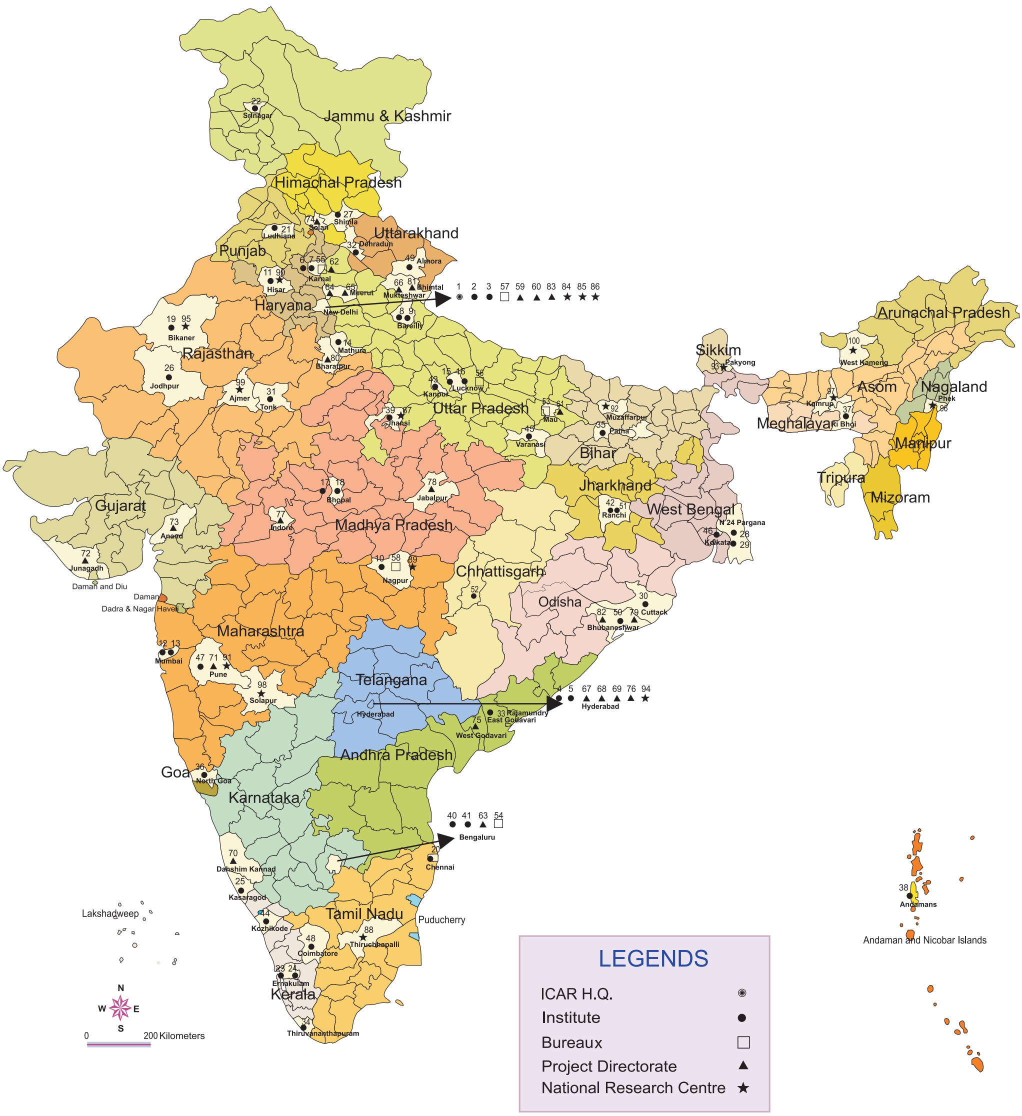
Vision 2050

Indian Institute of Maize Research

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



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Vision 2050

भामअनुसं
IIMR

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(Indian Council of Agricultural Research)
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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-Indian Institute of Maize Research (IIMR), New Delhi 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.

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Preface

The year 2050 is 35 years away from now. For some, it may be far too futuristic to think about it today. But, in the world of science and technology development, especially in biological sciences like agriculture, this is not a very long period. Historically, there have been considerable time gaps between beginning of research and its significant output and adoption. Take hybrid maize, for example. G.H. Shull started his experiments on heterosis at Cold Spring Harbor way back in 1906. But, it was only in 1921 that the first double cross commercial maize hybrid was released in Connecticut and the more popular single cross hybrids came into picture much later in 1960s- a long gap of 54 years after Shull's experiments. Another dimension with agricultural technologies is their asynchronous availability across geographies. Single-cross hybrids were commercialized in the developed world much earlier than many developing countries, like India. Similarly, since 1996, farmers of many countries have shifted to modern maize cultivars developed through genetic engineering. It is clear, that in the fast changing world of science, we have to be at the frontiers of research at all times and should have the capability to envision the future, if we want to be globally competitive. The Vision 2050 document has been prepared in this backdrop.

In India, maize is the crop of the future. As compared with other grain crops, demand for maize would rapidly rise because of its myriad uses in various industrial products and processes and requirement for animal feed. With the large scale advent of maize -based bio-fuel in North America, its global demand would always remain high. By 2050, India would have to triple its maize production from the current levels and that too with limited natural resources and a changing climate. Being, a C4 crop, maize is better adapted to the vagaries of the climate. Productivity and sustainability of maize-based systems can be further improved by suitable research interventions.

Globally, maize research is a highly competitive area, in which many international organizations and multinational corporations are investing heavily. The pace of research has dramatically increased after sequencing of the maize genome in 2009. The ICAR-Indian Institute of Maize Research (IIMR) is the only institution in India, exclusively mandated for maize research. In Vision 2050, we have tried to envision the future operating environment and challenges ahead. We are now repositioning ourselves to address these challenges through our 14 Grand Initiatives, which will form the bedrock of the IIMR strategy. IIMR is committed to embark upon a path of world class science and become the most-sought-after technology provider in the maize sector.

It is my proud privilege to express sincere gratitude to Dr. S. Ayyappan, Secretary, DARE and DG, ICAR for his invaluable guidance in promoting maize research in India. I am also deeply thankful to Dr. J.S. Sandhu, DDG (CS), Prof. S.K. Datta, former DDG (CS), Dr. I.S. Solanki, ADG (FFC) and Dr. R.P. Dua, former ADG (FFC) for their consistent support, encouragement and timely suggestions for strengthening maize research. I am grateful to Dr. B.S. Dhillon, Vice Chancellor, Punjab Agricultural University and former Chairman, Research Advisory Committee (RAC) of IIMR for his valuable suggestions to improve this document. I am also thankful to all the members of RAC, Institute Management Committee, and various stakeholders for helping us improve the Vision document. I consider it a moment of exhilaration while expressing thanks to all the scientists of IIMR for their concrete contributions in preparation of the 'IIMR Vision 2050'.

(O.P. Yadav)
Director
ICAR-Indian Institute of Maize Research

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Context

Maize is the third most important crop of country after rice and wheat. Its grain is used as feed, food and industrial raw material. It is cultivated round the year, though more than 80% is grown in rainy or kharif season (July to October). The most important maize growing states are Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Rajasthan, Bihar, Uttar Pradesh and Madhya Pradesh, which account for more than 80% of the total maize area of the country and also account for similar share in production.

Both area and production of maize have been steadily increasing. Since 1950, area under maize has increased from 3.31 to 9.0 million ha and production from 1.73 million tonnes to 24.4 million tonnes in 2013-14. The increase has been very rapid in the last 10 years as a result of increase in productivity and expansion of area due to spread of its cultivation in Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu.

In India, it is estimated that maize demand will continue to increase because of its diversified uses and increasing population. To meet the growing demand, enhancement of maize yield in coming years across all the growing locations in India is a big challenge in the era of climate change. Meeting such challenge will only be possible through science-based technological interventions like single cross hybrid technology and application of novel molecular tools and techniques in maize improvement. Furthermore, the changing growth pattern of the economy and policy changes with respect to subsidy in agricultural inputs, commodity export-import, industrialization, foreign direct investment in agriculture, etc., are likely to affect the growth pattern of the crop. So, to stimulate new ideas and fresh thinking for breakthroughs there is a need to have long-term vision for benefit of humanity at large.

ICAR- Indian Institute of Maize Research (IIMR) has mandate to conduct strategic research on various issues that are relevant to maize production. The institute is also responsible for generating technologies for enhancement in maize productivity. The overall target is to meet the ever-increasing demand of maize for human food, animal feed and industries for starch, oil, and other value-added products. The whole gamut of research is conducted through this institute operating from 4 locations, i.e. New Delhi, Ludhiana, Begusarai and Hyderabad. The

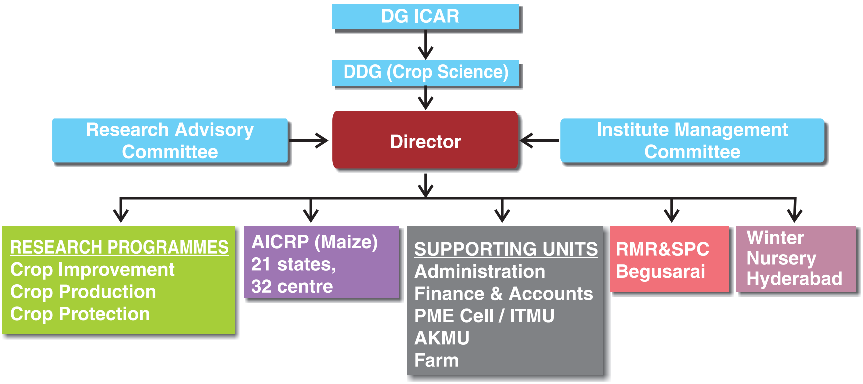

Fig. 1 Organogram of ICAR-Indian Institute of Maize Research

institute also coordinates All India Coordinated Research Project on Maize with 32 centres spread over 21 states (Fig. 1).

Mandate

The institute has following mandate:

1. To carry out basic, strategic and applied research aimed at enhancement of production and productivity of maize in the country
2. To conduct and coordinate multidisciplinary and multi-location research to identify appropriate technologies for varied agro-climatic conditions in different parts of India
3. Germplasm collection, evaluation, maintenance and its enhancement
4. To develop specialty corn cultivars such as Quality Protein Maize, baby corn, sweet corn, bio-fuel etc. on account of its diverse uses
5. To conduct training, frontline demonstrations and on-farm research to maximize and accelerate adoption of research findings and innovative technologies
6. To serve as core centre for supply of maize research material and information
7. To develop linkages with national, international and private sector for collaborative research programmes
8. To provide consultancy services and undertake contractual research

Maize Research in India

Maize improvement in India has evolved very strongly since 1950. The first phase involved improvement of landraces during 1950-60. The principal breeding efforts were mainly focused towards improvement of local material through mass selection and hence the productivity remained very low (547 kg/ha). The Indian Council of Agricultural

Research (ICAR) launched the first All India Coordinated Research Project on Maize in 1957 to develop and evaluate improved cultivars of maize. In 1961, the first set of four double-cross hybrids, viz. Ganga 1, Ganga 101, Ranjit and Deccan were released for commercial cultivation in India. These were followed by series of double-cross hybrids like VL 54, Him 123, Deccan 101, etc. These hybrids showed distinct superiority (30-40%) over the landraces. However, they remained potentially susceptible to leaf and stalk rot diseases. To address these limitations in the shortest possible time, the susceptible parents of the hybrids were replaced with a resistant variety as pollen parent which initiated the era of double top-cross hybrids in India. Ganga Safed 2, Hi-Starch and Ganga 5 were prominent hybrids released between 1963 and 1968. However, seed production of these hybrids remained largely neglected and hence the hybrid research could not gain as much momentum as it was expected. As a result, emphasis was again shifted from hybrid to composite breeding. Many composite varieties were released and adopted and the productivity enhanced, but it remained below 1000 kg/ha (Yadav et al. 2014).

Late eighties witnessed the launching of single cross hybrid (SCH) breeding programme and adoption of New Seed Policy. SCH breeding activities witnessed many positive changes and accomplishments in generating vital scientific information as well as commercial products. Research efforts were focused on the development of vigorous genetically diverse inbred lines that have good performance per se as well as in cross combinations. This resulted in development of high yielding SCHs for different agro-ecological regions of the country. The major strategy therefore, became to evolve and disseminate inbred-based hybrid technology.

A total of 212 hybrids and 119 composites of maize have been released till date. These represent a wide range of maturity to cater to the need of farmers in different production ecologies of various states. The improved cultivars have been widely adopted by Indian farmers. The adoption of improved cultivars and production technology had a synergistic effect on crop productivity and provided encouraging results (Fig. 2). The maize productivity has reached more than 2600 kg/ha with a total production of 24.3 million tons from an area of 9.0 million ha. By 2050, 3.25 times increase in production, 2.2 times increase in productivity and 1.4 times increase in acreage is anticipated (Dass et. al. 2009).

Different strategic issues have also been addressed in maize improvement. Heterotic pools were developed as a long-term strategy to

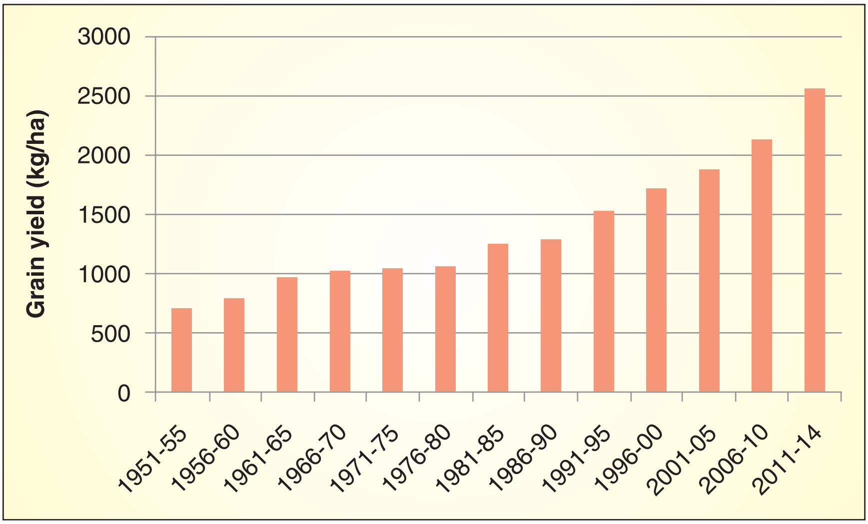

Fig. 2 Trend in maize productivity in India since 1951

derive inbred lines for use in hybrid development. Sources of resistance to major insect-pests and diseases have been identified and utilized in resistance breeding programmes. The application of molecular tools and techniques has also been used to understand the natural genetic diversity existing in the Indian maize germplasm and its utility in maize breeding. Recently, parental lines of Vivek hybrid 9 were introgressed with opaque2 (o2) gene through marker assisted selection (MAS) and the hybrid between introgressed line was released as Vivek QPM hybrid 9. Opaque2 gene alters the maize kernel endosperm composition of amino acid profile in desired direction with enhanced levels of essential amino acids like lysine and tryptophan. The success of Vivek QPM Hybrid 9 has given an impetus for large scale conversion of elite normal maize inbred lines into Quality Protein Maize (QPM) lines.

Indian maize breeding has a very strong linkage with the International Maize and Wheat Improvement Centre (CIMMYT), Mexico. CIMMYT has supplied diverse kind of germplasm (yellow maize, white maize, quality protein maize, waxy corn, high oil maize etc.) to Indian maize breeding programme. The QPM breeding is one of the most benefitted programmes. QPM possesses improved nutritional value as compared to normal maize due to enhanced levels of amino acids namely lysine and tryptophan. In 1970s, three QPM composites viz., Shakti, Protina and Rattan were released. In the last decade India has developed nine quality protein hybrids, viz. Shaktiman 1, Shaktiman 2, Shaktiman 3, Shaktiman 4, HQPM 1, HQPM 4, HQPM 5, HQPM 7 and Vivek

QPM Hybrid 9. While doing so, CIMMYT's maize germplasm has been extensively used by the Indian programme.

Resource management research has focused on development of agro-techniques for resource conservation in maize-based production systems, development of technologies for better management of abiotic stresses like drought, excess moisture, cold, heat etc.

Reduced or conservation tillage system is gaining more attention in recent years with the rising concern over natural resource degradation. In India, conservation agriculture is being practiced under rice-maize cropping system in coastal Andhra Pradesh and north eastern Karnataka. Farmers are taking up sowing of maize in residual soil moisture after rice harvest and also saving about 20-30 days of land preparation time. In rice-maize cropping system, farmers are harvesting >10,000 kg/ha of maize grain.

The institute envisages vision for sustainable maize production systems in the scenario of climate change and resource degradation for ensuring food security in the country and prosperity of farmers through eco-friendly technologies. Hence, a long-term vision detailing challenges, operating environment, goals, opportunities and way forward towards 2050 is the need of the hour.

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Challenges

By the year 2050, the world as we know today, would change in many exciting ways. The world's population would exceed 9 billion and average global temperature would rise, and most importantly, the world would be running out of fossil fuels, necessitating a massive shift to alternative source of energy. By this time, India would be the largest economy of the world, most populous nation of the planet and a majority of its population would be living in the urban areas. The pressure of population, a severe natural resource crunch and an impending ecological decline may trigger a major agricultural crisis, unless we act now and bring in paradigm scientific interventions to deal with these issues.

Bridging yield gaps and incremental gains by improved management practices may help us to enhance production by a few years. But what would happen beyond that? How long the huge environmental foot-print of conventional agriculture can be sustained? What about myriad non-food related opportunities that agriculture can provide? More importantly, do we visualize a half of India's population still toiling on farms in 2050 and earning just tenth of its GDP? We must answer these questions now and we should not shy away from harnessing science to answer some of these.

Although, on face of it, the grain situation of the country may look quite comfortable today and some people may not be enthusiastic about deploying high science in agriculture, but this thinking should not be allowed to rear a sense of complacency in our research efforts. Agricultural research has long gestation periods and decisions taken today would impact our ability to sustain a high productive, but eco-friendly agriculture in decades to come. Some of the daunting challenges of 2050 before agriculture in general and maize in particular are as follows:

Abiotic and Biotic Constraints

Improving the genetic potential of Indian maize would continue to be a major challenge. Today, hybrids with yield potential of up to 14 t/ha are available. However, it becomes difficult to achieve even half of this potential because of high incidence of biotic and abiotic stresses in farms. It is clear that the major challenge in germplasm enhancement lies in introducing stress tolerance traits. Development of high yielding cultivars with built-in higher level of resistance against stresses is a daunting task. This becomes all the more challenging due to unpredictability of plant-pest-natural enemies interaction in the context of changing climate. Maize seed, grain and processed maize product are highly vulnerable to stored grain pests. Protection in field and in godowns in sync with maize agro-ecosystem is yet another challenge.

Natural Resources Degradation

The natural resources degradation, fading organic carbon from soil, declining factor productivity, decreasing farm land due to more land under non-agricultural uses in future and profitability due to escalating input prices in agricultural production will further aggravate the problem of sustaining maize production systems.

Enhanced Feed and Fodder Requirements

Fodder is an important issue as the country is presently facing a net deficit of 61% for green fodder. In the absence of nutritious fodder, the farmers are feeding their cattle with low quality roughage or rice straw, thus, adversely affecting the milk production potential of the animals. The competition for land and meeting the feed and fodder need for the support of livestock and poultry production will be another challenge in this scenario.

Malnutrition

Micronutrient and protein malnutrition is a serious concern particularly in the rural masses as they solely depend upon cereals for food. Millions of people suffer from protein, Vitamin-A, iron and zinc deficiency. It is estimated that about 123 million people in Southeast Asia are at risk of vitamin A deficiency and 1.7 million are affected by xerophthalmia. Iron, zinc and lysine and tryptophan amino acids that determine protein quality are usually found deficient in maize consuming population. In times to come, systematic research in maize needs to be undertaken in India to address this issue.

Peri-urban Agriculture

In context of peri-urban agriculture and urbanization, the profitability will be an issue for enhancing maize area and utilization, as majority of the population in India will be urbanized by 2050. The higher income, increasing urbanization and changing food habits will likely to shift the food preference in the country and there is possibility for increasing demand of protective healthy foods based on milk and meat.

The futuristic production system involving specialty and nutritious maize are needed for sustaining agriculture in peri-urban areas.

Demanding Seed Supply

Low cost and quality seed production will be a major issue for enhancing adoption rate of hybrid maize cultivation. Farmer, private, cooperative and public sector participatory seed production programme needs to be evolved in future for assuring quality seed availability.

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Operating Environment

Activities of each organisation are shaped by a dynamic matrix comprising of socio-economic and institutional environment, emergence of new technological paradigms, actions and achievements of others, changing farming conditions and consumer demand etc. This matrix constitutes the 'operating environment' which shapes the vision and goals of an institute. The overall emphasis in coming decades will focus on increased production and conservation of natural resources to make agriculture a sustainable enterprise. Nutritional security coupled with biosafety concerns will dominate the efforts in agricultural production system. The key drivers of the operating environment with respect to maize research are as follows:

Use of Maize in Everyday Life would Increase Manifold

Presently in India, only 10% of maize is used as foodgrain, while remaining is used to meet non-food demand, viz. poultry feed, animal feed, brewing alcohol and other industrial uses (Kumar et al. 2013). It is estimated that one quarter of items found in a modern grocery store of a developed country contain maize in some form. Toothpaste, dish detergent, paper, clothing dyes, explosives and soaps- there is a vast list of products that contain maize constituents. Key ingredients in convenience food like xanthan gum, polyols, artificial sweeteners, fructose etc. are all derived from maize. Other products where maize is used are: food containers and plastic food packaging, disposable dishware and gift cards, batteries, deodorants, hand sanitizers, cough drops, baby powder, diapers, matchsticks, medicine and vitamin tablets, textile products, colourings and dyes, glue and other adhesives, candies, yoghurt and many more. Maize-based breakfast cereals, cooking oil, snacks, sweetcorn, babycorn, popcorn etc. are already gaining much popularity in India.

Further, increasing energy consumption in all walks of life call for finding alternate sources of energy, in which bio-fuel from maize is a distinct possibility, which might be explored in our country. Maize is the most important natural multiplier and an economical source of starch. Starch comprises of about 68- 74% of maize kernel weight, which can easily be converted into glucose and subsequently fermented into ethanol. Presently, US is playing the lead role by using 30% of its maize for bio-fuel production. Bio-fuel from maize will be need of the hour as it will help in energy security along with high procurement prices. The expanding spectrum of demand would necessitate focused research tailored for specific segments of the myriad value chains.

A Massive Expansion in Area Under Single Cross Hybrids would Transform Indian Maize Scenario

Today, single cross hybrids are clearly, the preferred cultivars of maize for achieving high yield. Year after year, area under single cross hybrids is expanding. However, presently single cross hybrids constitute just 25-30% of total plantings in a given year. It is estimated that single cross hybrids would constitute 90% of the total area by 2050. This would provide a major boost to the maize seed industry.

Private Sector R&D would Lead to Enhanced Investment in Maize Research

With the liberalization of economies the world over, the private sector has emerged as a key player in agricultural research. While public sector institutions continue to concentrate on developing appropriate technologies, the private sector tends to focus on crops that would generate profitable returns. Maize is one of the most extensively researched commodities by multinational seed corporations, as it allows maximum 'value capture' due to prevalence of hybrids. The enhanced investment in maize research is resulting in access to capital and knowledge intensive genomics and biotechnology platforms for rapid genetic gain in the hands of few large multinationals. The Indian seed industry is yet to develop capabilities of this scale and has to scout for 'technology providers' to stay competitive. However, by pooling resources in consortia mode, the small and medium enterprises can leverage synergistic partnerships of innovation and sharing. Being the apex institute in the public domain, the Institute has a unique opportunity to emerge as a 'nucleus' and facilitator of such partnerships. Public sector working in tandem with private sector will be able to synergize the strength of both in meeting the challenges ahead. The interface of Public-Private Partnerships (PPPs) would be a defining and recurrent feature of agricultural research in the next forty years.

Global Expansion of Genetically Engineered Maize Cultivars offer New R&D Opportunities

A major global development with respect to maize is widespread adoption of genetically engineered cultivars in last twenty years. Today,

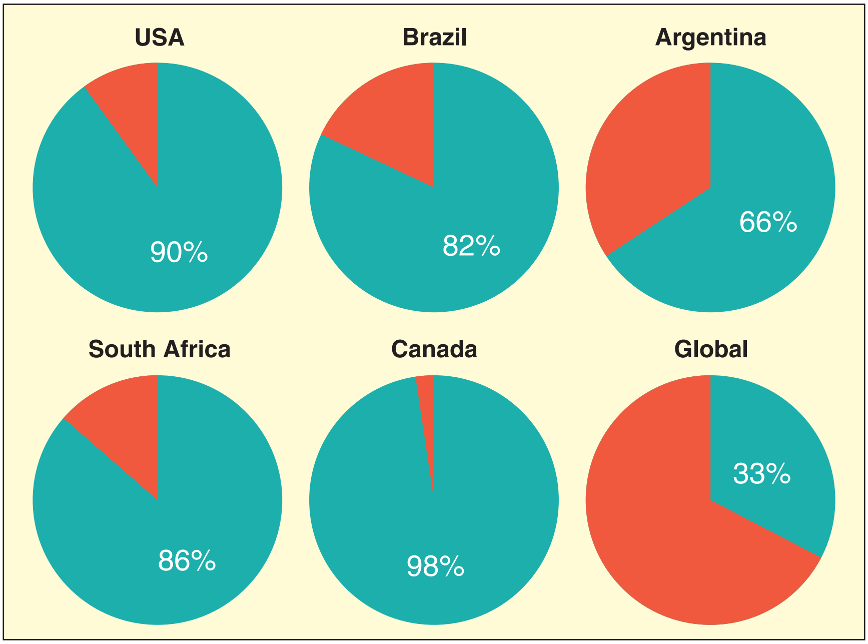

Fig. 3 Adoption rate of transgenic maize cultivars in some countries (James, 2013)

hybrids with transgenic traits are planted in 17 countries in an area of 57.3 million ha, which amounts to 33% of global maize acreage (Fig. 3). More than 80% of the area under maize in the USA, Canada, South Africa and Brazil is under transgenic cultivars.

Among all crops, maize has the highest number of transgenic events (96) approved for cultivation. Traits like multiple insect resistance, herbicide tolerance, drought tolerance, enhanced lysine, modified amylase and male-sterility are already available to maize growing farmers of many countries for cultivation. Other important traits like next generation of insect resistance, nitrogen use efficiency, low phytate, high oil, biofortification etc. are in advanced R&D pipeline. It is clear that the Indian farmers would lose the competitive edge vis-a-vis their global peers, if such traits are not available to them. Currently, in India, multi-locational field trials of transgenic maize are going on for insect resistance and herbicide tolerance traits by private sector developers. Stem borer resistant transgenic maize developed by the Institute is also undergoing greenhouse trials. There are several opportunities for public-funded research institutes, to come up with trait specific 'non-proprietary' transgenic cultivars, especially for resource poor small and marginal farmers.

Next Generation Agronomics would Provide Superior On-farm Solutions

A genotype, however superior it may be, cannot achieve its full potential unless it is put into an enabling agronomic context. In future, comprehensive agronomic service packs would be available combining the best of precision agriculture technologies with intelligent management practices. Customized agronomic consultancy services will be order of the day. Agronomic techniques based on conservation agriculture have the potential to change the sustainability aspect dramatically.

New Frameworks on Biodiversity and Intellectual Property would Transform Research Landscape

The bedrock of any crop improvement programme i.e. the genetic resources, are no longer considered as the "the common heritage of mankind" but are now bracketed by 'principle of sovereign rights'. The WTO TRIPS regime has catalyzed a new cultural outlook on planning, conduct, and sharing of biological research. It is expected that in line with the global trends, emphasis, enforcement and compliance of intellectual property rights would strengthen in India in coming years. On one hand this presents a never-before opportunity of monetising R&D and benefit from a steady revenue stream, while on the other side, it poses new complexities in germplasm exchange and 'public character' of the research like ours. The techno-legal contours of these aspects are being shaped by existing and upcoming legislative interventions of biodiversity, plant variety protection and utilisation and protection of publically funded Intellectual Property, etc. These aspects are creating a new operating environment for maize researchers whereby they are expected to not only remain at the frontiers of technology generation but also be well versed with nuances of technology management.

Changing Perceptions about Research Interventions in Agriculture Would Necessitate New Channels of Public Engagement for Scientists

In the post-modern world, it has become fashionable in some quarters to discredit new technological interventions, especially so in agriculture. Modern agricultural practices comprising of high yielding varieties (HYVs), synthetic fertilizers, plant protection chemicals, new genetic experiments, global agricultural

> I now say that the world has the technology — either available or well advanced in the research pipeline — to feed on a sustainable basis a population of 10 billion people. The more pertinent question today is whether farmers and ranchers will be permitted to use this new technology?"
>
> **–Norman Borlaug**

trade etc. are dubbed as 'unnatural' and undesirable. This feeling may translate into reduced appreciation and support for agricultural research, leading to slow down in research intensity and thereby compromising the goals of sustainable development. However, it should be unmistakably understood that it would not be possible to deal with the challenges of 2050 by incremental, business-as-usual and conventional approaches. New agricultural technologies have long gestation periods and decisions taken today would impact our ability to address the challenges tomorrow. Therefore, there is a need to communicate the potential and desirability of new agricultural technologies to the general public in a more effective way.

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Opportunities & Strengths

In comparison with other major grain crops, maize has benefitted to a great extent by new technological opportunities. Today, the most robust hybrid seed technology is available in maize and the highest number of transgenic events have been approved for this crop. In future also, maize is expected to rapidly absorb new technologies and play a pivotal role in addressing the issues facing the humanity by 2050. Few game-changing new technologies are already in the horizon that would revolutionize maize research by 2050.

Genomics and Molecular Breeding

At present, stage has reached where traditional methods of crop improvement alone are not sufficient and the recent advances in molecular breeding and genomics have to be integrated with conventional approaches for rapid gain. There are various molecular approaches which are well developed and have already been used in maize breeding programme, such as gene mapping, marker assisted selection (MAS), marker assisted recurrent selection (MARS), association mapping etc. Also, there are some techniques which are well understood but their use is still at initial stage for maize improvement, like, nested association mapping (NAM) and whole genomic selection (WGS). It is expected that by 2050, every line/ germplasm/ breeding material of maize will be well characterized to design the desired phenotype.

Next Generation Mutation Techniques

Techniques like, mutant-assisted gene identification and characterization (MAGIC) and targeting induced local lesions in genomes (TILLING) allow identification of single-base-pair (bp) allelic variation in a target gene in a high-throughput manner. In future, TILLING would provide a powerful

Targeted Mutagenesis

Path breaking researches over last few years in the upcoming field of targeted mutagenesis indicate that by 2050 it would be routine to make site-specific modifications to the plant genomes, including targeted mutations, gene insertions, and gene replacements etc. Targeted mutagenesis would rely on different kinds of sequence-specific nuclease systems, like: zinc finger nucleases, transcription activator-like effector nucleases (TALENs), LAGLIDADG homing endonucleases ('meganucleases') and many other better systems which are yet to be developed.

approach for gene discovery, DNA polymorphism assessment, and plant improvement. It represents an extension of the use of spontaneous and induced mutants in plant breeding.

Genetic Engineering and Gene Stacking

By 2050, the area under transgenic cultivars would enlarge manifolds in India and the world, and even more importantly, number of transgenes and transgenic traits in one cultivar would multiply. This would necessitate a shift from the present day genetic engineering to the futuristic 'genome engineering'. Emerging technologies of today like, maize mini-chromosome (MMC), polycistronic transgenes, polyprotein expression systems, marker-free transgenesis, marker excision, targeted mutagenesis and many others which enable gene stacking and precise modification, would blossom by 2050 and take the designer maize cultivars to the next level. Based on the current global maize R&D pipeline, a futuristic timeline of new genetically engineered traits can be envisioned (Fig. 4).

RNAi technology

The discovery of genome regulation by non-coding RNAs has brought a paradigm shift in our understanding of biological processes of plants. A scientific race is going on globally to deploy this newfound knowledge for developing novel solutions for agriculture. There are already several RNAi products for maize in R&D and regulatory pipeline, like the next generation insect resistance, virus resistance, aflatoxin resistance, QPM traits etc. It is believed that by 2050, the extent of trait engineering by interfering and 'activator' RNA molecules would be as high as the current practice of overexpressing proteins. New plant protection molecules based on sprayable RNAi are also in the offing.

New Opportunities for Combating Biotic Stresses

Advancement in the field of biotechnology will help us to manage biotic stresses by developing improved strains of biocontrol agents. The long term strategy to manage the losses due to disease should involve biotechnological tools for identification of genes against major pathogens and cloning of resistant gene(s) from different donors and their utilization in elite parental lines through gene pyramiding using marker assisted selection and conventional breeding approaches. Besides food safety issues like mycotoxin contamination of grains due to moulds is a major constraint and health hazard to humans and animals which

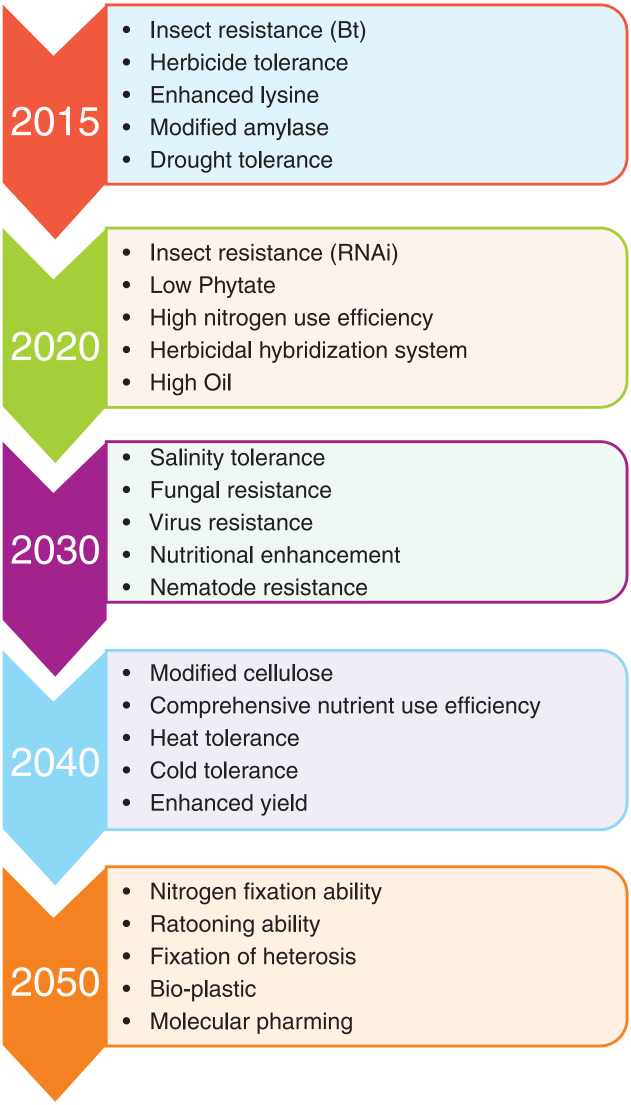

Fig. 4 Technology forecasting for transgenic traits in maize (based on global R&D pipeline of various organizations)

needs to be addressed in the coming years. The future strategy for mycotoxin should involve/include exploitation of genotypic tolerance to mould infection, mycotoxin build up and identification of biocontrol agents. Development of detoxification protocol by utilizing microbial agents/non-toxic chemicals is also a new opportunity to manage biotic stresses.

Phenomics

Molecular breeding offers ideal tools to accelerate maize breeding, however, suitable phenotyping protocols are essential to ensure that the much-anticipated benefits of molecular breeding can be realized. As of now, whole genome sequence of maize is in hand, therefore in future, phenomics in association with advance molecular and genomic technologies can play a more important role to indentify and understand genes controlling complex traits. Greater emphasis needs to be given to reducing the within-experimental site variability, characterization of the environment and appropriate phenotyping tools. Yield is a function of many physiological processes throughout the crop cycle, and thus integrative traits that encompass crop performance during different phases of growth will provide a better alternative to non-destructive measurements of a given plant process. Recently, more emphasis has been given on development of new phenotyping tools based on remote sensing including non-destructive measurements of crop growth based on spectral reflectance and infrared thermometry.

Nanotechnology

Nanotechnology has the potential to revolutionize maize systems with new tools for molecular treatment of diseases, rapid disease detection, enhancing the ability of plants to absorb nutrients etc. Smart sensors and smart delivery systems will help in combating major maize pests and pathogens. The pesticidal properties of nano-particles of various elements will be studied so that they can be utilized as an alternative to chemical pesticides. In coming decades nanostructure catalysts will be available which will increase the safety and efficiency of pesticides allowing lower doses to be used. Nano-particles can serve as 'magic bullets', containing herbicides, chemicals, or genes, which target particular plant parts to release their content.

Cellulosic Ethanol and Molecular Pharming

In the bid to tackle 'peak oil' and climate change, bio-fuels would become increasingly more important in the global energy matrix by 2050. Ethanol potential of maize can be dramatically increased if its cellulosic biomass can also be converted into fuel. This would be possible by cell wall engineering and synthetic biology techniques. Maize-based cellulosic ethanol will not only help us achieve 'agri-based energy security,' but also, it will transform rural India by diverting enormous petrodollars to the farmers. By 2050, maize would not only provide food, feed and fuel, but also, it would be a source of recombinant pharmaceuticals, biopolymers and biodegradable plastic.

ICT Enabled Extension

The pace of increase of mobile phones and other electronic gadgets at grass root level will greatly help farmers to get access to the latest agro technology and scientists disseminating customized information to the farmers.

Improved Production Technology

There are considerable losses of nutrient and water in agriculture production in India. It can be minimized by the development and use of conservation agriculture based crop production practices, sensor based nutrient and water management, decision support tools and agro-ecological niche specific agronomic practices.

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Goals and Targets

Presently, maize is the third most important cereal crop in India after rice and wheat. However, globally maize is at number one position in terms of production. The last five years saw a sort of 'mini-revolution' in maize production in India. During last five years, maize production in India increased phenomenally with growth rates touching almost 8%, which is highest among all grain crops. The boom in maize production is expected to continue.

By 2050, 3.25 times increase in production, 2.2 times increase in productivity and 1.4 times increase in acreage is anticipated (Dass et al. 2009). It is expected that maize cultivation is likely to be extended in Jharkhand, Chhattisgarh and Odisha, and in Indo-gangetic plains.

The increasing global temperature is adversely affecting the wheat production in the North-western plain regions of the country. The sudden spurt in temperature in the month of February and March in the last few years has adversely affected grain filling in wheat. However, the condition will be ideal for maize, and quality protein maize could play an important role at this stage. The loss in the form of wheat will effectively be compensated by quality protein maize. Spring maize in Punjab and Haryana; summer maize in eastern states; winter maize in different states of the country except Himalayan belt, and specialty corns in tourist states like, Andaman and Nicobar islands, Kerala, Jammu & Kashmir, Himachal Pradesh and Uttarakhand, would further contribute to area expansion in maize.

To achieve the above mentioned production targets and meeting the challenges as highlighted in Chapter 2, following Research and Development targets are anticipated:

Germplasm Enhancement

The specific targets to address the challenge of germplasm enhancement are as follows:

- Development of diverse productive inbred lines resistant to biotic and abiotic stresses from temperate X tropical hybridization programmes.
- Generation of information on heterotic groups for different kinds of maize; evaluation for combining ability; classification as pollinators (high pollen productivity), and seed parents (high seed productivity).
- Breaking yield plateau (undesirable linkage between yield and

biomass) in early maturing maize through the development of long term breeding programmes based on cyclical selection/recurrent selection for each trait of economic importance to bring changes in gene frequency in desirable direction.

- Cloning and characterizing genes of interest; Marker Assisted Selection (MAS) for various biotic/abiotic stresses to identify potential inbred lines.
- Identification of nutrient-responsive, high water use efficient, high nitrogen use efficient, high sink efficient inbred lines and the underlying genes for combination breeding.
- Mobilization of gene(s) for traits of interest through transgenesis and cyclical selection/recurrent selection to alter gene frequency in desirable direction based on conventional research supplemented with neo-techniques.
- Development of high yielding single cross hybrids for different maturity groups resistant/ tolerant to biotic and abiotic stresses (Fig. 5).
- Development of high yielding single cross hybrids having temperate background suitable for winter season as well as assured irrigation in Indo-gangetic region of North Western plains.
- Improved plant architecture for better performance under higher plant density in the wet tropics.
- Identifying physiological traits that improve performance stability in target environments.
- Developing the most suitable genotype by environment by management (GxExM) combinations that improve reliability of maize production in India.
- Identification of germplasm for durable resistance to tropical and subtropical diseases like sorghum downy mildew, Rajasthan downy mildew, brown stripe downy mildew, banded leaf and sheath blight, pre- and post- flowering stalk rots, Turcicum leaf blight and ear and stem rots, bacterial, viral and nematode diseases and insects like *Chilo partellus* and *Sesamia inferens*.
- Use of doubled haploid technology for accelerated inbred line development

Managing Biotic Stresses

The target for managing biotic stresses is to completely remove toxic pesticides from the pest management strategy. The specific goals are:

- Development of improved strains of biocontrol agent.
- Survey and surveillance to find out region specific prevalence of

insect-pests and diseases and their dynamics.
- Developing pests and disease forecasting models.
- Identification of different biotypes of maize stem borer.
- Research on habitat management as an eco-friendly pest reduction tactic.
- Study of various plant biochemicals and nano-particles to find their pesticidal properties.
- Exploration and utilization of sex pheromones to manage maize stem borers.
- Establishment of insect natural enemy friendly parks in maize growing areas.
- Development of surface coating materials and moisture resistant storage bags to manage storage insect pests, aflatoxins and other fungal pathogens.

Fig. 5 Evaluation of single cross maize hybrids at IIMR. Germplasm enhancement would continue to be a major goal in maize research

Mitigating Abiotic Stresses

The target is to enhance tolerance to important abiotic stresses like drought, water-logging, salinity, high temperature, cold, nutrient stress etc. in elite maize hybrids and parental lines. Specific approaches for management of abiotic stresses are as follows:

- Collection, characterization and maintenance of source maize germplasm for abiotic stress tolerance.
- Development of trait index for different abiotic stresses.
- Identification of upstream regulating genes for different traits associated with abiotic stress tolerance.

- Developing mapping populations for different abiotic stresses to serve as base populations for further improvement.
- Identification of major QTLs conferring multiple abiotic stress tolerance.
- Development of high end phenomics based precision phenotyping protocols for non-destructive measurements of crop growth-related parameters based on spectral reflectance and infrared thermometry under abiotic stresses.

Nutritional Enrichment

The targets to achieve nutritional security through maize comprises of following interventions:

- Synthesis of hybrid-oriented populations, quality analysis and identification of tryptophan, lysine, carotene enriched material; development of nutritionally superior inbreds and single cross hybrids.
- Development of QPM germplasm with higher yield and identification of major and minor endosperm modifiers and their mobilization through genomic assisted breeding.
- Introgression of various quality traits, viz. tryptophan/lysine, (super) sweetness, poppiness, micro-nutrients, etc. into normal germplasm.
- Generation of information through large–scale studies on QPM hybrids for elucidation of their nutritional benefits on humans (infant, adult and old), poultry, pigs, livestock, fish etc.
- Promoting QPM under nutrition mission-mode approach, especially catering to the food needs of tribals where maize is staple food using QPM in mid-day meals of school going children.

Sustainable Production Technology

The goal of sustainable maize production will be achieved through following interventions:

- Development of location specific, low cost and eco-friendly production technology based on conservation agriculture, precision nutrient management and mechanization in maize systems.
- Development and fine-tuning of package and practices of single cross hybrids as per the conditions of specific region, season, etc.
- Production technology for higher seed yield of inbreds.
- Conservation agriculture in maize systems for improving resource-use efficiency.
- Precision input management for higher productivity and profitability using sensor, Geographic Information System (GIS), computer

programming, etc.

- Development of decision support system for stakeholders.
- Development and design of futuristic competitive maize systems.

Feed and Fodder Issues

The issue of feed and fodder scarcity will be addressed by achieving following targets:

- Development of germplasm with high biomass.
- Development of synthetic and composites with high biomass for fodder purpose.
- Maize x Teosinte hybridization programme for inducing tillering in maize.
- Exploitation of ploidy levels i.e. amphiploidy for the development of higher biomass in fodder varieties.
- Promotion of baby corn and sweet corn based cropping system.

Peri-urban Agriculture

Some of the issues to be addressed to make peri-urban agriculture more profitable through maize cultivation are:

- Development of baby corn oriented germplasm and its utilization for developing single cross hybrids of baby corn with quality attributes of international standards.
- Development of super- sweet corn (sh-2) hybrids.
- Development of short duration nutritionally rich single cross hybrids of pop corn with high popping volume.
- Development of germplasm with high oil content (> 6.0%).
- Identification of source germplasm for high Fe, Zn and Vit. 'A.'
- Promotion of specialty corn villages: satellite towns/rural areas of metropolitan cities with fast communication network like Delhi, Mumbai, Bengluru, and others.

Seed Production

To address the challenge of seed production there is a need to develop multiple models comprising of different stakeholders and alternative site of seed production. Some of the models are as follows:

- Development of economically viable region-specific seed production technology based on specifics of region, cropping season, hybrid maturity etc.
- Development of seed production hubs in different areas as to minimize transportation costs and ensure timely availability of quality seed.

- Roping in KVKs for seed production.
- Contract farming.
- Public private partnership for seed production.
- Post-harvest processing and storage.

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Way Forward

To address the challenges of 2050, the Institute has identified 14 cross-cutting Grand Initiatives (GIs). These initiatives signify various existing and futuristic inter-related and inter-dependent verticals of IIMR.

GI 1: Explore basic mechanisms of plant development and adaptation to biotic-abiotic stresses in maize

Basic plant biology research focussing on maize is the primary mandate of the institute. Our focus on basic research would significantly increase in coming years. We are specifically interested in unravelling fundamental developmental pathways in maize and their modulation by adaptive responses to stresses. This GI would enable us to enhance our visibility in the arena of global science, in terms of high impact research.

GI 2: Screen germplasm and discover trait specific novel genes from maize genomes

Germplasm screening has been the core competency of IIMR. Over several years, thousands of maize lines for traits like insect resistance, disease resistance, drought, heat and water-logging resistance, etc. have been evaluated and sources of resistance/ tolerance have been identified. However, very few such sources have been effectively used in breeding programme or genetic engineering because the genes for the resistance are yet to be isolated. Once these genes are isolated, characterized and validated, they can be effectively used by marker assisted selection (MAS) in breeding schemes or over-expressed by genetic engineering. Thus, germplasm screening would continue to be a major activity, which would have downstream contribution to GI 3 and GI 4.

GI 3: Thoroughly integrate marker assisted selection and doubled haploids in breeding schemes

Speed and precision of maize breeding will be enhanced by using well established techniques of marker-assisted and whole genome selections. The genome sequence of maize is now available (Schnable et al. 2009) and resequencing costs have come down dramatically. Maize is one of the crops with richest genomic resources available in terms of SNP and conventional molecular markers. Novel genes identified from our GI 2, would be a unique and additional resource base for introgressing important genes through marker-assisted selection. The introgressed gene combinations would be rapidly fixed using doubled haploid technology.

GI 4: Spearhead development of public sector events of transgenic maize

As indicated in previous sections advent of even more number of transgenic traits is a reality of global operating environment with respect to maize and we have to adequately respond to this aspect. The two most important pre-requisites for any transgenic development programme are: availability of few good genes and a robust transformation protocol. While we have developed remarkable competency in maize transformation, we lack key genes of our own. GI 1 and GI 2 would fill this very critical gap in our research. Our initial focus would be use of native genes and promoters and use of system independent synthetic genes, like artificial miRNAs and other RNAi cassettes. Non-native constructs would be developed in various partnerships. The prioritized traits are: insect resistance, herbicide tolerance, disease resistance and abiotic stress tolerance in short-term; mycotoxin management, low phytate and nutrient use efficiency in medium term and nutritional enrichment, modified cellulose and molecular pharming in long term research agenda.

GI 5: Deliver superior single cross hybrids with diverse genetic base for various segments

The single cross hybrids have been the bedrock of the Indian maize programme for the last one decade, which saw quantum jump in maize productivity. However, narrowing of the genetic base of the elite germplasm is a matter of concern. There is a need to broaden the genetic base, develop new heterotic pools and continue to breed newer single cross hybrids with diverse base. Superior germplasm developed in GI 3 and GI 4, would have to be eventually incorporated in single cross hybrids for various end-user segments. Availability of doubled haploid technology is expected to enhance the speed of inbred line development. The inbred lines would be used to test various hybrid combinations. The stability and yield of hybrids would be ascertained in multi-locational trials before they are commercialized.

GI 6: Invent a new generation of eco-friendly and biosafe technologies for maize value chain

In the times to come, biosaftey concerns would dominate public discourse on food and agriculture. Biological interventions would be deemed more desirable than chemical interventions at all the stages of value chain- from farm to fork. Bio-fertilizers, bio-pesticides and pest control though cropping system, habitat management and Integrated Pest Management approaches would be in demand. The Institute is committed to address these concerns by delivering innovative biological solutions.

GI 7: Develop and popularize high yielding, profitable and ecologically sustainable maize-based farming systems

The newly developed genotypes and associated technologies have to be constantly contextualized in an on-farm agronomic system. With large scale urbanization, in future, production technologies would be heavily mechanized. The products developed from GI 5 and GI 6 and also technologies available from other sources have to be appropriately integrated to work out efficient, profitable and sustainable maize-based farming systems.

GI 8: Foster precision input management for higher productivity, profitability and environmental sustainability

Under this initiative, the focus would be to develop cutting-edge precision agriculture technologies for maize and bringing out modules of Good Agricultural Practices based on Low External Input Sustainable Agriculture (LEISA) concept.

GI 9: Popularize resource conservation technologies in maize systems

We would like to expand our activities in the domain of conservation agriculture that "strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment". The availability of herbicide tolerance trait would give a massive fillip to conservation tillage in next few years, which would necessitate higher research intensity in this critical area.

GI 10: Provide innovation support at critical points in maize value chain to strengthen value addition and secondary agriculture

Maize has a wide spectrum of non-food uses. Even in food segment, there is scope of considerable value addition in terms of novel foods based on speciality corn. Bio-fuel alone provides the single largest opportunity for value addition. The processing industry that uses maize feedstock has unique R&D issues, which were not adequately addressed in the past. The Institute is poised to engage with all the stakeholders and provide innovative solutions at critical points to strengthen maize-based secondary agriculture economy.

GI 11: Build new robust partnerships for science, product development and stewardship

The ICAR- Indian Institute of Maize Research is an important but not a solo stakeholder in the maize bio-economy. We will seek active collaboration and partnership with national and international organizations of public and private sector in all the activities that we do. Our capability in conducting world class research requires networking with national and international laboratories working at the frontiers. The Institute is a pioneer in initiating and spearheading a coordinated varietal testing programme at national level through All India Coordinated Maize Improvement Project (AICMIP). We would strengthen this network to make it a single-stop, all-encompassing and most credible platform of varietal testing, including testing of upcoming cultivars with transgenic traits. The Institute would also give a major thrust on Public Private Partnerships, specifically aimed at five key verticals: a) licensing of in-house technologies; b) co-development of products and technologies; c) expansion of varietal testing platform; d) seed production and e) industrial consultancies.

GI 12: Maintain and reinforce linkages with farmers and consumers

The Institute is already running a vibrant extension programme, which would be strengthened further. GI 7, GI 8 and GI 9 are of direct relevance to the farmers and their inputs would be incorporated in the research phase itself. Through its partners, the Institute would continue to support diffusion and adoption of latest maize production technologies among farmers. While our interface with farmers had been traditionally strong, we have to do more efforts in developing an interface with consumers. By 2050, a much larger share of the population would be on the 'consumption side' rather than the 'production side'. There would be a greater need to engage with urban consumers about their preferences and choices. Also, there would be a need to educate urban consumers about agricultural systems, who would be curious to know from where and how their food comes.

GI 13: Contribute for human resource development

Now it is globally accepted that, good public research cannot be conducted in the absence of a stimulating academic environment. It is not a co-incidence that all the good places of research in the world are also top class academic institutions. IIMR scientists are contributing for research as well as to academics. In line with the 'Student Ready' initiative and other such policies of ICAR, we are looking forward to considerably expand our Doctoral and Post-doctoral programmes in coming years with the help of our academic partners. With this, we would get bright young minds to work on cutting edge research on one hand , while on the other, students will get a quality agricultural education- a win-win situation for both research and human resource development. We would also build customized training programmes of short duration, catering to needs of various stakeholders.

GI 14: Provide a futuristic institutional framework for all round excellence

Twenty first century science cannot be done in an antiquated administrative framework of the twentieth century. The quest to do world class science poses fresh management and cultural challenges before publically funded scientific establishments. In line with the global best practices and thrust on e-governance, the Institute is committed to heavily adopt office automation and become a 'paperless' organization. Routine office processes, which consume unnecessary time and energy, like purchase, payroll, leave management, finance, internal communication, etc. would be done in electronic mode to increase efficiency and transparency. The Institute would enthusiastically implement reforms and new frameworks, like Result Framework Document, Sevottam, Right to Information, Electronic delivery of services, Citizen's Charter, etc.

Innovation strategy of IIMR

IIMR is the only institute in the country, exclusively mandated for maize research. Globally, maize research is a highly competitive area, which requires us to be at all times at the forefront of innovations and scientific excellence. The pace of research has dramatically increased after publication of maize genome in 2009. The Institute is gearing towards development of frontier technologies for 2050. The Institute is poised to enhance its attention on basic research, which is the most important pre-requisite for new technologies (Fig. 6).

The Institute aims to augment its IP portfolio and become the most sought after maize technology provider of the country. In line with global best practices, the Institute would focus its core competencies in basic scientific research, validation and IP generation for new technologies, while it would venture into commercialization mostly in collaboration with the industry in PPP mode. The success of the institute in fostering a

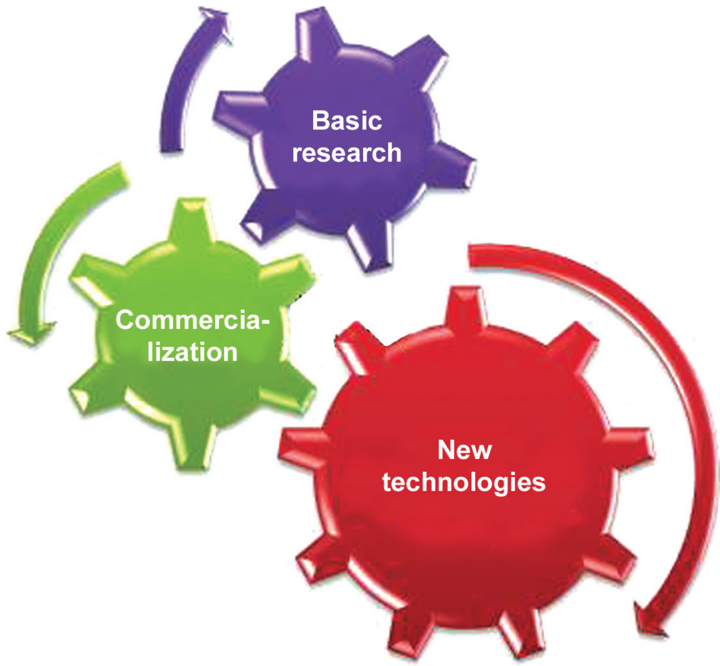

Fig. 6 Basic research and commercialization will drive use and further development of new technologies

new innovation chain pipeline could be measured by its enhanced quality of research publications, large IP portfolio, revenue from licensing and royalty, and ultimate impact assessment of technologies on the economy and the environment (Fig. 7).

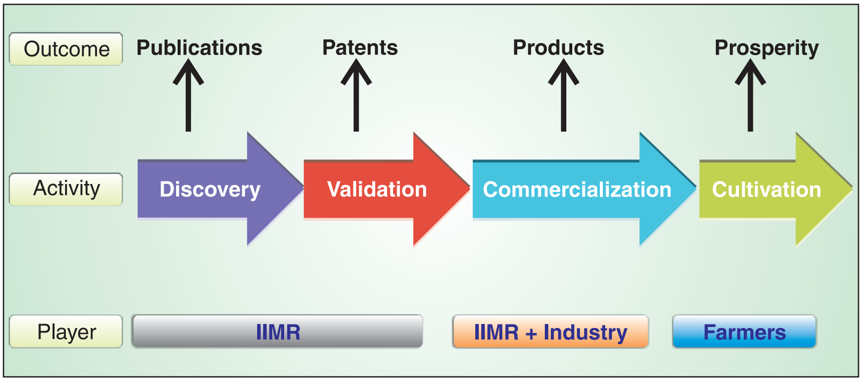

Fig. 7 Innovation chain pipeline of IIMR

It is hoped that by 2050, new scientific interventions would usher in an era of maize cultivation that is more productive, more profitable and more eco-friendly.

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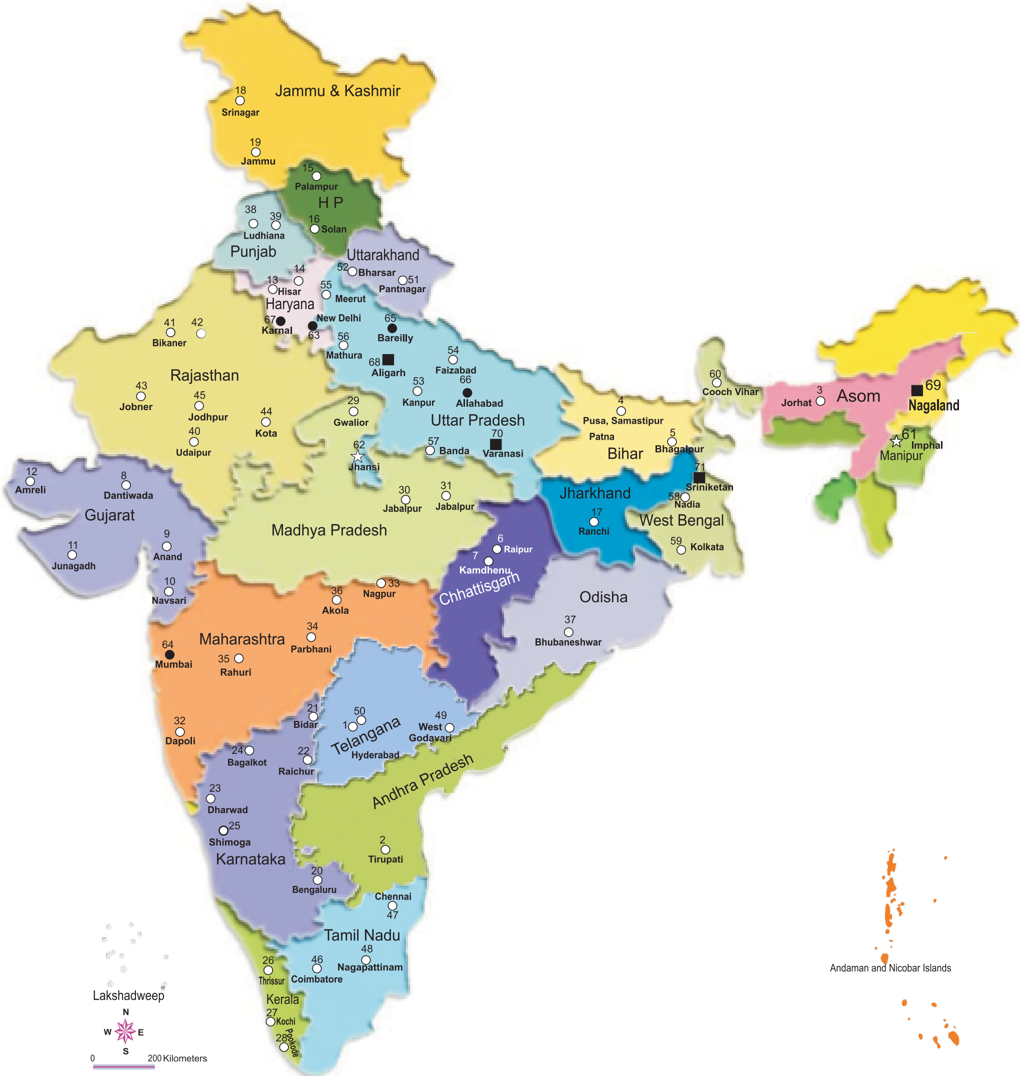

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