

Maize - an alternative cereal for crop diversification in changing climate

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Abstract: In India, the cereal consumption and hence, production patterns have changed with more rice and wheat and less coarse cereals such as millet, maize and sorghum, resulting in consistent decline in groundwater availability especially in the country's northern states, raising concerns for cereal production and self-sufficiency. *Kharif* maize, with less water requirement than paddy, has been recognized as a candidate crop in crop diversification plan to break predominant wheat- paddy status quo. Moreover, maize - wheat cropping system lead to about 10 per cent higher productivity of wheat than paddy-wheat crop rotation. But poor competitiveness of maize v/s paddy, price instability, yield gaps and instability of performance, less mechanized, rice-wheat oriented infrastructure, market and processing are major issues for a large scale cultivation of maize. Maize yield enhancement, which is a major driver for its economic viability and farmer's acceptance, need to be addressed on priority dovetail with mechanisation, nutritional enrichment and infrastructure development especially for specialty corns. Maize, being a multi-purpose crop and its strong emergence as industrial crop ensures its stable and perpetual demand. In India, as our major cereal consumption needs are met from domestic production, the country has an excellent opportunity for strengthening crops like maize as an alternate cereal with less water requirement, reduced environmental burden of agriculture and more nutrition.

Keywords: Alternate cereal · Accelerated breeding · Maize · Genetic enhancement · Productivity

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Introduction

India is on the brink of a severe water crisis due to heavy-water extraction for irrigated agriculture and a weakening monsoon. Green revolution, though, led to self-sufficiency in cereal production but fuelled largely by depletion of freshwater resources for irrigation, nutrient pollution from injudicious fertilizer application and rising greenhouse gas emissions.

As vegetarian Indian diets generally derive a large fraction of nutrients from cereals, these mounting population and environmental concerns necessitate decisive assessment of the rice-wheat status quo of the Indian food system and need for alternate pathways toward healthier food baskets with less environmental burden (De Fries *et al.*, 2015). While emphasizing the considerable urgency for improved compatibility between food security and environmental stewardship in India, Davis *et al.* (2018) mentioned that a national analysis of the potential nutritional and water use benefits of alternative cereals (viz., maize, millets, and sorghum) is still lacking for India. Endorsement of maize, a lower blue water footprint crop (maize has 49 mm H₂O per year cumulative blue water requirement, whereas rice has 307 mm H₂O per year), as a candidate to replace paddy during *Kharif* season will contribute in a profound way as three-fourth of Indian maize production is in the *Kharif* season which depends mainly on the south west monsoon (Kayatz *et al.*, 2019). India's public distribution system is the best platform to begin/realise the transition to alternate cereals.

The impacts of climate volatility on cropping systems/patterns and their productivity, and on severity and alteration of biotic and abiotic stresses, have also emerged as serious challenges for sustainable agriculture. The spread of desert locust, *Schistocerca gregaria*, in western parts of India in winter 2019-20 is the recent example of the threats due to

climate volatility. There are many other examples of changes in incidence and severity of pests. The deadly polyphagous pest fall armyworm (FAW), *Spodoptera frugiperda*, with a strong preference for maize (*Zea mays* L.), has invaded India in May 2018. Since its first report from Karnataka, it has spread to almost all the states (except Himalayan region). Pink stem borer, *Sesamia inferens*, a key insect pest of paddy was earlier restricted to the peninsular India. Its incidence was reported in other crops also. In Punjab, it used to appear in paddy but not in wheat till recently. The predominance of paddy-wheat crop rotation may have hastened the incidence of some pests along with their climate change-aided biological and ecological adaptation to the conditions in new areas.

In this scenario, we need to shift our agriculture towards more resilience and sustainability to ensure national food and nutritional security and farmers' livelihood. Maize is an important alternative to paddy for crop diversification particularly in Northern India in the wake of depleting water resources, reduction in on farm diversity and environmental pollution due to paddy straw burning. Moreover, maize-wheat cropping system leads to 10–12 per cent higher productivity of wheat than paddy-wheat crop rotation. But poor competitiveness of maize crop in comparison to paddy in terms of low productivity, price instability, wide gaps in potential and farmer's field yields, less mechanization, rice-wheat oriented infrastructure, marketing and processing are major issues for a large scale cultivation of maize.

We, here, made efforts to highlight the researchable aspects to be strengthened to make maize as a commercially viable alternative cereal in prevailing Indian scenario.

Maize – a crop of diversified utility

Maize is queen of cereals, surpasses all other cereals and food crops in its ability to adapt to diverse agro-ecological niches and being cultivated from 58°N to 55°S latitude. In India, it is traditionally a *Kharif* season crop, but it is now cultivated in *Rabi* and spring seasons too. Being a C₄ plant, it has a competitive edge over C₃ cereals and has inherent potential to cope up upcoming challenges of drought, high temperature, and carbon dioxide limitation conditions. The grain feed industry is growing at a Cumulative Annual Growth Rate (CAGR) of 6–7 per cent globally and in India at 9 per cent with poultry, cattle, piggy and aqua feed sectors emerging as major growth drivers (Rakshit *et al.*, 2021). The Indian animal feed market was worth INR 400.5

billion in 2018. The market is further projected to reach INR 898.5 billion by 2024, growing at a CAGR of 14.3 per cent during 2019–2024 (India-animal-feed-market Report-20-21).

With the largest global livestock population, the dairy sector is playing a critical role in providing livelihood opportunities to millions of people, largely women, in rural sector of India. Since 2006, India has witnessed a major shift from vegetarian diets toward diets containing larger amounts of meat. Factors like urbanization, greater exposure to newer cultures, and increasing disposable incomes could be possible reasons for the shift.

Poultry is a highly vertically integrated industry in India and matches the efficiency levels of many western countries (Opportunities in poultry sector in India, 2020). Feed accounts for about 60 per cent of the maize consumption in India. The major driver of maize demand is poultry feed which accounts for 47 per cent (as the main source of energy in poultry feeds) while other livestock feed accounts for 13 per cent of total maize consumption (Rakshit *et al.*, 2021). Piggery is also becoming an important and providing employment opportunities to rural farmers with supplementary income to improve their living standards. The availability of feed plays an important role in transforming subsistence pig farming to a market-oriented meat business. As a fish feed, maize enables generative fish gain maturity very fast.

Maize also serves as an important source of green fodder and stover fodder amongst the non-legumes as its plant biomass is a good source of protein (11.4 per cent) and total digestible nutrients (66.2 per cent - which are highest among non-legume fodders). The proteins and total digestible nutrients, respectively, in pearl millet are 8.8 per cent and 58.2 per cent, sorghum 9.0 per cent and 55.0 per cent, Napier *bajra* 8.7 per cent and 59.3 per cent and guinea grass 10.8 per cent and 62.4 per cent. Moreover, maize fodder is soft and easy to cut, does not require much labour and has low machinery cost for processing.

Maize is also preferred for silage making over other fodders due to its softness, higher starch content (about 18 per cent) and no anti-nutritional components. Green fodder and silage which is cut at silking to milking stage is more nutritious, less fibrous and more digestible. Green maize is rich in protein and possesses sufficient quantities of soluble sugars required for proper ensiling. Cows fed on maize silage produced more milk and consumed more silage dry matter in than those fed sorghum silage (Lance *et al.*, 1964). Maize silage is used extensively for lactating

dairy cows that require high-energy feed for maximum milk production (Marsalis *et al.*, 2010).

Development of dual purpose maize

For optimum milk production, around 40 kg of green fodder is required to feed per animal per day. However, a huge deficit exists between the demand and supply of green fodder in India. The specific research efforts to develop maize for dual purpose (grain + stover) and fodder (green maize harvested at dough stage) have not been rigorous. Given the prevalent fodder shortage in India, the quality stover from superior dual-purpose maize varieties can replace sorghum stover with substantial decrease in the feeding cost (Erenstein *et al.*, 2011). Therefore, there is an imperative need to develop maize varieties which can be used as green fodder and for silage making by harvesting at milking stage or as dual purpose for both grain and quality dry stover at harvest. In addition to serve as food, dual-purpose maize can meet both the poultry industry demand for grain and the demand for good quality stover to feed cattle. Focusing on maize breeding for fodder is very important for the promotion of dairy industry which is essentially required for diversification of agriculture.

PAU bred J1006, fodder purpose variety, and released in 1989 is a ruling variety even today along with an introduction, African Tall. In an evaluation by the National Dairy Development Board (NDDB) of PAU-bred hybrids, PMH-1 was reported as a very good for silage making.

Maize grain productivity enhancement

Undoubtedly, we have made significant progress in enhancing productivity which rose from 1 to 3 t/ha during 1965-66 to 2019-20 at the national level. To further enhance productivity, however, some traits need to be given greater emphasis. Development of longer maturity duration hybrids than those presently available, and incorporation of temperate germplasm from US and other regions having high genetic potential and rapid grain filling, need to be emphasized (Sandhu *et al.*, 2019). With combine harvesting, lodging resistant has gained importance for which strong root system, thick stem, low-medium ear placement and stay green traits are needed. The long duration hybrids should also have rapid dry down of ears/grains. Development of hybrids well adapted to high plant density (HPD) is another key area to break the yield plateau

(Dhillon *et al.*, 2019). Historical perspective of maize breeding and quantum jump in maize productivity in last centenary in tropical countries has well demonstrated that yield potential per plant has not increased over the years. With high plant density (HPD), productivity per unit area was increased. Tropical maize is inherently distinguished with tall stem, numerous long dropping leaves, bushy tassel, rapid post-silking leaf senescence and prone to lodging (Sandhu and Dhillon, 2021). There are a few reports of evaluation of hybrids under HPD (Dhillon *et al.*, 1978) but no systematic efforts have been made to develop the plant type through incorporating key traits- plant height, leaf angle, anthesis to silking interval (ASI), barrenness, kernel number and weight, tassel branching along with resistance to lodging in tropical maize. The selections for these traits over years have led to success of HPD in temperate maize. Therefore, there is need to re-design maize for amenability to HPD stress (Sandhu and Dhillon, 2021).

Temperature and moisture extremes, unseasonal rainfall, droughts, floods, cloud bursts, cyclonic storms etc. are becoming more frequent and consequently, the impacts of climate volatility on severity and alteration of biotic and abiotic stresses, have emerged as serious challenges for the scientific community (Dhillon *et al.*, 2019). Water logging (WL) is an emerging stress resulting from large and unpredictable fluctuations in weather patterns. The contingent flooding by excessive rainfall and inadequate drainage constraints the maize production in Asian tropics and other parts of the world (Singh *et al.*, 2017) and over 18 per cent of the total maize cultivating area in South and Southeast Asia alone are frequently affected by water logging problems. Maize is susceptible to water logging stress especially during germination and at the flowering stage when excessive rains lead to pollen wash and hampers seed set (Dhillon *et al.*, 2019). So, there is an urgent need for deeper insights into the mechanisms of crop adaptation to water logging. QTLs for adventitious root formation (Mano *et al.*, 2005); for leaf injury (Mano *et al.*, 2006); for aerenchyma formation under non-flooding conditions (Mano *et al.*, 2007); for root dry weight, root length, plant height, shoot dry weight, total dry weight and WL tolerance coefficient (Qiu *et al.*, 2007); for aerenchyma formation in non-flooding conditions (Mano *et al.*, 2008); for effective brace root tier number and total brace root tier number (Ku *et al.*, 2012); for seedling height, shoot dry weight, shoot fresh weight, root length, root dry weight and root fresh weight (Zhang *et al.*, 2013); for chlorophyll

content, brace roots, root lodging and yield (Zaidi *et al.*, 2015) and QTLs for shoot fresh weight, root fresh weight, root length, root dry weight, shoot dry weight and seedling (Osman *et al.*, 2017) have been reported which have potential to improve WL tolerance in maize. The molecular markers available and strategies to utilize have been reviewed by Sandhu *et al.* (2021). The identified QTLs should be fine mapped and these tightly linked DNA markers can be further used for transferring WL tolerance traits from tolerant inbred to economically important inbred lines having desirable agronomical backgrounds through marker-assisted backcrossing (MABC) or development of WL tolerant superior line through marker-assisted recurrent selection (MARS). Most of the QTLs were identified for root biomass and adventitious root whereas other important root parameters like root surface area, root density, root volume has not been accounted for by researchers due to its labour-intensive phenotyping. The invent of high throughput phenotyping can add flavour to evaluation methods, which may enable the scientist to have a detailed understanding of WL tolerance especially for root traits.

Bridging yield gaps through agronomic interventions to realize potential yield and promotion of drip irrigation to harness the potential of spring maize are other major areas seeking attention. These should get priority as these efforts will have immediate impact. National maize productivity is 3.05 t/ha whereas experimental yields of improved hybrids hover around 6.5–7.5 t/ha. To make maize a commercially viable crop, this wide gap needs to be plugged in through large scale front-line demonstrations of the high yielding varieties, along with the improved production and protection technologies particularly during *Kharif* season. Some of the factors which also need to be emphasized are use of good quality seed, precision sowing, weed control, and taking care of the crop facing biotic/abiotic stress.

Redesigning maize as a nutri-cereal

Now, there is clarion call to re-orient our research strategies to nutritional security of masses. With its high content of carbohydrates, fats, proteins, some of the important vitamins and minerals, maize acquired a well-deserved reputation as a ‘poor man’s nutri-cereal’ (Prasanna *et al.*, 2020). Normal maize protein possesses low nutritional significance to humans because of very limited amounts of major amino acids, such as lysine (1.6–2.6 per cent) and tryptophan (0.2–0.6 per cent) (Chandran *et al.*, 2019),

which is less than half of the recommended dose specified for human nutrition. Development of high yielding, high lysine and tryptophan maize, commonly known as Quality Protein Maize (QPM) and biofortified maize enriched in beta-carotene (provitamin A) holds significant promise. The bioavailability of Zn in maize grains is only 20 per cent in the human gut (Andersson *et al.*, 2017). The major impediment of low bioavailability of Zn has been the presence of phytic acid/phytate that constitutes nearly 75–80 per cent of the total phosphorus in maize grains (Raboy, 2001). Phytate being negatively charged has a strong tendency to chelate positively charged metal ions, such as Zn, thereby resulting in highly insoluble salts with poor bioavailability of the nutrient (Zhou and Erdman, 1995). Hence, bringing down the phytate in maize could be an important strategy for Zn biofortification. Further, the high carotene content of yellow grained maize is considered very useful in imparting yellow colour to egg yolk so is important in poultry industry. Poultry diets based on maize and soybean [*Glycine max* (L.) Merr.] require methionine supplementation because both grains have inadequate methionine concentrations. Feed supplementation with commercially produced methionine is used to alleviate these deficiencies but also increases poultry production costs (Waldroup *et al.*, 1981). Genetic approaches to increase the level of methionine in maize grain will provide a more nutritionally balanced feed source.

Specialty maize

There is a good possibility of diversifying maize cultivation by promoting specialty maize types, namely baby corn, pop corn, sweet corn and waxy corn. Baby corn is a very delicious, nutritious vegetable and has high export potential to further boost to its cultivation. Sweet corn is being utilised in hotels and big restaurants. A significant quantum of green biomass is available from specialty corn cultivation, which can efficiently be used as animal fodder. These are high value crops and therefore helpful in increasing farm income. In baby corn, prolificacy and male sterility are important traits. In pop corn, popping ratio is 20–25:1 which needs to be upgraded. Waxy maize having nearly 100 per cent amylopectin compared 75 per cent amylopectin and 25 per cent amylase in normal maize kernels, is gaining popularity as instant energy source. There is a significant export market for waxy maize in Europe and Asia.

Major constraint in the commercial cultivation of specialty maize types, like that in biofortified, is their poor agronomic performance as compared to normal corn. Thus, research efforts need to be strengthened for which resources need to be generated may be through Research-Industry interface. In addition, infrastructure facilities like small scale processing units, cold chains, storage facilities and strong linkage of farmers and industry are need to be addressed.

New breeding approaches coupled with accelerated line development

Breeding methods namely modified S1 recurrent selection, recurrent selfed plant mass selection and comprehensive recurrent selection have higher genetic gain per year compared to population improvement methods available earlier. Advances in next-generation sequencing technologies have taken the implementation of SNPs for genetic analysis to a new level. The use of marker assisted selection (MAS) in plant breeding programs has been accelerated since the advent of the genomics era. Rapid progress has been made in the developed world in rapid development of inbred line through doubled haploid (DH) technology using haploid inducer stocks. This approach shortens the time span required for the line development by 3-4 generations. This should be integrated as systematic and regular activity in commercial breeding program. The efforts on the identification of desirable genes and QTLs governing biotic and abiotic stresses and their funneling into maize gene pool must be expanded. *Maize* stem borer, *Chilo partellus*, is already a serious pest and now FAW, *Spodoptera frugiperda*, with a strong preference for maize, has emerged as a very serious one. The increased incidence of banded leaf and sheath blight caused by *Rhizoctonia solani*, also needs an urgent attention. Heat and moisture stress tolerance are also key components for spring crop. Transfer of identified QTLs for these stresses in spring maize parental lines through MAS will expedite the breeding program.

The availability of new molecular tools has potential to accelerate introgression breeding and have enhanced interest in the identification and exploitation of desirable genes in landraces and wild progenitors. Teosintes are a valuable source for broadening and enriching the maize gene pool. The close genetic relationship between the two subspecies, namely maize and annual teosinte (*Zea mays* sp. *mexicana*) has greatly stimulated interest in this regard.

Zea mays sp. *mexicana* has excellent potential to produce high biomass and can expand the fodder production potential of maize. Research is going on at PAU to use the genes for resistance to leaf and sheath blight in this subspecies (Garg *et al.*, 2019). Other teosintes, namely *Zea perennis* and *Zea diploperennis* showed resistance to biotic stresses and *Zea luxurians* and *Zea nicaraguensis* are adapted to frequent rainfalls and possess unique flooding resistance traits. The annual teosinte, *Zea mays* sp. *parviglumis*, the closest ancestor of modern maize, has good tillering and re-growth ability and hence, can serve as an excellent source to fodder maize breeders to develop multi-tiller high biomass yielding cultivars (Choudhary *et al.*, 2020).

Conclusion

To realise the demand driven potential of maize as ‘the future cereal crop’, a dedicated effort by researchers and holistic support by policy makers is an inevitability. Under Punjab conditions, with existing crop productivity of near 4 t/ha, there is a loss of about Rs. 17,500 Rs/ha in economic returns to maize growers in comparison to paddy. Such profit gaps has to be plugged in for initial promotion of large scale maize cultivation. It is necessary to have coupling of strategies and interventions around technological innovations, policy support, marketing linkages, supporting infrastructure and strong public private partnership for economic viability of maize crop. Improvement in the maize value chain across its various stages will be extremely crucial for making Indian maize competitive in international market both in terms of quality and prices.

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