



Doubling maize (*Zea mays*) production of India by 2025 – Challenges and opportunities

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ABSTRACT

Maize (*Zea mays* L.) is a commodity of high economic significance in India. Its demand and production is increasing more rapidly as compared to other major commodities. It is estimated that by 2025, India would require 50 million metric tonnes (MMT) maize grain, of which 32 MMT would be required in the feed sector, 15 MMT in the industrial sector, 2 MMT as food, and 1 MMT for seed and miscellaneous purposes. Over this, there would be about 10 MMT of export potential also. Thus, in the next 10 years there is a necessity and opportunity for doubling India's maize production from the current level of approximately 25 MMT. Prevalence of yield limiting biotic and abiotic stresses, lower adoption of modern production technologies in certain regions, extension and policy gaps, etc. remain major challenges before the Indian maize sector. Therefore, strong technological and policy interventions would be required to achieve the goal of doubling maize production. By 2025, productivity level of 5-6 tonnes/ha need to be targeted, in order to double the production without significant increase in acreage. Technological interventions like cultivar development and diversification, incorporation of stress resilience in the germplasm, accelerating the breeding process through new tools, and adoption of modern cultivation and protection practices including conservation agriculture technologies would play a key role in increasing the productivity. At the same time, policy interventions like strengthening of post-harvest handling infrastructure, price stabilization mechanisms, and value chains, streamlining of extension system, augmenting hybrid seed delivery mechanisms, appropriate policy on genetically modified seeds etc. will be essentially required.

Key words: Demand, India, Maize, Production, Productivity, Projections

Maize (*Zea mays* L.) is the third largest grain crop in India, after rice and wheat. It is cultivated in an area of 9.09 million hectares (M ha), has an annual production of 24.26 million metric tonnes (MMT), and an average national productivity of 2.56 metric tonnes per ha (tonnes/ha) (Yadav *et al.* 2015). It is grown during rainy (*kharif*), winter (*rabi*) and spring seasons, but major production is in the rainy season. Maize has wide ecological adaptability and is grown in almost all parts of the country, though Andhra Pradesh (20%), Karnataka (17%), Maharashtra (11%), Bihar (9%), Tamil Nadu (8%), Madhya Pradesh (6%), Rajasthan (6%) and Uttar Pradesh (5%) are the major maize producing states.

Maize is the principal feed crop of the country. About 59% of the total production is used as feed, while the remaining is used as industrial raw material (17%), food (10%), exports (10%), and other purposes (4%) (Kumar *et al.* 2013). Because of its diverse uses in the feed, industry

and food sectors, maize is considered as an internationally important commodity driving world agriculture. Globally, it is grown in 184 M ha across 165 countries, with total production of 1 016 MMT, and average productivity of 5.52 t/ha (FAOSTAT 2014). It has emerged as the most-produced grain in the world, surpassing rice in 1996 and wheat in 1997. Its production is increasing at twice the annual rate of that of rice and three times that of wheat (Fischer *et al.* 2014).

During 1950-51, India produced only 1.73 MMT maize. In the next eight years, the maize production was doubled, touching 3.46 MMT in 1958-59. This increase was due to expansion in area and enhancement of yield. During this period, the area under maize cultivation increased by 35%, while the yield increased by 48%. It was also relatively easier to enhance the production on the back of a low base for both area and productivity. In 1970-71, maize production of India once again doubled to reach 7.49 MMT. During this period also, there was increase in both acreage (37%) and productivity (58%), though the enhancement in latter had greater contribution in doubling the maize production. The maize production of the country doubled again to 14.98 MMT in 2003-04 (Fig 1). During this period, maize area

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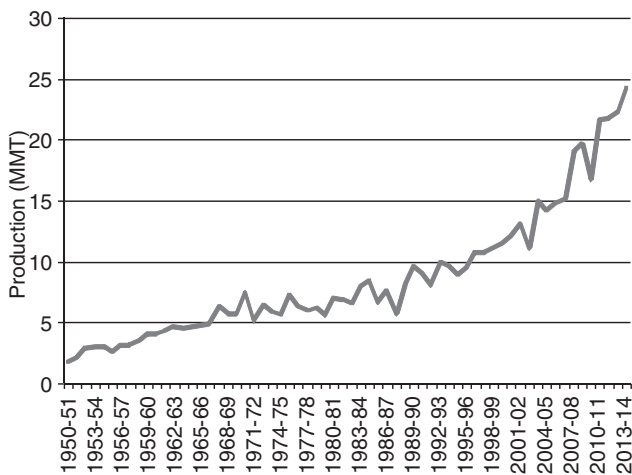


Fig 1 Trends of maize production in India since 1950-51 (Source: Agricultural Statistics at a glance 2014, Ministry of Agriculture, Government of India).

expanded by 25% only, which was relatively lesser than the previous two periods while, the major share in production enhancement was that of productivity, which increased by 60%. During the last five years (2010-2015), maize production of India has crossed 20 MMT, and presently stands at approximately 25 MMT. In this review, we discuss the necessity, opportunities and challenges for doubling the Indian maize production to around 50 MMT in the next 10 years, i.e. by 2025.

Taking the production from about 25 MMT to 50 MMT in 10 years translates into a required compounded annual growth rate (CAGR) of 7.18%. During the previous 10 year period (2003-04 to 2013-14), maize production in India has shown a CAGR of 4.98%. This clearly means that in the next 10 years, strong technological interventions and demand pull would be required in order to target the doubling of the production.

Production of commodities in a nation is largely determined by their demand and techno-economic competitiveness to produce and market them. In case of maize, the technological landscape for increasing maize production is largely positive as significant yield gap between realized and potential yield levels exists and enough opportunity lies of increasing the production by bridging this gap. However, another important question is whether or not there shall be enough demand pull to propel the production.

DRIVERS FOR FUTURE MAIZE DEMAND

Demand for feed

Presently, around 15 MMT of maize grain is used as animal feed, with poultry feed alone accounting for about 12.5 MMT. Maize is an ideal poultry feed and it would continue to be used heavily in this sector. Thus, growth in the poultry industry would have a direct impact on maize demand. The Indian poultry feed market is expected to grow at annual rate of 7-8%, with overall feed market

growing at CAGR of 8% (Anonymous 2015). With these growth rates, it is expected that by 2025, India would require about 32 MMT of maize grain for meeting its feed requirement.

Demand for industrial uses

The starch industry in India is at a nascent stage with the annual per capita consumption of starch in the country being merely 1.3 kg, as compared to 64.5 kg in the USA and over 10 kg in Asian countries like China and Indonesia. However, the same is likely to improve in the coming years, as starch finds diverse applications in the food and beverage, paper, pharmaceutical, textile, biofuel and other industries. Thus, with the rising demand for starch products from various industries, the Indian starch industry is expected to grow by around 15% per annum in the coming years (Anonymous 2012). Maize is a major source of industrial starch and it is expected that demand of maize for industrial uses would increase to 15 MMT by 2025 from the present level of 4.25 MMT.

Demand for food

In 2011-12, human consumption of maize in the rural areas was 1.56 kg/person/year, while in the urban areas it was 0.168 kg/person/year (NSSO 2014). Projecting from the 2011 census data, consumption of maize as direct human food stands at 1.36 MMT in the year 2011-12. From the past consumption surveys by NSSO, it is evident that the per capita consumption of maize in rural areas has reduced by more than 35% from 3.7 kg/annum in 2004-05 to 2.4 kg per annum in 2009-10, and further down to 1.56 kg per annum in 2011-12. In 2011-12, consumption of maize as food was reported relatively higher (more than 5 kg/person/annum) in the states of Himachal Pradesh, Gujarat, Jammu and Kashmir, Madhya Pradesh and Rajasthan. In urban areas, maize consumption continues to be low. However, keeping in view the recent interest of urban consumers in speciality corn, like sweet corn, baby corn, popcorn, quality protein maize (QPM) etc., and rising popularity of multi-grain flour, it is expected that demand for maize as food may touch 2 MMT by 2025.

Demand for export

India was a net importer of maize till late 1980s. However, it has emerged recently as maize grain exporter. In 2012-13, India exported 4.8 MMT of maize, but decreased slightly in next two years because export demand keeps on fluctuating as it depends on price of Indian maize vis-a-vis price from other exporters (Fig 2).

A large portion of Indian maize exports (85-90% of total) is exported to the South-East Asian countries like Indonesia, Vietnam, Malaysia and Taiwan, while, the remaining 10-15% is exported to the Middle-East countries, like United Arab Emirates, and South Asian countries like Bangladesh, Nepal and Bhutan. The Asian nations together constitute about half of the total world maize import of about 100 MMT. India enjoys both price and freight

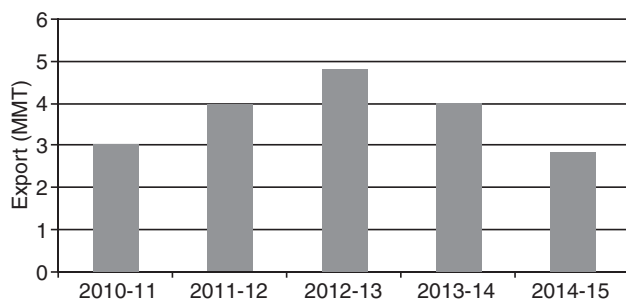


Fig 2 Quantity of maize export from India during last five years (Source: Department of Commerce, Government of India).

advantage in such a huge global maize market (Kumar *et al.* 2013). Across the 11 Asian nations importing more than 1 MMT of maize, India has a major presence as an exporter in only South-East Asia, mainly Vietnam and Indonesia. India should make efforts to increase its export to other important maize importers like Japan, Korea, Taiwan and China, as demand in these countries is continuously growing. With strong trade interventions and competitive pricing, it is expected that by 2025, India would have the opportunity to export about 10 MMT of maize, provided the domestic demand is met and there are exportable surplus.

Taking into account the demand scenarios in individual sectors, the overall maize demand is expected to be very robust in the next 10 years. By 2025, India would require 50 MMT maize for domestic consumption, of which 32 MMT would be required in the feed sector, 15 MMT in the industrial sector, 2 MMT as food, and 1 MMT for seed and miscellaneous purposes. Over this, there would be about 10 MMT of export potential. India needs to produce overall about 60 MMT of maize by 2025 to fulfil the domestic and export demand. Thus, doubling India's maize production by 2025 would be an opportunity.

CHALLENGES TO IMPROVING MAIZE PRODUCTIVITY

Drought is recognized as the most important constraint across the rainfed environments, which constitutes 75% of maize production area in India. This situation is likely to exacerbate in the coming decades due to changing climate, often leading to inadequate and/or uneven incidence of rainfall in the crop season alongside temperature changes (Bernstein *et al.* 2007). India is also facing increased frequency and magnitude of extreme weather events, including flooding, high temperatures, high wind, etc. (Prasanna *et al.* 2014). The changing climate not only affects the frequency and intensity of abiotic stresses, but also affects intensity of biotic stresses on crop plants. Maize in India is already affected by an array of diseases and insect-pests; these include the post-flowering stalk rots (PFSR), turicum leaf blight (TLB), banded leaf and sheath blight (BLSB), downy mildews, ear rots, stem borers and weevils, besides high incidence of mycotoxins in maize grain harvested in some parts of the country. With climate changes, diseases like PFSR and BLSB and insect-pests like pink

stem borer may become more serious.

Maize is particularly vulnerable to the reproductive stage heat stress. Climate projections also suggest that elevated temperatures, especially in the drought-prone and rainfed areas are likely to result in significant crop yield losses (Cairns *et al.* 2013). Spring maize is an important option for intensifying and diversifying cropping systems in India, but is prone to severe heat stress during flowering/early grain filling stages, particularly in the upper and middle Indo-Gangetic plains highlighting the importance of developing improved maize cultivars with built-in tolerance to high temperature stress (Cairns *et al.* 2013, Yadav *et al.* 2015).

Besides abiotic and biotic stresses, poor soil fertility (including micronutrient deficiencies) in degraded lands and low nutrient use efficiency also rank among the most important factors limiting maize productivity and yield stability in both high potential–low risk environments as well as low potential–high risk environments.

Low adoption of improved production technology continues to be a major challenge for improving maize productivity in India. Presently, only 65% of the maize area is under high yielding cultivars. Poor agronomic management of crop causes sub-optimal realization of yield potential of cultivars. Weed infestation in the *kharif* season is the single biggest challenge in maize-based cropping systems. Post-harvest losses due to poor drying facilities is yet another challenge before the Indian maize sector.

TECHNOLOGICAL AND POLICY INTERVENTIONS FOR DOUBLING MAIZE PRODUCTION

In next 10 years, strong interventions will be required to double the nation's maize production. An annual growth rate of 7-8% would be required to achieve the target. The main focus has to be on increasing the productivity rather than expanding the acreage. Productivity level of 5-6 tonnes/ha should be targeted, in order to double the production without expanding the area. However, a strong demand pull will also result in some expansion of maize area, mainly through cropping intensification. The maize area is expected to touch 12 M ha by 2025. Kumar *et al.* (2013) have predicted that major expansion in maize area is expected in Karnataka, Maharashtra, Odisha, Andhra Pradesh and Tamil Nadu. The ecology of maize cultivation in these states is relatively favourable and these states registered 141 to 445% growth in maize area during past 20 years (Table 1). The area has expanded in both the seasons during past two decades with net addition of 1.8 and 1.2 M ha area in *kharif* and *rabi* seasons, respectively (Fig 3). However, the growth in area has been much faster in *rabi* (267%) compared to *kharif* (33%) season which indicates that maize is now finding place in favourable ecologies. Thus, expansion of maize cultivation in irrigated favourable environment is likely to pay rich dividend for realizing the higher maize production in future. Like area, the productivity has also contributed significantly in enhancement of maize production. The enhancement in the yield has been to the tune of 57% during

Table 1 Area under maize in different states during 1995-2014 (Source: DACNET, Ministry of Agriculture and Farmers Welfare, Government of India).

States	Area in quinquennial period ('000 ha)				Change in 2010-14 over 1995-99 (%)
	1995-99	2000-04	2005-09	2010-14	
Karnataka	446	625	986	1315	+195
Rajasthan	938	1004	1036	1040	+11
Maharashtra	266	335	562	878	+230
Andhra Pradesh	362	531	756	874	+141
Madhya Pradesh	855	874	868	848	-1
Uttar Pradesh	1059	899	840	751	-29
Bihar	761	634	637	674	-11
Gujarat	391	433	480	487	+25
Jammu & Kashmir	305	325	317	309	+1
Himachal Pradesh	309	300	303	295	-5
Tamil Nadu	51	110	220	278	+445
Others	414	604	772	917	+121

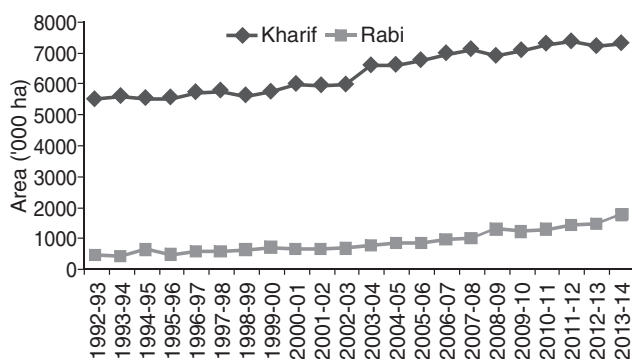


Fig 3 Trends of maize area in India during different seasons (Source: DACNET, Ministry of Agriculture and Farmers Welfare, Government of India).

last 22 years, though the increase has been more copiously in past one decade (Fig 4).

Kumar *et al.* (2013) have envisaged that India's maize production would touch 43.63 MMT in 2020, without any increase in area, provided hybrid adoption reaches 90% and the overall average yield reaches 5 tonnes/ha. The present

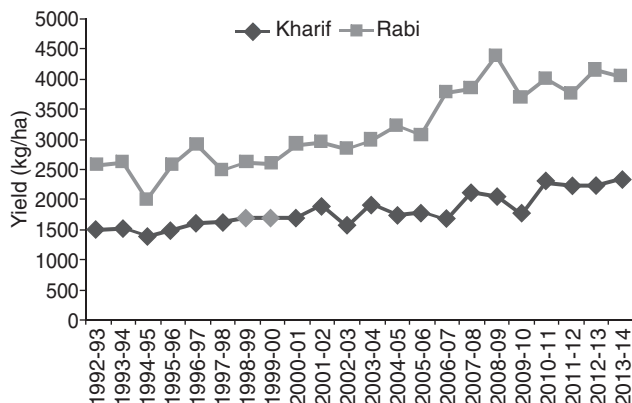


Fig 4 Productivity of maize in different seasons (Source: DACNET, Ministry of Agriculture and Farmers Welfare, Government of India).

maize productivity of some of the major maize growing countries like USA (10 tonnes/ha), China (6.0 tonnes/ha), Brazil (5.3 tonnes/ha), Argentina (6.6 tonnes/ha), and also in the neighbouring South Asian countries like Bangladesh (6.6 tonnes/ha) and Pakistan (4.2 tonnes/ha), indicate that there is a potential to increase Indian maize productivity from the current level of 2.56 tonnes/ha.

To achieve the targeted productivity level for doubling the maize production, both technological and policy interventions will be essential. While policy interventions are required to remove the bottlenecks in the Indian maize sector in the short-run, strategic maize research is vital to significantly enhance genetic gains and for sustainable intensification of maize-based cropping systems in the country.

Technological interventions

Diversification of germplasm base and heterotic grouping of germplasm: Genetic uniformity leads to vulnerability of the crop to pathogens, insects, and abiotic stresses, thereby compromising maize yields in the short as well as long run. Therefore, there exists a strong need to continuously infuse newer germplasm from diverse sources in maize breeding programmes of different organizations, engaged in maize improvement. Utilization of new and unadapted germplasm is a long process requiring a coordinated effort in germplasm collection/acquisition, and field and laboratory evaluation. In addition to reducing genetic vulnerability, introgression of diverse germplasm is pre-requisite for enhancing performance of all traits, including yield and yield components. The broadening of the germplasm base can provide novel traits, thus enhancing product value for stakeholders, and ultimately to the consumer. A project on the lines of Germplasm Enhancement of Maize (GEM) in the USA (Blanco and Gardner 2014) is required in Indian maize breeding programme as well.

Presently, there is little information on heterotic patterns in the Indian maize germplasm, except for some pioneering studies carried out at the Punjab Agricultural University (Dhillon *et al.* 1997). Assigning maize inbred lines to distinct heterotic groups would allow rapid exploitation of higher magnitude of heterosis. The strengthened germplasm base would provide much needed input for continued development of better hybrids, leading to enhanced maize production.

Development of stress tolerant germplasm: Presently, single-cross maize hybrids with a yield potential of 12-14 tonnes/ha are available; however, such a yield is obtainable only under stress-free and high-input conditions. On the other hand, maize fields in India are now increasingly experiencing more frequent droughts, rising temperatures, and occasional excess rainfall/flooding, as well as new pathogens and insect-pests. Therefore, the future of maize production, and consequently, the livelihoods of several million smallholder farmers who depend on maize for their income and livelihoods in India, especially in the *kharif* season, depends to a great extent on access to climate resilient cultivars.

For developing climate-resilient maize germplasm, breeding programmes need to incorporate, more efficiently, packages of traits. Maize farmers require varieties with tolerance to drought stress and elevated temperatures. Similarly, tolerance to both drought and waterlogging is becoming increasingly important. For developing such varieties, breeding programs may need to be expanded for simultaneous selection under combinations of stresses. This would warrant development of managed-stress screening sites and standardized protocols for specific combinations of stresses predicted in the target environment (Prasanna *et al.* 2014). In addition, advances in plant genetic engineering, RNA interference and targeted mutagenesis techniques also offer new opportunities in the long run to engineer maize germplasm resistant to biotic and abiotic stresses (Castiglioni *et al.* 2008).

Enhancing genetic gains and accelerating maize breeding with new tools/strategies: The ability to develop, in a cost- and time-efficient manner, elite maize hybrids with high yield potential and necessary adaptive traits (abiotic and biotic stress resilience) will be critical for the improved productivity and diversification of cropping systems. While conventional breeding was successful in developing an array of elite maize hybrids, rapid advances in breeding tools and techniques, especially doubled haploidy (DH), mechanization of breeding operations (to the extent possible), molecular marker-assisted breeding, high-throughput phenotyping for traits of interest, year-round nurseries, and decision support tools/systems offer excellent opportunities for improving genetic gains and enhancing breeding efficiency (Prasanna *et al.* 2014).

The DH technology enables rapid development of completely homozygous maize lines and offers significant opportunities for fast-track development and release of elite cultivars (Prasanna 2012). Besides simplified logistics and reduced costs, use of DH lines in conjunction with molecular markers significantly improves genetic gains and breeding efficiency. In India, both DH technology and molecular markers are presently used only by a few breeders/institutions. There is a need to rapidly integrate DH technology in maize breeding programmes, especially in the public sector.

With the rapid reduction in genotyping costs, new genomic selection technologies have become available that allow the maize breeding cycle to be greatly reduced, facilitating the inclusion of information on genetic effects for multiple stresses in selection decisions. Genome-wide association studies (GWAS), implemented through high throughput genotyping and precision phenotyping, has emerged as a powerful strategy for dissecting complex traits and identifying superior alleles contributing to improved phenotypes in maize (Prasanna *et al.* 2014). Concerted efforts are required to develop breeder-ready markers for resistance to some major diseases of maize in India.

Molecular marker-assisted breeding is the way forward in effectively meeting the greater challenge of developing cultivars with combinations of relevant adaptive traits,

including biotic and abiotic stress tolerance (Prasanna *et al.* 2014). The success of such a strategy strongly depends on the ability to accurately phenotype a large number of genotypes. However, the capacity of several institutions, including public and private sector institutions in India, for undertaking precision phenotyping, particularly under repeatable and representative levels of stress in the field, is lagging far behind the capacity to generate genomic information. Field phenotyping of appropriately selected traits, using low cost, easy-to-handle tools, is now possible, and should become an integral and key component in the maize breeding pipeline (Prasanna *et al.* 2013). There is also a distinct need for the public and private institutions to come together and establish “phenotyping networks” for comprehensive and efficient characterization of genetic resources and breeding materials for an array of target traits, particularly for biotic and abiotic stress tolerance and nutritional quality. This would significantly accelerate genomics-assisted breeding, diversification of the genetic base of elite breeding materials, creation of novel varieties, and countering the effects of climate change.

Conservation agriculture technologies: The Conservation Agriculture (CA) technologies provide an opportunity for planting of full-duration maize hybrid which result in higher yields owing to extending the crop season by 10-15 days due to saving of time in tillage operations. Beside this, these practices lower down the tillage cost by ₹ 2 000-4 000/ha and hence improve farm profitability. The adoption of zero-till maize in coastal Andhra Pradesh, Cauvery delta (Tamil Nadu) and Karnataka after harvest of rice became a success story of CA in India where farmers are harvesting more than 10 tonnes/ha (Jat *et al.* 2009, Timsina *et al.* 2009). The adoption of CA helps in moisture conservation and improvement in soil health and also been found beneficial in other cropping systems of maize when it is grown in rotation with wheat and mustard (Jat *et al.* 2011). The retention of residue and crop rotations in CA practices helps in arresting soil erosion and improvement in soil organic carbon and thus improves sustainability of maize systems. The adoption of site-specific nutrient management practices alongwith CA in maize can further enhance the crop productivity and nutrient-use efficiency (Kumar *et al.* 2015). Thus, in future the adoption of CA plus precision nutrient management in maize is expected to pay rich dividend in India for enhancing crop yield and soil health.

Policy interventions

In the next 10 years, a significant impact on maize production can be made by adopting appropriate policy measures. These steps can easily boost production in short-run, by bridging the yield gap using existing technologies. Adoption of single-cross hybrids, authorization of genetically modified (GM) maize for traits highly relevant to farmers, popularization of scientific package of practices for cultivation, price stabilization mechanisms, incentives for maize-based processing industries, etc. are some of the

measures that can help catalyze the countries' maize production scenario in both short-term and long-term.

Thrust on adoption of single-cross hybrids: In maize, single-cross hybrids are the most productive type of cultivars available today. A large number of single-cross hybrids were released for cultivation, that have yield potential of even more than 12 tonnes/ha. However, single cross hybrids currently constitute only 25-30% of total maize acreage. Rest of the area is planted with double cross hybrids and open pollinated varieties that are intrinsically low-yielding. Therefore, there is a need to popularize single-cross hybrids with niche adaptation on a greater scale. Producers of single-cross hybrid seeds should target their products in zones of specific adaptation of that particular hybrid. The government extension machinery also has to play a positive role in dissemination of single cross hybrids by linking them with the seed subsidy programmes and conducting front line demonstrations at the farmers' fields. The seed producers should explore innovations in seed production programmes, so as to reduce the cost of single-cross hybrid seeds.

Public-private partnerships especially for production and delivery of high-quality improved seed in the target geographies: To fully harness the advantages of improved single-cross hybrid maize cultivars, a robust seed production system is vital. Compared to varieties, which are self-perpetuating, hybrid seed production is a technically complex and resource demanding enterprise to be taken every year on continuous basis. Both public and private sectors are involved in maize seed production and distribution. In public sector, National Seeds Corporation, 15 State Seed Corporations, several State Department of Agriculture and Agricultural Universities are involved in seed production. However, major share in seed industry is of private sector. Hybrid seed production and marketing of maize hybrids developed by the public sector is undertaken by public sector organizations but enough seed is not produced to meet the demand (Yadav *et al.* 2015). Therefore, Public Private Partnership (PPP) between public sector research institutions and small and medium private seed companies needs to be strengthened further for production and marketing of public-bred hybrids. This would catalyze rapid dissemination of newly released hybrids, leading to enhanced productivity and production.

Popularization of scientific package of practices for intensification of maize-based cropping systems: The yield gap among different maize producing regions leaves ample scope for vigorous perusal of various extension measures. There is a need to disseminate the improved production technologies comprising scientific package of practices in the areas of low adoption. It is critically important to identify productivity limitations in different agro-ecological zones in India. In central and southern India, leaf diseases, stalk rots and drought are the major limiting factors. About 25-30% area in this region is affected by drought. In medium-yielding zone of northern and eastern India, there are problem of excess water and stalk rot. Similarly, for hill areas there is limited availability of good adopted cultivars. The scientific

package of practices, comprising of improved seeds, soil nutrient and tillage management, high planting densities, use of farm machinery, plant protection measures, post-harvest handling, etc. should be fine-tuned for each zone and disseminated through an effective extension system.

Policy on GM maize: Weeds and insects are two serious impediments that impact maize production and productivity in India. Presently available herbicides have only limited schedule of application in pre-emergence conditions and are not very effective during critical crop growth period. Similarly, the maize stem borer is a notorious pest and is reported to cause yield loss of 26-80% annually (Reddy and Zehr 2004). Effective GM-based technologies for weed management and stem borer control are already available and being used by maize farmers in other countries on a large scale for almost last 20 years. Adaptive trials of herbicide tolerant and insect resistant maize cultivars were going on for the past 9 years in India too. India needs a practical and futuristic policy on GM crops, with a timely and objective assessment of the GM technologies. This would certainly provide more options for crop management to the Indian farmers, at par with their global peers. A clear policy on GM maize or GM crops in general, would also augment ongoing scientific efforts for development of other relevant traits, like drought and disease resistance.

Strengthening post-harvest infrastructure: There is a huge shortage of proper post-harvest infrastructure facilities in India. It is estimated that in India, about 2.45% of maize is lost at the farmers' level during harvesting, threshing, winnowing, transportation and storage (Anonymous 2002). In Karnataka, the state with the highest maize cultivation in India, the post-harvest loss at the farm level was estimated to be 3.02%. About 0.68 kg/q of maize was lost at the storage level. About 0.49 kg/q was lost at the drayage level, whereas at transportation, threshing, packaging and cleaning level, losses were 0.44, 0.34, 0.15 and 0.10 kg/q, respectively (Basappa *et al.* 2007). There is a need to establish a chain of community-based driers to improve final grain quality. The installation of community dryers at producer level can address the issue of low quality of maize due to aflatoxins and storage pests developed due to high moisture at harvesting. The installation of affordable community/metal silos at producer level not only saves maize grains from pest infestation but it also prevents distress sale of crop at cheaper prices.

Price stabilization mechanisms: Realization of remunerative prices to maize farmers is a pre-requisite for motivating farmers to adopt scientific package of practices and increase maize production of the country. Unlike rice and wheat, maize as a commodity has grown on its own strength in the market dynamics. Although, the minimum support price (MSP) is announced every year, there is hardly any public procurement of maize, as it is largely outside the ambit of public distribution system (PDS). The market prices of maize have generally ruled higher than the announced MSP because of the strong market demand. One of the features associated with maize marketing in India is its

exposure to export market. About 3-4 MMT of the total produce is exported and this export volume depends on prevailing prices in the international market. Major maize producing and exporting countries are adopting technological advances and facilitating greater production at reduced costs. The depreciation of currencies of many countries, relatively lesser yield of Indian maize, and tight regulatory environment may further reduce competitiveness of Indian maize, unless corrective measures are taken. The continuing fall in the crude oil prices and the ample US-shale oil output is likely to trigger price compression of ethanol and other bio-fuels, which in turn may cause a reduction of consumption of maize, leading to depression in prices. Maize exports from India in 2014-15 have fallen to 2.8 MMT, from a high of 4.8 MMT in 2012-13- a reduction of 41% (Fig 2). The fall in export volume triggered an exceptional domestic price crash in 2014-15, as seen in the major maize producing state Karnataka. In the years of price crash, there should be some mechanisms for compensating the farmers through government supported price stabilization funds. In the larger context, however, it is expected that strong domestic market demand would continue in next 10 years and farmers would get remunerative prices.

Strengthening maize value chains: The complete production-to-end user value chain needs to be strengthened for the higher growth of maize in India. The price difference between the farmer's realization and the end user is about ₹ 585/tonne of maize production which can be eliminated by creating the business model of direct purchase by end user/ industries without brokers. The contract farming or cooperative farming can be effective in such direction so that the benefits of maize production can be shared between the producer and the industries for improving affordability to the end users. The logistics for bulk handling systems of maize from farm to port needs to be strengthened through development of good roads and carriage to facilitate global market competitiveness in export. The development of efficient and integrated maize grain market is essential to drive simultaneously the maize seed sector (Kumar *et al.* 2013). So, the value chain strengthening from producer to end user will enhance maize production and consumption.

Incentive for maize-based processing industries: The maize processing industry in India is still in its infancy, unlike countries like US and China. There is a huge potential to increase the use of maize in industrial applications. Maize starch is used as an adhesive in the textile industry, as a thickener in food industry, for increasing paper strength in paper industry, as filler in pharmaceutical industry, as feedstock for manufacture of glucose, dextrose, ethanol and a number of other products (Eliasson 2004). Maize wet milling is the chief process employed for processing of maize starch within India. In India, about 40% of the total companies engaged in starch production are new entrants. These entities require greater incentives for establishing a robust maize starch industry. Growth in the starch industry would translate into greater demand of maize and remunerative prices for the farmers.

Empirical analysis presented here clearly indicates that in the next 10 years, doubling of maize production of India should receive high priority to meet the rising demand from different maize consuming sectors and to tap the emerging opportunities for maize export internationally. Both research and policy interventions would be necessary to achieve this goal. These interventions would help in achieving the target productivity level of 5-6 tonnes/ha by 2025. Coordinated efforts of various organizations and stakeholders would create right environment and provide opportunity to overcome the challenges and double India's maize production and productivity by 2025.

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