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Unlocking the Golden Grain: Economic Trajectories, Constraints and Future Horizons of Maize in India in the Changing Climate Scenario

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ABSTRACT

Maize (*Zea mays* L.) has become one of the most dynamic and economically important cereal crops in India owing to its adaptability, versatility, and the increasing demand for it in the country due to its suitability for a wide range of agroecological zones. The present review paper deals with the economic status and future prospects of maize cultivation in India. Maize has seen significant expansion in area, production and productivity over the last 30 years, much due to the adoption of high yielding hybrids, better agronomic practices and the growing demand by the poultry feed industry and industries. The agroecological benefits of the crop, such as water use efficiency, adaptability to different climates and cropping systems, render it a suitable substitute for water-hungrier crops like rice. Recent agronomic developments like precision agriculture, mechanization, site-specific nutrient management and climate smart practices have improved productivity and resource-use efficiency. Maize is highly profitable and also has a positive cost–benefit ratio than other cereals and is less input intensive in comparison to other cereals with the increasing market opportunities. Despite this, there are several limitations in the sector, such as low productivity in rainfed fields, pest and disease pressure, climate variability, price volatility, and poor institutional support, particularly weak procurement systems, and limited infrastructure. The manuscript also brings to attention the increasing importance of maize in the bioeconomy in India, especially in ethanol production, which will be further bolstered in the future by national blending mandates. The maize value chain is further strengthened by increased industrial applications, value added products, and increased private sector participation. However, sustainable development and food security issues, particularly the competing uses of food, feed and fuel, must be addressed with thought and policy-making considerations. In conclusion, maize has tremendous potential for supporting agricultural growth, improving farmers' incomes and strengthening energy security, provided that various technological, economic and policy bottlenecks are overcome to achieve sustainable and inclusive development.

Keywords: Climate resilience, climate-smart, cost-benefit ratio, food security, sustainable development

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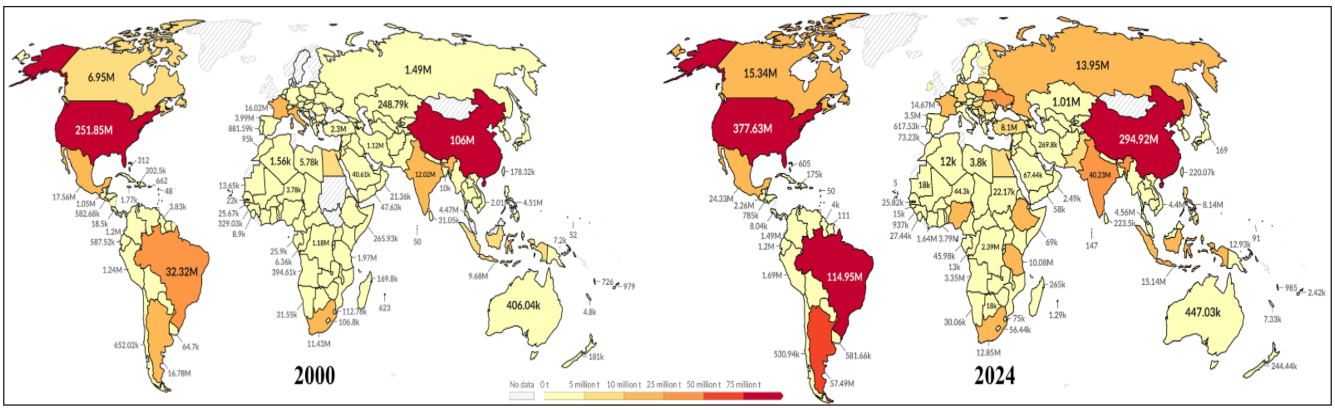
Maize (*Zea mays* L.) is one of the crucial cereal crops in the world due to its high yield, adaptability and versatility of end use. Maize is often referred to as the "queen of cereals," and it is a key staple for food security, animal husbandry, and industrial manufacturing globally (Maitra *et al*. 2024a; Maheswari *et al*. 2025a, b; Ray *et al*. 2025a, b). Maize is the third largest cereal crop in India after rice and wheat, and its significance has grown significantly in the past 30 years due to technological progress, growing demand, and policies support (Fig. 1) (Erenstein *et al*. 2022). It's increasing role in diversified agriculture systems makes it a significant consideration in the framework of economic growth and structural transformation of Indian agriculture. The important of maize crop in Indian agriculture is imperative, due to its diverse applications in food, feed, fodder and industrial uses (Parvaz *et al*. 2025; Sairam *et al*. 2025a, b). In the past, maize has always been used as a food grain in the tribal and hilly areas but with the passage of time, its use in recent years has gone towards commercialization. Production of maize is now nearly 60–65% utilized in the animal feed industry, especially in the fast-growing poultry industry where maize is the primary component of the energy-rich feed (Sairam *et al*. 2024). This transition has helped to build the interfacing of the cropping system with the livestock sector, marking the progress toward the protein economy in India. Moreover, maize is a vital green and dry fodder for livestock and plays a significant role in integrated farming systems and improving farm sustainability (Meena *et al*. 2026).

Maize is also a major industrial crop with a variety of applications in food processing and manufacturing industries. It is highly utilized as a raw material in the production of corn oil, liquid glucose, dextrose, and starch, as well as various other processed food products (Deepak and Jayadeep 2021). Maize consumption in human food is used in traditional foods and processed foods like cornflakes, snacks, tortillas and bakery products, and has been increasing due to urbanisation, income growth, and dietary changes (Manasa *et al*. 2021). While consumption of maize as food directly represents a smaller proportion of maize use, there is a constant increase in demand for value-added food products from maize. Further, India has export potential in maize, with the neighbouring and Southeast Asian countries such as Nepal, Bangladesh and Vietnam, but sometimes export volumes are reduced due to the growing domestic demand for maize. Additionally, maize has a high contribution to the agricultural gross domestic product (GDP) and rural livelihoods in India from an economic point of view. The crop is a high-income option for farmers especially small and marginal farmers because of its relatively low water requirement, adaptability to various agro-climatic conditions and rapid turnaround of crop (Bhat *et al*. 2024). In recent years, the gross value of output from maize has continued to grow and it is becoming more significant. Besides, maize production has a broad value chain that encompasses seed production, input supply, processing industries, transportation and marketing which in turn generates farm and non-farm employment opportunities. It has the potential



Source: Food and Agriculture Organization of the United Nations (2025) with major processing by Our World in Data

Fig. 1: Global maize production over two decades

to improve rural economies through linkages with livestock and industrial activities and increase income diversification (Grote *et al*. 2021).

Additionally, maize has become an important crop in the developing bioeconomy in India, especially for ethanol production, in recent years. Maize is being increasingly used as a raw material for ethanol production due to the ethanol blending initiatives by the Government of India (GoI), which help release traditional sugarcane-based ethanol and shift to alternatives from grains (NAAS 2024). The Government of India's ethanol blending programs, including E10 and E20, have boosted the demand for maize as a raw material for ethanol production, thereby facilitating the transition from sugarcane-based ethanol to alternatives derived from grains (NAAS 2024). Despite the high competition from sugarcane, maize now forms a major proportion of feedstock for ethanol production and is being supported by favourable policies, pricing incentives and investments in distilleries using maize as feedstock. This shift is significant for energy security, fossil fuel import reduction and in favour of a sustainable bio-based economy. Simultaneously, it helps to boost the rural economic development through new market opportunities for farmers, and enhancing agri-industrial linkages. The growing use of maize for ethanol, however, also brings up food-feed-fuel trade-offs, requiring policy interventions with balance to provide sustainable development (Nduwimana *et al.* 2020). Considering the above facts, this paper reviews the economic status and future prospects of maize cultivation in India.

Growth of maize cultivation in India

Maize production in India has increased by a lot during the past few decades and is now a cereal crop grown for commercial purposes. The expansion has been supported by increased demand from the poultry feed sector, the starch industry, the ethanol industry, and technological progress and government incentives (Erenstein *et al*. 2022). In recent years Maize production in India has exceeded 40 million tonnes and is one of the highest global producers due to the sustained increases in the area and productivity. The adoption of hybrid maize and diversification of cropping systems has further consolidated its role in the Indian agriculture sector (Datta *et al*. 2026).

Trends in area, production, and productivity

Maize production, area coverage and productivity has witnessed a consistent growth in India over the last 30 years. The maize area had an estimated compound annual growth rate of 2.0%, production increased 4.6% and productivity increased 2.6% over the last 30 years, from 1991 to 2020 (Likhitha and Permual 2025). The production increment has been increasing mainly because of higher yields and not because of just greater land area being cultivated. Productivity growth has been markedly increased after the early 2000s, largely as a result of the shift to hybrid seeds. Maize production in India has experienced a significant rise in the last few years, due to technological advancements and better crop management practices. Production has increased from approximately 20 million T in the early 2000s to more than 40 million T by 2024 (FAO, 2025). Likewise, adoption of high yielding hybrids and agronomic practices has led to an increase in yields, from approximately 2.5 t/ha in 2015-16 to nearly 3.7-3.8 t/ha in 2024-25 (USDA, 2025). These improvements illustrate transition towards more intensive and efficient maize production systems. Maize area has also increased moderately due to market demand and policy incentives, while the improvements have been the major factor in the expansion of area. The total maize area increased from around 9.6 million hectares in 2016–17 to over 12.8 million hectares in recent years. The expansion of this has been especially strong in non-traditional areas, where demand from the poultry feed and ethanol industries have been driving growth. Moreover, the introduction of minimum support prices (MSP), crop diversification schemes and ethanol blending policy has also pushed farmers to grow maize crops (Table 1).

Regional distribution and major producing states

Maize production is spread across agro-climatic regions in India with variations among regions. Karnataka, Madhya Pradesh, Telangana, Andhra Pradesh, Bihar and Maharashtra are the key maize producing states (APEDA, 2025). *Kharif* maize is mostly produced in Karnataka and Madhya Pradesh with Bihar being a prominent producer of rabi maize

Table 1: Decadal growth in area, production, and productivity of maize in India

Period	Area (Million ha)	Production (Million tonnes)	Productivity (t/ha)	CAGR Area (%)	CAGR Production (%)	CAGR Productivity (%)
1990–91	5.9	9.6	1.63	—	—	—
2000–01	6.6	12.0	1.82	1.1	2.2	1.1
2010–11	8.6	21.7	2.52	2.7	6.0	3.2
2020–21	10.2	31.5	3.09	1.7	3.8	2.1
2023–24	11.5	38–40	3.4–3.5	1.5	4.2	2.6

Source: Likhitha and Permual (2025).

Table 2: State-wise Share in Maize Production in India

State	Share in Production (%)	Cropping Season	Key Features
Karnataka	15–17	*Kharif*	Largest producer, rainfed dominance
Madhya Pradesh	13–15	*Kharif*	Expanding area, moderate yields
Telangana	10–12	*Kharif* & *Rabi*	High hybrid adoption
Andhra Pradesh	8–10	*Rabi* dominant	High productivity (irrigated maize)
Bihar	8–9	*Rabi*	Highest yields in India
Maharashtra	6–8	*Kharif*	Rainfed variability
Tamil Nadu	4–6	*Rabi*	Intensive cultivation
Uttar Pradesh	4–5	Both	Declining share
Others	20–25	Mixed	Diverse agro-climates

Source: Unjia (2021).

(Kasmeer *et al*. 2025). In recent decades, there has been a growing trend of moving away from the traditional maize-growing states like Uttar Pradesh and Rajasthan to the southern and eastern states that have experienced more rapid growth, such as Andhra Pradesh, Tamil Nadu, and West Bengal. Major part of the maize production in India is rainfed especially during *kharif* season. In the states like Bihar, Andhra Pradesh, and Telangana, however, the area of maize cultivation has grown substantially with irrigation, particularly of rabi maize, resulting in increased productivity. Generally, the yields of rabi maize are higher than *kharif* maize as the former is grown under controlled irrigation and favourable climatic conditions (Singh *et al*. 2024). This transition to irrigated production of maize is a significant factor in improving overall productivity growth and stability in production (Table 2).

Drivers of growth in maize cultivation in India

Maize growth has been strongly influenced by technology advancement in India. The use of single cross hybrid seeds, better agronomic management, mechanization and precision farming have contributed to the high productivity (Gurumu *et al*. 2025). The adoption of stress-tolerant and higher yielding cultivars has also contributed to increased stress tolerance to climate variability (Krishna *et al*. 2025). In India, the growth of the poultry industry and livestock production has been a major impetus to maize demand (Fig. 2). Maize is the most important feed ingredient and is a key component of the protein economy. Moreover, the surge in policy-driven conversion of maize to ethanol has established a new and expanding market for maize, which has also stimulated maize production. This is because of the dual use of maize as a food grain and for industrial purpose, which has accelerated the rate of growth of maize in India. Government policies have been important in favouring maize cultivation. Maize has been encouraged with the announcement of the minimum support price (MSP), encouraging diversification of crops (particularly away from

Fig. 2: Promotion of maize cultivation in India and its key drivers

water intensive crops such as rice), and supporting ethanol blending programs. The National Food Security Mission (NFSM) and biofuel policies have also bolstered the maize farming sector, enhancing productivity, access to markets, and support for prices (NITI Aayog, 2023).

Agroecological advantages of maize cultivation in India

It is interesting to note that maize cultivation in India has many agroecological benefits and is also seen as a desirable crop in the face of the changing climatic and resource conditions. Maize is flexible, makes efficient use of resources and can be integrated into a range of different farming systems, making it a sustainable substitute to other cereals, such as rice and wheat (Jat *et al*. 2025). Recent research shows that maize-based systems significantly increase water productivity, lower environmental impacts, and increase water resilience (in the face of climatic variability) in water-stressed parts of India (Fig. 3). These characteristics are what have led to greater maize focus in crop diversification and climate smart agriculture programs (Meena *et al.* 2025).

Adaptability to diverse agro-climatic conditions

Maize is quite adaptable and grow in a variety of agro-climatic conditions and can be cultivated in tropical, sub-tropical and temperate regions. It is cultivated from sea level to high altitudes in India on many soil types from alluvial to red and black soils. The genetic diversity and physiological flexibility are believed to be responsible for this adaptability, allowing it to thrive in various temperature ranges, precipitation levels and soil characteristics (Maitra *et al*. 2023; Ray *et al.* 2025a). Furthermore, the maize could be grown in all three seasons (*kharif, rabi*, and spring), which provides flexibility in cropping systems along with various legumes and maximizes land inputs (Maitra *et al*. 2019; Maitra and Gitari

2020). It is short duration and responsive to inputs, suitable for rain fed and irrigated (Maitra *et al.* 2001a). Maize has been found to adapt to a wide range of agro-ecologies and is a crop that is being encouraged as a resilient crop in the context of climate variability. This is a broad adaptability, which strengthens its contribution to the stabilisation of agricultural production under climatic uncertainties (Chavula and Kayusi, 2026).

Fig. 3: Agroecological benefits of maize cultivation in India

Higher water use efficiency

Maize is much more water-efficient than traditional water-intensive crops, like rice. The studies show that rice-based systems can use up to 1671 mm of water per system while maize-based systems can use only 316 mm per system, which represents significant water savings (Duan *et al*. 2026). In addition, maize may need almost 10 times less irrigation than rice, which will yield a much greater water productivity. Maize is drought-tolerant crop and requires less water, which makes it a suitable choice for water-scarce areas and unpredictable weather patterns. It is efficient in its use of water, which helps to promote resilience to drought and climate variability (Su *et al*. 2022). In addition, maize-based systems have been proven to increase water use efficiency by as much as 810% when provided with improved irrigation system than conventional systems (Brar *et al*. 2021). Maize is therefore an important element of a climate-smart agriculture (CSA) and sustainable intensification approach in India.

Cropping systems compatibility

Maize is an important crop for diversification especially in areas where paddy cultivation is water intensive such as Punjab and Haryana. Substitution of rice for maize in rice–wheat systems have the potential to decrease water use, energy use, and GHGs, with an equivalent or even greater farm benefit (Jat *et al*. 2025). In recent years, with the promotion of sustainable agriculture and the conservation of natural resources, this substitution becomes more and more encouraged by the Government policies. Maize is very well suited for intercropping and multiple cropping because of its growth habit and the flexibility to space requirements (Maitra *et al*. 2023b, 2025a). It can be intercropped with legumes, vegetables and other crops which brings a better land-use efficiency and farm income (Maitra *et al*. 2001, 2024a; Ray *et al*. 2025b). Maize-based sequential cropping and intercropping systems have demonstrated a higher productivity and efficiency of resource use of the entire system than monocropping systems (Sarkar et al. 2000). This compatibility enhances diversification and resilience of smallholder farming systems.

Environmental benefits

Better management of maize residues and less soil degradation support maize cultivation in improving soil health. Maize-based systems contribute to maintaining soil structure, increasing organic matter content and improve nutrient cycling compared to continuous rice cultivation. Soil biological activity and the sustainability of maize systems are further improved by implementing conservation agriculture practices (Manasa *et al.* 2018, 2021; Maitra *et al.* 2026a, b). The environmental impact of maize-based systems is less than rice-based systems. Research suggests up to 63% reduction in GHG emissions, along with substantial energy savings, diesel usage and labour savings with cultivation of maize. The low water and input needs makes maize a more environmentally friendly crop (Mohanty *et al.* 2016;

Jat *et al.* 2025). Maize's contribution to sustainable agriculture development and climate change mitigation is largely due to such benefits.

Recent agronomic advances in maize cultivation

Maize cultivation in India has undergone a significant change from traditional to technology-intensive high yielding system of production thanks to recent agronomic development (Ray *et al*. 2024, Maitra *et al*. 2026c; Maity *et al.* 2025). The development of hybrid cultivation, precise agriculture, efficient use of resources and climate-smart technology has led to greater yield, profit, and sustainability (Mirriam *et al*. 2022; Mwadalu *et al*. 2022; Chen, 2025). These developments are especially crucial for mitigating issues like climate change, resource stress, and rising input prices, thereby bolstering crops resilience and economic viability (Fig. 4).

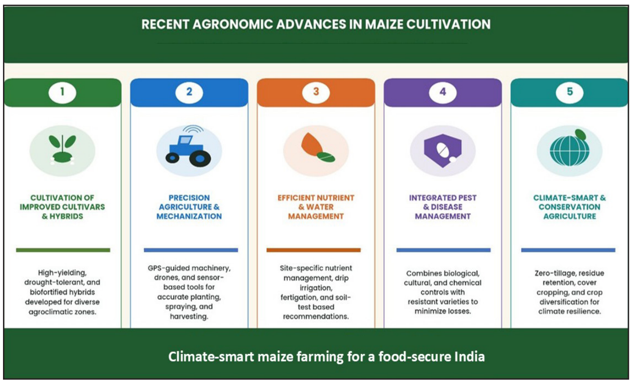


Fig. 4: Improved agronomic management practices in maize cultivation

Cultivation of improved cultivars and hybrids

One of the most important factors responsible for the enhancement of productivity in India has been the adaptation of high yielding maize varieties of single cropping system hybrid varieties. Maize varieties of single cropping system with high yielding hybrid varieties have been one of the most important reasons for the increase in the productivity in India (Makgoba *et al.* 2015). In India, over 80% of maize cultivations are hybrids which have resulted in significant improvement in maize yields compared to open pollinated varieties (OPVs). The hybrids show improved characteristics like high grain production, uniform harvesting maturity, improved fertilizer and water use efficiency (Kutka, 2011). Studies have shown that under optimum management conditions, hybrid maize yields 20–30% more than the conventional maize. The recent breeding activities have been directed towards the production of stress resistant maize varieties that can withstand drought, heat and biotic stresses (Danalatos *et al.* 2026). The use of drought-tolerant maize hybrids has been successful in rainfed areas to improve yield stability in areas where rain is limiting. Further, there has been development of biofortified maize varieties to tackle nutritional deficiency, food and nutritional security.

Precision agriculture and mechanization

The use of precision agriculture technologies in the cultivation of maize is gaining in popularity, due to the need to use inputs optimally and increase productivity. Sensors, remote sensing and drone monitoring make it possible to assess the health of crops, the moisture in the soil and the nutrients available, all in real time, which allow for the informed making of decisions (Sairam *et al.* 2024a; Krishna *et al.* 2025). Digital tools and mobile-based advisory services also help farmers to use site-specific management, which increases efficiency and input cost savings (Sairam *et al.* 2025c; Krishna *et al*. 2024a, b). Maize production has become less labour intensive and more time efficient in response to mechanization. The use of precision seed drilling, zero tillage planters, and combine harvesters has definitely helped in improving planting efficiency, lowering seed rates and minimising the losses after harvest (Chandel *et al*. 2024). Mechanized operations also help in reducing the cost of production and increasing profitability, especially in areas where there is a shortage of labour.

Efficient nutrient and water management

Site-specific nutrient management (SSNM) is one of the important innovations to optimize the use of fertilizers according to soil fertility and crop needs. In addition to improving nutrient-use efficiency and reducing input costs, SSNM practices increase crop productivity (Nduwimana *et al*. 2022; Sairam *et al.* 2023, 2025a). It has been established that balanced fertilization and integrated nutrient management can boost maize yield by 15–25% over conventional nutrient management (Bhat *et al*. 2024; Rishitha *et* *al*., 2025). The use of efficient water management practices in crop production, e.g. drip irrigation and fertigation has become more significant, especially in water stressed areas (Santosh *et al*. 2022 a,b: Zaman *et al*. 2017). Drip irrigation helps in lessening the loss of water, delivering more precise water and nutrient application to the root zone, resulting in better water-use efficiency (WUE) (Ghaffar *et al*. 2024; Santosh *et al*. 2025). Fertigation also promotes better absorption and utilization of the nutrients in the crop, leading to increased productivity and yield (Santosh *et al*. 2017; 2024b).

Integrated pest and disease management

Many Integrated Pest Management (IPM) strategies are in use to sustainably manage pests and diseases of maize. IPM involves both cultural, biological and chemical strategies to control pest damage to an acceptable level with reduced effect on the environment. Major pests like fall armyworm (*Spodoptera frugiperda*) have been managed better with IPM practices like use of biological control agents and pheromone traps (Sanon *et al*. 2025). Resistance to pests and diseases has been improved by biotechnological methods, such as genetically modified (GM) maize and molecular breeding. The development of better maize varieties that are more resistant and productive is being speeded up by marker assisted selection and genomic tools (Kim *et al*. 2026). The innovations help to ensure sustainable crop protection and yield stability.

Climate-Smart and conservation agricultural practices

Maize-based systems have emerged as the focus of conservation agriculture practices like zero tillage, residue retention and crop rotation, intercropping systems, help to increase soil health, water holding capacity, and production costs (Angmo *et al*. 2024). In maize-based cropping systems, conservation agriculture has been proven to reduce the use of inputs and maximize productivity and sustainability of the system (Kulagowski *et al*. 2021). Global agriculture is increasingly incorporating technologies such as stress-tolerant hybrids, efficient irrigation methods, cropping systems, and weather advisory services that can help mitigate climate change's impact. These technologies helps to mitigate the impacts of climate change, improve resilience, and ensure stable yields under adverse conditions (Bhadra *et al*. 2022; Santosh *et al*. 2024a; Priya *et al*. 2025; Omotoso and Omotayo, 2025). These practices are vital for maintaining food production of maize in the context of the escalating climatic uncertainties.

Profitability of maize cultivation compared to other cereals

Farmers have realised that maize cultivation in India is a more attractive option than traditional cereal crops like rice and wheat, largely because of reduced input costs and improved resource-use efficiency, as well as increasing market demand (Kaur *et al*. 2020). Recent studies provide empirical evidence that maize-based systems can be more profitable than rice-based systems, and yield better benefit–cost ratios, particularly in water-limited areas (Kaur *et al*. 2020). The profitability benefit is mainly due to lower irrigation, labour and energy cost and the growth in demand from the feed and industrial segment.

Cost of cultivation analysis

Cost of production in maize cultivation is mainly comprised of seed, fertilizer, labour, irrigation and machinery costs. Maize cultivation has been shown to have comparatively low input costs compared to rice, especially with regards to water use and the labour intensity (Singh and Kataria, 2025). For example, rice farming has much greater energy consumption, requires more labour, and involves more frequent irrigation, making the production of rice more expensive. Maize seed and sowing cost ranges from ₹ 10,500 – ₹ 11,500 per hectare at the farm level in India and total cultivation cost is also moderate in comparison to other cereals (Singh and Kataria, 2025). Additionally, maize is less intensive in terms of field operations and in pesticide application, which also results in lower costs. Other studies have also indicated that in addition to the above benefits, the implementation of conservation agriculture methods can contribute a further cost saving of approximately 10–15% in maize production. Maize is much less resource intensive than rice (Meena *et al*. 2025). Rice consumes almost 10 times more water than maize, meaning that prices of water, electricity and diesel are higher. Likewise, labour demand in rice production is approximately 30–40% greater than that in maize production, especially in the transplanting and harvesting process (Jat *et al*. 2025).

Returns and yield economics

Production costs of maize are lower than rice in certain areas, despite the lower yields, maize can offer better economic returns. Research in the north-western parts of India shows that the best returns from maize production are 32-46% greater under various production scenarios compared to rice production (Jat *et al.* 2025). Based on the farm level analysis in Tamil Nadu, it is found that maize is highly profitable with an average net income of about ₹ 50,000 per hectare (Kiruthika *et al.* 2023). Moreover, maize based cropping systems with diversified crops e.g. maize, potato, onion have been found to have significantly higher gross and net returns than rice based cropping system. One of the most important measures of economic viability is the benefit–cost (B:C) ratio. The B:C ratio for maize production ranges between 1.5 and 1.6 as reported by the studies and is higher for rice production in the same situation (Kumar *et al.* 2013). Better management and hybrid seeds further enhance profitability, and maize therefore has the potential to boost farm income. Furthermore, the economic advantages of conservation agriculture-based maize systems have been shown to be higher, up to USD 991/ha, than those of the conventional systems, highlighting the contribution of technological interventions to enhance economic returns (Krupnik *et al.* 2022).

Comparative advantage

Market price trends are an important determinant of crop profitability. India's maize prices have become more stable and are also on the rise, driven by the growing demand from the poultry feed industry and the ethanol industry. Maize is currently priced at ₹ 2,200-2,500 a quintal in certain regions, thanks to government procurement and industry demands (Maize Mandi Price, 2025). By contrast, government procurement policies and export restrictions can affect rice prices, and there is little price responsiveness in the market. Further, the growing demand for maize in producing biofuels enhanced its price prospects. Maize is highly competitive economically with other cereals and commercial crops. The production costs are lower, the profits are higher, and it has several markets, such as ethanol, and food and feed. As evidenced by the field studies, maize offers the potential for increased profitability even at slightly reduced yields, because of cost savings and greater resource use efficiency. Furthermore, farmers are increasingly moving away from crops such as cotton and rice towards maize which is lower in cost of production and higher in net returns under favourable market conditions (Jat *et al.* 2025). This indicates the expanding potential of maize as a competitive and economic crop in Indian agriculture.

Constraints in maize cultivation in India

Maize cultivation in India despite being an emerging crop with increasing significance and profitability still has a number of agronomic, economic and institutional constraints which restricts the maximum potential of maize. These issues impact productivity, profits and sustainability, especially of small and marginal farmers. To improve maize-based systems and support sustainable development of the sector, these constraints need to be addressed (Fig. 5).

Agronomic constraints

In India, a substantial amount of maize is grown in rainfed conditions resulting in poor and to some extent variable yield. Maize is highly sensitive to monsoonal rainfall, and is susceptible to drought and unpredictable weather conditions. In rainfed areas, productivity is generally lower than the national average, as a result of the inherent quality of the soils, their lower use and the absence of irrigation facilities (Das *et al*. 2025). The under-performance of rainfed maize is still a big challenge. Maize crops face multiple disease and pest challenges, resulting in a loss of yield and quality of the crop. Fall armyworm (*Spodoptera frugiperda* L.) has become one of the most serious pests of maize, and with a poor management plan, can cause significant losses in maize yield (Makgoba *et al.* 2021). Other pests and diseases, including stem borers, leaf blights and rusts, exacerbate production risks. Farmers' poor understanding and awareness further worsen these issues. On the other hand, maize farming is a serious concern related to climate change and variability (Xu *et al*. 2023). High temperatures, unpredictable rainfall and extreme weather like droughts and

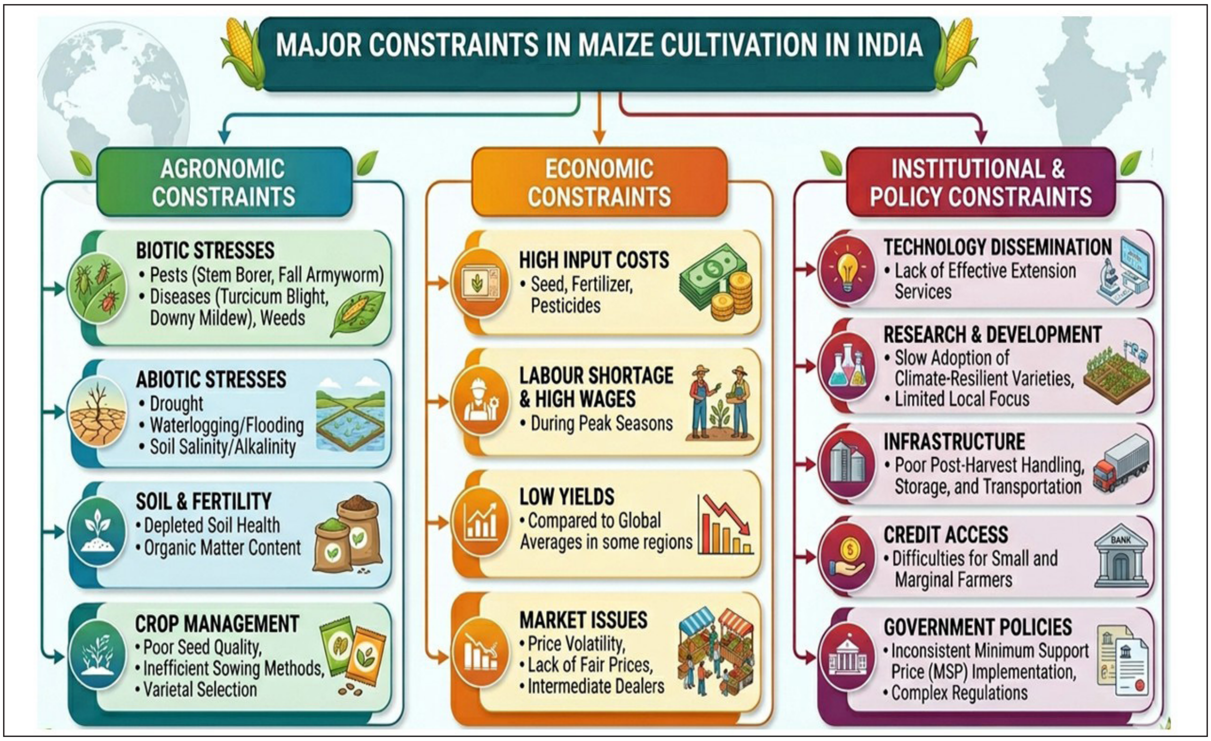


Fig. 5: Constraints face by farmers in India in maize cultivation

flooding have a negative impact on crop growth and production (Maitra *et al.* 2001b;2024b; Ray *et al.* 2025c). Research has shown maize is very sensitive to temperature stress, especially during flowering and grain filling. Climate induced stresses not only lower productivity but also heightens the risk of production in vulnerable agro-ecological areas (Maitra *et al.* 2025b; Mukesh *et al.* 2024).

Economic constraints

There are not robust government procurement systems in place, and maize is not as protected as rice and wheat, causing price volatility and market uncertainty. While minimum support prices (MSP) are declared, the procurement systems are largely poor and farmers tend to sell maize at prices less than the MSP because of limited market access. Demand–supply factors, particularly in the ethanol and feed industries, cause additional price variability, which influences farm income stability. Cost of inputs including hybrid seeds, fertilizer, pesticides and machinery is increasing, which has resulted in the increase in the cost of maize production (Meyo and Egoh, 2020). Maize is less input intensive than rice, but the introduction of new technologies needs extensive initial investment which is not always possible for smallholders. The rising costs of fuel and labour also add to the production costs and ultimately lessen the profits (Jat *et al.* 2025). Many maize farmers, especially in rural and remote areas, still do not have access to institutional credit and crop insurance. Informal credit facilities at high interest rate often become the medium of financing for small and marginal farmers, making them more vulnerable. Crop insurance schemes are available, but they are not always sufficient in scope and implementation, and therefore do not have the desired effect in reducing production risks.

Institutional and policy constraints

Effective dissemination of improved technologies and practices is hindered by weak agricultural extension systems. Many farmers are not aware of and have little knowledge of modern agronomic techniques, precision farming and pest management. Consequently, technologies are not used optimally and productivity is not optimal. Enhancing extension is very important to help reduce the knowledge gap and to enhance farm outcomes. Poor infrastructure for storing, processing, and value adding is one of the main challenges in the maize sector. Lack of good storage facilities causes post-harvest losses and deterioration in quality that affects the market value. Further, inadequate processing facilities hinder the growth of maize industries, impacting the demand and realisation of the price (Jat *et al.* 2025). Strengthening the supply chains and infrastructure is important to increase market efficiency and farmers' income.

Economic feasibility of maize cultivation

Maize production in India is gaining economic viability and appeal, especially in the light of its cost–return structure, growing market demand, and policy support. Under efficient cultivation practices, maize is generally more profitable than many conventional crops, and is more resilient to resource limitations but, factors like farm size, market dynamics, climate risks, and institutional support systems affect its economic feasibility.

Cost–Benefit Analysis

Maize production has been found to produce significant net returns at the farm level in all studies conducted to date under improved management conditions. For example, the empirical findings from Tamil Nadu reveal that maize farmers' economic viability was high, with an average net income of approximately ₹ 50,000 per hectare and a benefit–cost ratio of ~1.6. (Kiruthika *et al.* 2023). Research in the Indo-Gangetic plains shows that increasing the profitability and resource use efficiency of maize systems can be achieved through improved irrigation and nutrient use efficiency (Biswas *et al.* 2025). The returns are mainly because of reduced input costs, good use of resources as well as due to various market segments (ethanol, feed & food industries). All these are attractive reasons for smallholder and commercial farmers to value maize. In maize production, economies of scale exist because the larger the farm size, the lower the cost per unit of output, as larger maize farms are mechanised, are able to buy inputs in bulk, and have better access to markets. The results show that the operational cost ranges significantly from region to region ranging from approximately ₹ 36,899 per hectare in Madhya Pradesh to ₹ 62,942 per hectare in Tamil Nadu, which is attributed to differences in scale, labour utilization, and technology adoption (Singh and Kataria, 2025). Higher productivity and profitability are achieved through the use of advanced technologies like precision farming, drip irrigation, and mechanization, which are more suitable for large-scale farmers. Yet smallholders can also generate economic benefits and access better inputs and services through cooperative farming.

Risk and Uncertainty

Maize production is still subject to significant uncertainties due to climate variability. The variability in the yield caused by drought, heat stress, and unpredictable rainfall can affect the farm income substantially. The rainfall-dependent maize farming systems are especially sensitive and vulnerable, which results in income insecurity and production hazards. Some of these risks, however, can be reduced through adoption of climate resilient practices and improved varieties (Dlamini *et al.* 2025). Another key consideration for economic viability is market price fluctuations. Maize prices move with the demand from the feed market, ethanol market, export market and seasonal demand and supply (Kumar *et al.* 2013). According to reports, price volatility has been reported even within a short period of time because of the procurement delays and market speculations, which have negatively impacted the stability of farmers' income (Tothova 2011; Maitra *et al.* 2020). In addition, by having limited government procurement activities as compared to rice and wheat, maize farmers are exposed to market risks which makes price realization uncertain.

Role of Government Policies

The economic viability of maize production is important and is greatly influenced by government policies. The announcement of minimum support price (MSP) provides a benchmark price, although procurement mechanisms are relatively weak compared to other cereals. Input subsidies like seeds, fertilizers, and irrigation equipments help in lowering the production costs and enhance profitability. Crop diversification policies, particularly the promotion of replacing water-intensive food crops, e.g., rice, with maize, have also spurred adoption (Singh and Kataria 2025). Maize is the biggest beneficiary of the ethanol blending program in India. Maize prices have generally improved as it is a relatively stable market of increasing demand due to the increased feedstock demand for ethanol. This policy change has not only reinforced the place of maize in the bioeconomy, and helped to diversify rural incomes, but also poses questions about food-feed-fuel competition and the need for an appropriate policy mix for sustainable development (Dixon *et al*. 2010).

Value Chain Analysis

The value chain of maize in India includes input suppliers (seeds, fertilisers, machinery), farmers, traders, processors and end users in the feed, food and industrial sectors. Backwards and forwards linkages in maize value chain have been reinforced by the growing demand from poultry feed, starch industries, ethanol production. To increase market efficiency and lower transaction costs, it is necessary to have efficient supply chain and improved logistics. The private sector plays an important part in bolstering the maize value chain, investing in maize seed production, processing industries, and market infrastructure (Sintayehu *et al.* 2026). Contract farming is gaining ground as a tool to secure farmer-firm contracts, price stability, and inputs and technical support. It helps to mitigate market risk and enhance profitability, especially for the small and marginal farmers (Bunkar *et al.* 2025). To make the maize cultivation in India economically viable and sustainable, the public-private partnership and value chain integration should be strengthened.

Market Demand and Future Prospects

The demand for maize in India has expanded rapidly in recent years, driven by structural changes in the livestock sector, growing industrial applications, and supportive biofuel policies. There have been structural changes in livestock sector, increased industrial demand and favourable biofuel policy which have resulted in a sharp increase in India's demand for maize in recent years. This shift has made maize a relatively export oriented crop which is now strongly absorbed in the domestic market, and of strategic importance. Maize's market prospects have improved substantially as demand for the grain has increased, notably from feed and ethanol producers, and put maize at the forefront of the agriculture sector's growth and development of the bioeconomy (Thileepan *et al.* 2025; Afolabi *et al.* 2021).

Domestic demand trends

The poultry and livestock industry has the greatest demand for maize in India. The challenges faced by the poultry sector are enormous, not only because of the rapid growth of the industry, but also because of the increasing per capita demand for animal protein, which has brought about a corresponding increase in demand for maize as a feed ingredient. Maize use has also risen steeply in industries as well as for its use as feed. Maize is used in the starch industry for glucose production, dextrose, and other derivatives, and in the processed food industry, for production of a variety of value-added products (Deepak *et al.* 2022). One of the significant developments of late is the increasing demand for maize for producing ethanol, with over 127 lakh metric tonnes being used per year for this purpose, aided by the quick growth of grain-based distilleries and biofuel projects.

Global market and export potential

The global maize market has seen significant changes in India's position due to the growth of domestic demand. In the past India exported maize to its neighbouring countries including Nepal, Bangladesh and Vietnam but the golden time of exportable surplus is declining due to the rising demand for maize consumption within the country (Nduwimana *et al.* 2020). Indeed, India has become a net importer of maize in recent years, with imports reaching almost one million tonnes in 2024–25. Meanwhile, exports have also been affected because of the domestic price hikes and supply concerns that have made India less competitive in the international markets. India, however, is not losing its export market potential since the factors of proximity to Asian markets and a growing production base remain available to India as long as productivity gains and cost efficiencies are realized.

Role of ethanol industry in future growth

The future demand of maize in India is likely to be transformed by the ethanol industry. The government's 20% ethanol blending mandate by 2025–26 is likely to see a huge rise in the demand for grain-based feedstocks and more particularly for maize. The use of maize as a traditional feedstock like sugarcane and broken rice has significantly increased for ethanol production because of availability and conversion efficiency. Maize is expected to reach a combined consumption for the feed and ethanol industry of 65-70 million tonnes in the next few years (NAAS 2024). This policy driven demand will likely help to stabilize maize prices, stimulate investment in maize industries, strengthen the farm incomes, but also drive competition between different maize end uses (Abokyi *et al.* 2020).

Emerging opportunities

It is encouraging that there are new ventures in maize processing, which further enhances its future potential. Maize is seeing new applications with the development of bio-based industries, such as bio-plastics, biodegradable materials and advanced biofuels. At the same time, urbanisation and consumer trends are boosting the demand for value-added maize products like breakfast cereals, snacks and processed foods. The private sector is also playing an increasing role in seed production, processing industries and contract farming, which is also driving the growth of the maize value chain. These developments increase the efficiency of market operations, increase price realization and make technology and markets more accessible for farmers (Ma *et al.* 2024).

Sustainability and food security concerns

There is a significant discussion on the sustainability and food security issues regarding the high demand for maize, especially for industrial use. The high demand for maize, especially for industries, is a major concern in terms of sustainability and food security. Maize used for ethanol production might affect food and feed supply, causing potential supply imbalance. This has led to the "food versus fuel" debate, with the greater demand for ethanol driving up maize prices and impacting the ability to afford maize for feed and food production (The Food Versus Fuel Debate, 2012). The recent trend suggests that increasing domestic demand has already affected the prices and supply of exports, further highlighting the necessity of policy mix that takes into account the delicate balance between the two. To promote sustainable development of the maize sector, it is important that competing demands are carefully managed and strategies are developed to improve productivity, resource use and equitable allocation (Fukase and Martin, 2020).

CONCLUSION

Maize has thus become an important crop with a considerable economic and industrial value in Indian agriculture, moving it from being a cereal-based crop to a dynamic, market-oriented commodity. The versatility of use in food, feed, fodder and industrial applications, combined with increased demand from the poultry industry and ethanol production has greatly increased its significance in the last decades. The steady increase in production and productivity has been mainly attributed to hybrid technology and better maize agronomic practices, which signal a structural shift in maize growing. Regional transitions towards high productivity states, and the spread of irrigated maize systems, further illustrate its adaptability and potential for intensification. Maize has several agroecological benefits, such as its ability to grow across a wide range of climatic conditions, its high water-use efficiency and its versatility as a crop in different cropping systems. It is an important crop in the context of diversification as an alternative to water-intensive crops such as rice and is thus important to climate-smart agriculture. Precision farming, nutrient and water management, pest control, and climate-smart practices have helped to enhance productivity, resource-use efficiency, and sustainability. The technological innovations and biofortified and stress tolerant varieties have contributed to increasing the climate resilience of maize. Maize production has proven to be profitable in comparison with other cereals as it is relatively less expensive to grow, is utilizing inputs efficiently and has larger market opportunities. Its economic viability has improved due to the benefit–cost ratios, rising industrial demand, and growing value chains. Though farm size, availability of technology and market situations have an impact on profitability. However, the cultivation of maize is constrained by a number of factors such as low productivity under rain-fed conditions, the presence of pests and diseases, climate variability and volatility, and inadequate institutional support. It is also lacking in quality procurement systems, infrastructure and access to credit and insurance, which further constrain its potential. Emerging market demand and policy support are closely intertwined with the future growth of maize in India. Maize production and use are likely to continue to grow as they are driven by the swift expansion of the ethanol industry and rising demand from the feed and processing industries. The opportunities in the bio-based industries and value-added products, as well as the participation of the private sector, are very likely to continue to support the maize value chain and improve farmer incomes. But it is important to note that as the maize supply is diverted to industrial applications, the issues of food security and resource allocation have become a cause of concern, thereby necessitating the need to have balanced and sustainable policy frameworks in place.

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