostic gold standards for citrus greening disease, virus and virus like diseases.
- Diversity analysis,characterization, documentation and conservation of *Phytophthora* spp. infecting citrus.
- Identification of Avr genes from *Phytophthora* and R-genes from citrus rootstocks.
- Identification of marker linked to *Phytophthora*-root rot resistanceand

improvement of citrus rootstocks for resistance against *Phytophthora* spp. using marker assisted selection approach.

- Understanding the mechanism of callus formation in gummosis infected citrus trees.
- Understanding the mechanism of *Trichoderma* to control *Phytophthora* in citrusand formulate an integrated management strategy for citrus *Phytophthora* diseases.
- Evaluation of new molecules, bioagents and integrated approach for management of *Phytophthora* diseases.
- Studies on pesticide resistance monitoring in *Phytophthora* diseases.
- Studies on other fungi involved in citrus decline
- Enhancement of detection sensitivity for low-titer pathogens like viruses (CTV, ICRSV, CMBV, CEVd) and greening bacterium using high through-put rapid diagnostic methods (viz, mPCR, qPCR (real time), DNA chips, Microarray)

iv) Post-Harvest Technology, Processing and Value Addition

- Evaluation of machines for automatic or semi-automatic harvesting.
- Development of eco-friendly treatments such as combination of antagonist with GRAS chemicals and physical treatment for better shelf life.
- Nano-composite packaging for fresh fruits and processed products.
- Value addition through aroma and flavour recovery using SFE technique.
- Evaluation of methods of juice concentration, juice powder and juice blending.
- Value addition and waste utilization of commercial citrus fruits
- Development of value added products using nano-technology.
- High pressure juice processing and citrus alcoholic beverage preparation.
- Development of integrated juice processing technology.

v) Transfer of Technology and Extension

- Working out economics of viable technologies.
- Seeking involvement of public and private organizations during 'Kisan Mela' and other extension activities
- Undertake trainings for the officials engaged in the citrus growing areas.
- Undertake feasibility study of contract farming in 'Nagpur' mandarin
- Technology dissemination and adoption through public-private partnership.

- Development of Citrus Information System.
- Transfer of technology through trainings, demonstrations, farmers' fairs, group discussions, meetings etc.

vi) ComputerApplications

- Mandarin/Citrus Information System.
- Citrus Germplasm Resource Information System (CGRIS).
- Citrus data base- Knowledge bank as an Open Access Repository.
- Technology dissemination

Future Scenario on Research Front

With the opening up of major centres of academic, research of the world and larger volumes of trades taking place in future, the meaningful and vigorous collaborations between the institutions would occur breaking the monopoly/isolated working climate. This is in turn bound to happen, leading to many revolutionary gains, dynamic reforms would become visible, resource constraints would be rudimentary, and outcomes would be positive benefitting the partners mutually, reinforcing the multifaceted collaboration. Accordingly, the vision must have the perfect setting so that the strategy stands the test of time and delivers the envisioned results.

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Way Forward

Bridging scientific and technological gaps needs utmost focus if India is to catch up with the productivity and orchard longevity witnessed in some of the developed countries like USA, Spain, Australia and South Africa. Citrus plantations in these countries are quite large backed up by technological intervention. Citrus industry in these countries is regarded as trade-related agri-business. On the other hand, in India, despite substantial scientific knowledge and extension programmes, the impact of technological intervention is slow on the citrus industry on account of poor network of technology transfer and adaption, hampered further through illiteracy, ignorance, and small land holdings. Such grass root level problems will have to be tackled through public-private partnership or private-private partnership so that greater investment is attracted from Non-government sources.

Citrus research has to be demand-driven and market-responsive. Therefore, research needs to be envisioned through multidisciplinary mode. Some of the issues like citrus decline, burgeoning menace of *Phytophthora*, lack of dwarfing rootstock for high density planting, depleted fertilizer and water use efficiency and soil carbon sequestration, compatible IPM module involving greater intervention of bioagents (predators and parasites), disease diagnostics and meagre processing are the issues that concern citrus researchers cutting across disciplines. A greater intervention of biotechnological tools (genomics, proteomics, transcreptomics), developing decision support system, application of geospatial tools and climate change resilient technologies have been portrayed more distinctively towards redressal of issues and strategies to be operated in years to come. While addressing these issues, emphasis has to be laid on conventional breeding, parallel to ongoing programme of clonal selection, protection and regeneration on a mass scale.

The collaborative research between ICAR and the institutes like CSIR, DBT, DST etc. and State Agricultural Universities needs a thorough revision, reorientation and better harmonization so that duplicity in research agenda is kept at bay and the envisioned goals only are made mandatory and pursued. Increased collaboration with national and international organization would be mandatory gradually side tracking the conventional R&D management and governance model. At this level, strategic partnership and alliances say public, private, international etc. will be unavoidable in order to resolve the years old knotty problems. Hence, striking a balance between futuristic research and problem solving research will be mandatory. Ultimately, multidisciplinary approach at all levels will be the need of the hour.

Human resource development and dissemination of innovative technologies would be the key to bring about change in research output and increase in citrus production as envisaged in goal for 2050, maintaining sustainability as a core issue.

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Laser typeset at M/s Print-O-World, 2568, Shadipur, New Delhi 110008 and printed at M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110 028.