# Potential impacts of allowing genetically modified maize production and imports in India

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# Contents

# Foreword

**Genetically modified (GM) crops have been in commercial cultivation globally for nearly three decades. Major crops such as soybean, corn (maize), cotton, and canola are widely cultivated using GM technology. In India, however, Bt cotton—approved in 2002—remains the only GM crop permitted for commercial cultivation.**

Since then, many organisations, both in public and private spaces have been researching on developing genetically enhanced crops. Crops like brinjal and mustard have been developed with the desired traits and cleared for field trials. Unfortunately, due to regulatory hurdles and public resistance, these crops have yet to be commercialized. A number of other crops with promising traits have been developed at the research level, but growing uncertainty has discouraged many scientists from investing further effort into bringing these innovations to market.

The hesitation surrounding large-scale adoption of GM crops stems from a variety of concerns. Key among these are potential risks to biodiversity, long-term ecological effects, and unforeseen health impacts. There are apprehensions about genetic contamination of native species; increased chemical usage due to emergence of tolerant/ resistant insect genotypes, and unintended harm to pollinators such as butterflies and beneficial insects. The evolution of herbicide-resistant weeds and pest-resistant crop varieties could paradoxically lead to increased pesticide use and other insects becoming more problematic, undermining one of the key promises of GM technology.

Another ecological concern is the potential release of GM proteins into the soil, which may affect microbial biodiversity. This is particularly critical at a time when the importance of soil microorganisms in climate change mitigation—as part of nature-based solutions—is being increasingly recognized.

In developing countries like India, fears also persist around loss of crop biodiversity and the dominance of multinational corporations in agriculture, raising ethical and sovereignty concerns.

Moreover, the uncertainty associated with newly introduced genes—especially those sourced from unrelated species, including microbes—presents another challenge. Potential allergic reactions or long-term health effects are difficult to assess due to variability in food preparation, storage, and individual responses. These unknowns further complicate regulatory decisions and public acceptance.

Despite these concerns, it is crucial to view GM technology as a tool that, if carefully managed, can contribute to sustainable productivity enhancement. No agricultural technology—whether fertilizers, biopesticides, or GMOs—is entirely risk-free. The objective must be to weigh the benefits against potential drawbacks, while ensuring that irreversible harms are avoided.

India has established a robust regulatory framework to govern the development and deployment of GM crops. At the institutional level, the Institutional Biosafety Committee (IBSC) ensures initial oversight. The Review Committee on Genetic Manipulation (RCGM) under the Department of Biotechnology monitors ongoing research and permits small-scale field trials. For large-scale deployment, research outcomes are reviewed by the Genetic Engineering Appraisal Committee (GEAC), which operates under the Ministry of Environment, Forest and Climate Change (MoEFCC).

Given the strength of this multi-tiered regulatory process, India is well-positioned to re-evaluate the role of GM crops in addressing productivity challenges. Maize has emerged as a key crop in recent years—both as an alternative to water-intensive paddy in states like Punjab and its increased consumption as food, fodder, and feedstock for biofuel. Globally, maize ranks second only to soybean in GM adoption, with a wide range of approved events for both single and stacked traits. International studies have indicated the superior performance of GM maize over conventional varieties, particularly in yield and resilience.

As India scales up maize cultivation, a scientific review of GM options is both timely and necessary. Harnessing the full potential of GM crops—through transparent, evidence-based decision-making—could help us achieve greater food and environmental security while meeting our sustainability goals. The report provides evidence-based recommendations on GM maize which is important for making decisions on its adoption.

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# Potential impacts of allowing genetically modified maize production and imports in India

Tom Kirk, Bruno Santos, Megan Vasko, 30th November 2024

## Key findings

- There is scientific consensus that GM foods, and food products from animals which have consumed GM feedstocks, are safe to eat, however, a majority of consumers in India (and in many other countries) view GM foods as unsafe to eat.

- Analysis of three separate meta-analyses indicated GM maize increased yields by 14.1% compared to conventional maize. Seed costs were found to increase by 21%, however, pesticide costs (and quantities) decreased by 43.4%. Overall, GM maize increased farmer profit by 62.3% compared to conventional maize.

- Allowing GM maize cultivation would increase domestic production by 6% to 14% by 2030-31, reduce the amount of land required for growing maize, and deliver significant financial benefits to farmers (and ethanol producers). Once fully adopted, GM maize will eventually increase annual farmers profits by ₹161 to ₹208 billion per year (across India).

- In countries where cultivation of GM maize is allowed, it usually reaches very high levels of adoption, frequently accounting for 90% of the total maize area planted. High adoption confirms the positive impact of GM crops on farmer profitability. (GM cotton in India is another example of extremely fast adoption of a GM crop).

- Despite the benefits to farmers and reduced land use, allowing GM maize cultivation will not be enough to meet rapidly increasing demand. GM maize would increase domestic production by up to 14% by 2030-31, reducing the predicted shortage by up to 26%. To properly address this shortage, requires more maize imports.

- Without policy change, demand growth is likely to lead to maize shortages and higher maize prices. (India became a net importer of maize in 2023-24.) This would lead to decreased production and exports from poultry, dairy, starch, and ethanol sectors, creating economic distress, increasing unemployment and adding to food insecurity.

# 1. Introduction

Maize (corn, *Zea mays*) is the third largest cereal crop in India by total production, after rice and wheat[1]. In the 2022-23 crop year India ranked 4$^{th}$ in the world for maize area planted, and 4$^{th}$ for maize production, however, India lags significantly behind the global average productivity, with an average yield in 2022-23 of around 3.6 tonnes per hectare, compared to a global average of 5.8 tonnes per hectare[2].

Despite comparatively low productivity, total production of maize in India increased by a factor of three from 2002 to 2022[3]. The majority of maize consumed in India is used for animal feed (58% in the 2023-24 crop year). Combined, the starch and ethanol industries consume over a quarter of maize produced (13% and 16%, respectively), while only a small amount is consumed as food (5%)[4]. Due to fast growing agricultural and industrial sectors (especially ethanol), demand for maize is expected to grow faster than supply. This is likely to lead to shortages and higher prices in the future.

Genetically modified (GM) maize exhibits specific traits such as pest resistance and herbicide tolerance. This is achieved by inserting genes from other organisms into the maize genome[5]. Proponents claim GM maize offers an opportunity to increase yields and farmer profitability. If true, adoption of GM maize would have indirect benefits for the broader supply chain, including animal feed consumers and ethanol producers, by providing a more reliable and abundant source of maize

This paper explores the potential impacts of allowing the cultivation and import of GM maize in India, with a focus on impacts for Indian farmers and for the broader supply chain.

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[1] Govt of India Department of Agriculture & Farmers Welfare (DA&FW) Final Estimate of Production of Food Grains for 2023-2024 crop year.

[2] Foreign Agricultural Service, Official USDA Estimates. (See Appendix 1:Table 4.)

[3] Our World in Data, via Food and Agriculture Organization of the United Nations (2023): https://ourworldindata.org/grapher/maize-production?time=2002..latest&country=~IND

[4] See Section 2.1: Table 1.

[5]https://www.fda.gov/food/agricultural-biotechnology/science-and-history-gmos-and-other-food-modification-processes

## 2. Background

### 2.1 Maize production and consumption in India

Maize production in India is split between two seasons: kharif (planted from March and harvested between September and October) and rabi (planted in In October/November and harvested in March/April)[6]. The majority of annual production (63%[7]) is during the kharif season, where production comes predominantly from the central and southern states. During the rabi season (30% of annual production[7]) there is little production in the central and northern states, but there is significant production from Bihar and West Bengal[6]. There is also a growing amount of zaid (summer) maize production (7% in 2023-34)[7], coming primarily from Uttar Pradesh.

The five largest maize producing states (Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, and Telangana) are responsible for 54% of national production[8], which has averaged 33.9 million metric tonnes over the last 5 years[7], though this has reached 38 million tonnes over the last two years (Table 1). Domestic production is forecasted to reach 51 million tonnes by the 2030-31 crop year, based on underlying trends in both land harvested and yield, which are both increasing (see forecast below).

Maize in India is mostly used for animal feed, with the poultry (including broilers and laying chickens) and dairy sectors consuming 47% and 12% of all maize in the 2023-24 crop year, respectively (Table 1). A small amount of maize (5%), generally of a higher quality, is consumed as food, while the balance is used for a range of industrial purposes. The starch sector uses maize for products ranging from food additives (e.g. stabilizers and thickening agents) to paper, and the beverage sector uses maize for distilling alcohol (e.g. maize can be used in distilling whiskey). The starch sector is particularly important, because it produces value added products, many of which are exported, boosting India's trade balance. The ethanol sector consumed 16% of maize in 2023-24, a significant increase from the previous crop year (1%). This rapid growth is expected to continue due to the government's National Policy on Biofuels, which aims to achieve a 20% ethanol blending[9] target by 2025-26[10]. The continuing increase in demand for maize for ethanol is addressed in the forecast detailed below.

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[6] Foreign Agricultural Service, Official USDA Estimates: https://ipad.fas.usda.gov/countrysummary/default.aspx?id=IN&crop=Corn
[7] See Appendix 1: Table 5.
[8] See Appendix 1: Table 7.
[9] Blending refers to proportion of a biofuel which is ethanol. For example, a biofuel may be 10% ethanol mixed with 90% petrol (or diesel, creating biodiesel).
[10] IEA (2024), India could triple its biofuel use and accelerate global deployment, IEA, Paris. https://www.iea.org/commentaries/india-could-triple-its-biofuel-use-and-accelerate-global-deployment.

*Table 1: Composition of demand for, and total production of, maize for 2022-23 and 2023-24 crop years[1].*

| | *Demand (million tonnes)* | | *Share of demand (%)* | |
|---|---|---|---|---|
| | **2022-23** | **2023-24** | **2022-23** | **2023-24** |
| Poultry feed | 17.3 | 20.5 | 50% | 47% |
| Dairy feed | 5.0 | 5.2 | 14% | 12% |
| Starch | 5.1 | 5.5 | 15% | 13% |
| Beverage (alcohol) | 0.7 | 0.7 | 2% | 2% |
| Human consumption | 2.0 | 2.0 | 6% | 5% |
| Ethanol (fuel) | 0.5 | 7.0 | 1% | 16% |
| Exports | 3.5 | 2.3 | 10% | 5% |
| Seed / wastage | 0.7 | 0.8 | 2% | 2% |
| **Total Demand** | **34.8** | **43.9** | **-** | **-** |
| Imports[1] | 0.0 | 0.0 | - | - |
| **Total production[2]** | **38.1** | **37.7** | **-** | **-** |
| Balance | 3.3 | -6.3 | - | - |

[1] Source: Industry estimates, via Techpro India Pvt. Ltd., 06/11/2024.

[2] See Government of India (see Appendix 1: Table 5).

A surplus of maize production in 2022-23 has changed into a deficit in 2023-24. As result, India is set to become a net importer of maize for the first time in decades[11]. Historically, India has exported between 2-4 million tonnes of maize per year, however, in the next crop year exports will fall to 0.5 million while imports are forecast to increase from 0 to 1 million tonnes. The shift from production surplus to deficit is reflected in the sharp increase in prices since May 2023 (Figure 1). The longer-term upward price trend, beginning in early 2020, suggests supply has been unable to keep up with increasing demand, which has resulted in steadily rising prices.

[11] R. Jadhav (2024), Ethanol push turns India into corn importer, shaking up global market, Reuters. https://www.reuters.com/markets/commodities/ethanol-push-turns-india-into-corn-importer-shaking-up-global-market-2024-09-04/.

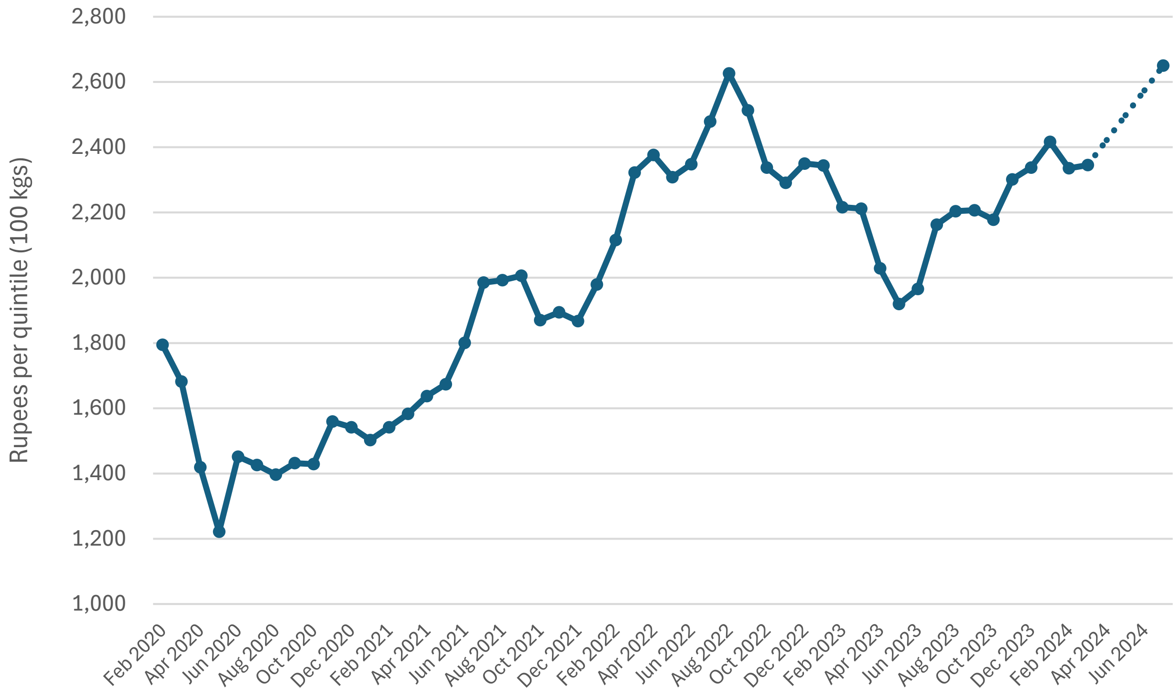


*Figure 1: Average monthly price of maize across Sangli, Erode, NZM, Gulabbagh and Chindwara markets from February 2020 to July 2024. (Source: Data compiled by Techpro India Pvt. Ltd. Note: Data missing from April to June 2024, which has been imputed)*

Underlying trends in land harvested and yield, which are both increasing, are driving increases in maize production; however, this will not be enough to keep up with forecasted demand growth (Figure 2). At current rates, domestic production will not grow fast enough to meet demand even without considering newfound demand from the ethanol sector. By 2030-31, domestic production is forecast to reach 50.9 million tonnes, 27.6 million tonnes short of domestic demand (78.5 million tonnes). Total domestic demand is expected to grow at a compounding annual growth rate (CAGR) of 9.5% between 2023-24 and 2030-31, which also assumes that exports would decrease to zero, while ethanol demand would grow at a 13.6% CAGR over the same period.

One possible mitigating factor is that maize shortages will lead to even greater price increases in the future. Higher prices would result in more land being allocated to growing maize (because it would become relatively more profitable); however, higher prices would come at the expense of sectors which consume maize, in the form of higher costs resulting in potentially severe economic distress (including unemployment and higher food prices). This would also negatively affect those on low incomes or facing food insecurity, because land converted to maize production will reduce the supply and increase the price of non-maize food crops.

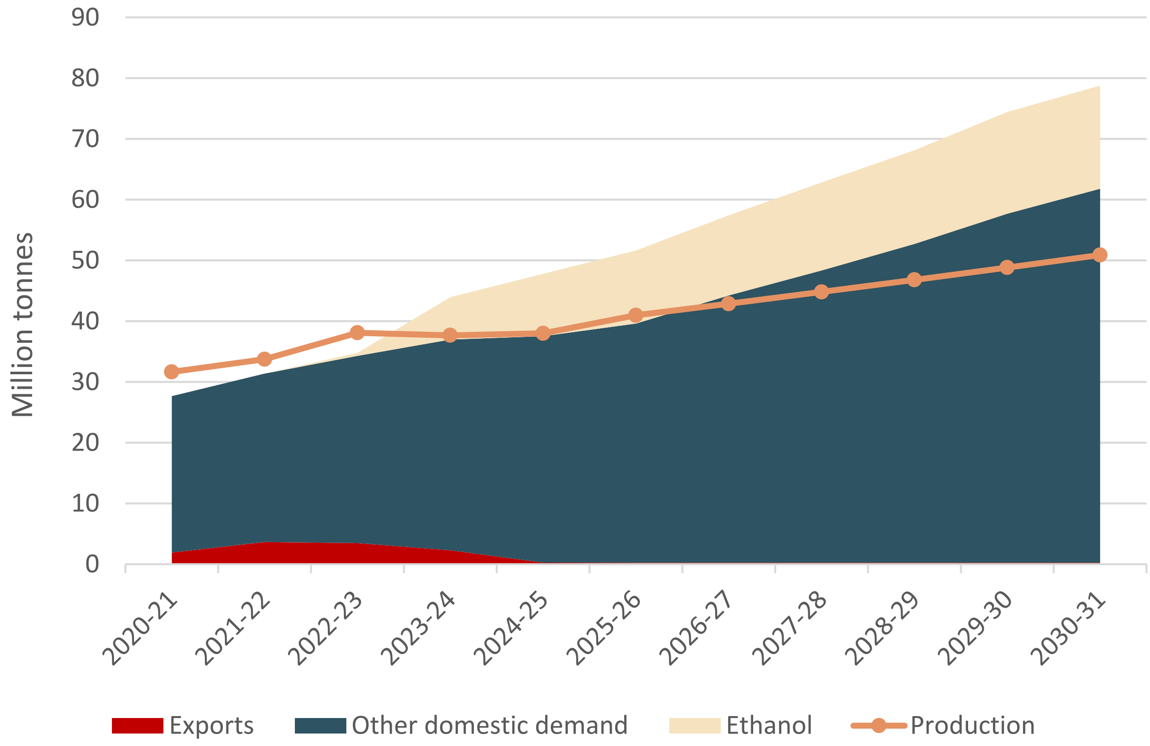


*Figure 2: Historic maize production and demand (for exports, ethanol, and other domestic purposes) from 2020-21 crop year to 2023-34, and forecast production and demand up to 2030-31. (Source: Supply based on analysis of USDA & GOI data – see Appendix 1: Table 5, and demand based on Industry data (see USGC).*

## 2.2 Genetically modified maize

Cultivation of GM maize is not allowed in India, and neither is importing GM maize. GM maize was first commercialised in the USA in 1996[12] and is currently approved for cultivation in 17 countries[13]. Globally, GM maize represents 34% of the total maize area harvested[12].

There are three main types of GM maize seeds (all of which are hybrids, meaning they are not suitable for producing seeds for subsequent harvests). The first type of GM maize to be developed was insect-resistant, because it was modified to produce the bacterial toxin from *Bacillus thuringiensis* (Bt), a protein which is poisonous to insects (e.g. the Fall armyworm, *Spodoptera frugiperda*). The second type is herbicide tolerant (HT) maize, genetically modified to counteract the negative effects of herbicide (specifically glyphosate), therefore allowing HT maize to be sprayed without killing the plant[14]. HT maize is tolerant to herbicide but not fully resistant. The third and most commonly cultivated GM maize type is “stacked”

[12] Global GM Crop Area Review, Agbio Investor, 2024

[13] What GM crops are currently being grown and where, The Royal Society, 2016.

[14] Mabutol-Afidchao, M. B. (2013). Genetically modified (GM) corn in the Philippines: Ecological impacts on agroecosystems, effects on the economic status and farmers’ experiences.

maize, which combines two (or sometimes up to four) different traits[12]. Stacked hybrids could include insect tolerant and herbicide resistant traits or could include multiple traits under each type of modification (e.g., resistance to above-ground and below-ground insects are both Bt-modifications, though these are separate traits and are therefore stacked). Another category of stacking, "pyramided" hybrids, involves stacking multiple traits which target the same pest. For example, pyramided Bt maize produces two proteins which protect against fall armyworm[15], increasing the effectiveness of the hybrid.

In addition to the current types of GM maize available, new types of GM maize are being developed. One example is drought-stress tolerant maize, which would suffer less yield loss under drought conditions[16]. Early results of trials for drought-stress tolerant maize in Africa have been promising[17]. As climate change makes drought events more likely, this potential development could be of great value in the future.

There is scientific consensus that GM foods are safe to eat[18,19], however, GM foods remain controversial. In a review of food safety literature, Domingo and Bordonaba (2011)[20,21] noted that "various studies have concluded that the transgenic [maize] varieties… were as safe as conventional quality protein maize". Notably, the only GM crop which India does cultivate is cotton, which unlike most GM crops, is not used for human food, although cotton byproducts are used as cooking oil and for animal feeds.

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[15] Horikoshi, Renato J et al. "A new generation of Bt maize for control of fall armyworm (Spodoptera frugiperda)." Pest management science vol. 77,8 (2021): 3727-3736. doi:10.1002/ps.6334

[16] Sheoran S, Kaur Y, Kumar S, Shukla S, Rakshit S, Kumar R. Recent Advances for Drought Stress Tolerance in Maize (Zea mays L.): Present Status and Future Prospects. Front Plant Sci. 2022 May 30; 13:872566. doi: 10.3389/fpls.2022.872566. PMID: 35707615; PMCID: PMC9189405.

[17] Obunyali CO, et al. Efficacy of Event MON 87460 in drought-tolerant maize hybrids under optimal and managed drought-stress in eastern and southern africa. J Genet Eng Biotechnol. 2024 Mar;22(1):100352. doi: 10.1016/j.jgeb.2024.100352. Epub 2024 Feb 1. PMID: 38494265; PMCID: PMC10941202.

[18] Is it safe to eat GM crops, The Royal Society, 2016.

[19] Nicolia, Alessandro; Manzo, Alberto; Veronesi, Fabio; Rosellini, Daniele (2013). "An overview of the last 10 years of genetically engineered crop safety research" (PDF). Critical Reviews in Biotechnology. 34 (1): 77–88. doi:10.3109/07388551.2013.823595.

[20] Domingo JL, Giné Bordonaba J. A literature review on the safety assessment of genetically modified plants. Environ Int. 2011 May;37(4):734-42. doi: 10.1016/j.envint.2011.01.003. Epub 2011 Feb 5. PMID: 21296423.

[21] Domingo and Bordonaba (2011) cite 9 studies that have concluded GM maize is as safe as conventional maize. They note one research group (Dr Seralini & University of Caen colleagues) that disagreed with the consensus, however, an expert review panel stated that "Seralini et al. (2007) provided no evidence to indicate that [GM maize] was associated with adverse effects".

Assessing the safety of GM foods used for animal feeds, reviews indicate there is "no clear evidence that [animal] feed composed of GM crops has adverse effects on animal health[22]" and that "No study has revealed any differences in the nutritional profile of animal products derived from GE-fed animals[23]". Many countries which do not allow the cultivation of GM crops do, however, allow the import of GM crops, primarily used for animal feed (e.g., much of the European Union, Turkey, and Indonesia, among others)[24].

Despite the scientific consensus, a majority of consumers in India (and in many other countries) view GM foods as unsafe to eat[25]. Some groups are concerned that GM crops undermine farmer autonomy over their crops and their seeds[26] because GM crops do not produce seeds that can be replanted in subsequent seasons (or in some crops are not allowed to be replanted in subsequent seasons, due to plant variety rights). This is common in many highly productive crops, where seed companies have invested in intensive selection to increase performance. Sales of improved varieties are the main way through which genetic improvement reaches farmers. Whether farmers choose to invest in more expensive seeds will depend on whether the benefits of the GM seeds outweigh the increased cost. If GM seeds contribute to greater profitability, this will be reflected in adoption rates.

The common consumer view about the potential negative impacts of GM maize (and other crops) is often packaged with broader social concerns about corporate power and the environment, where small-scale, agrarian, agriculture is considered to be better for farmers and for the environment (see Greenpeace's opposition to GM foods, for example)[27]. The likely implications of GM maize on farmers must however be determined by evidence.

[22] de Vos CJ, Swanenburg M. Health effects of feeding genetically modified (GM) crops to livestock animals: A review. Food Chem Toxicol. 2018 Jul;117:3-12. doi: 10.1016/j.fct.2017.08.031. Epub 2017 Aug 31. PMID: 28843598.

[23] Van Eenennaam AL, Young AE. Prevalence and impacts of genetically engineered feedstuffs on livestock populations. J Anim Sci. 2014 Oct;92(10):4255-78. doi: 10.2527/jas.2014-8124. Epub 2014 Sep 2. Erratum in: J Anim Sci. 2014 Nov;92(11):5293. PMID: 25184846.

[24] https://www.croplife.org.au/topics/ive-heard-europe-china-and-japan-dont-accept-gm-crops-so-why-are-they-allowed-to-be-grown-and-imported-in-australia/

[25] B. Kennedy & C. Lynne Thigpen, Many publics around world doubt safety of genetically modified foods, Pew Research Centre, 2020.

[26] https://viacampesina.org/en/india-karnataka-farmers-protest-proposed-field-trials-genetically-modified-maize-and-cotton/

[27] https://history.greenpeace.org/aotearoa/genetic-engineering/#origins

# 3. Direct impacts of GM maize

## 3.1 Potential impacts for Indian farmers

Before GM maize is allowed for cultivation it should be determined whether this change is likely to have a positive impact on Indian farmers. If adoption of GM maize does not benefit farmers, there would be no value in changes to the current policy. Even if GM maize increases yields (as proponents claim), the total farm-level profitability will also be affected by seed and pesticide[28], and potentially other, costs. Seed costs, for instance, are likely to increase because GM seeds are more expensive than regular seeds (see above). However, the effect of GM maize, specifically herbicide-tolerant maize, on total pesticide use is ambiguous, because while HT maize encourages application of one type of pesticide (glyphosate herbicide), it may discourage the application of other pesticides. Further, the use of insecticides (another type of pesticide) is likely to be reduced as Bt maize is resistant to yield-damaging pests (e.g. Fall armyworm).

There is a large body of literature assessing the impacts of GM crops, which often yield contradictory results. This allows pro-GM and anti-GM groups to point at individual studies in order to advance their particular claims. To avoid this, three separate global meta-analyses (examining some combination, or all, of yield, seed costs, pesticide costs, and gross profit) were reviewed to determine the likely farm-level impacts of adopting GM maize (Table 2). Countries included in the meta-analyses were from Europe, Africa, and the Americas.

*Table 2: Summary of findings from meta-analyses of GM maize (changes in yield, seed cost, pesticide cost, and profit for GM maize compared to conventional maize varieties).*

| | Yield | Seed cost | Pesticide cost | Gross profit |
|---|---|---|---|---|
| Klümper & Qaim et al., 2014[1,2] | +18.0%[2] | n/a | -39.1% | +68.2% |
| Pellegrino et al., 2018[3] | +10.1% | n/a | n/a | n/a |
| Finger et al., 2011[4] | +14.1% | +21.0% | -47.7% | +56.4% |
| **Average** | **+14.1%** | **-** | **-43.4%** | **+62.3%** |

[1] Klümper W, Qaim M. *A meta-analysis of the impacts of genetically modified crops*. PLoS One. 2014 Nov 3;9(11):e111629. doi: 10.1371/journal.pone.0111629.
[2] Results are for all GM crops, except for yield, which is maize-specific. Klümper & Qaim originally reported a 21.6% yield increase across all GM crops, however, the maize-specific result (for yield) was derived from disaggregated Klümper & Qaim data and reported in Pellegrino et al., 2018.
[3] Pellegrino E, Bedini S, Nuti M, Ercoli L. *Impact of genetically engineered maize on agronomic, environmental and toxicological traits: a meta-analysis of 21 years of field data*. Sci Rep. 2018 Feb 15;8(1):3113. doi: 10.1038/s41598-018-21284-2.

[28] "Pesticide" refers to all chemical crop protection products, including insecticides, fungicides, herbicide, etc. While HT maize may encourage the use of one specific type of pesticide (glyphosate – a herbicide), the aggregate impact on all pesticide use is what matters.

[4] Finger R, El Benni N, Kaphengst T, Evans C, Herbert S, Lehmann B, Morse S, Stupak N. *A Meta Analysis on Farm-Level Costs and Benefits of GM Crops*. Sustainability. 2011; 3(5):743-762. https://doi.org/10.3390/su3050743

The average GM yield across all three meta-analyses increased by 14.1% compared to conventional maize. One meta-analysis considered the effects of seed costs, which increased by 21.0%, and two meta-analyses considered the effects of pesticide costs, which decreased by an average of 43.4%. Klümper & Qaim (2014) found that pesticide quantities decreased by 36.9%, comparable to the decrease in pesticide cost. This suggests that GM crops are expected to reduce the total use of pesticides by shifting chemical crop-protection towards one all-purpose herbicide and away from other pesticides, i.e. reducing the use of cause-specific herbicides and insecticides which may require multiple applications. Aside from these ecological benefits, reduced pesticide use may also result in lower labour requirements, which would allow farmers to better utilise their time elsewhere, also reducing costs.

Overall, it is expected that the increased revenue from greater yield and decreased pesticide costs outweigh the increase in seed costs, as the average GM profit margin (reported in two meta-analyses) increased by 62.3% compared to conventional maize. This high return on investment is likely why GM maize varieties have been adopted so quickly by farmers around the world[29]. This is significant, particularly when noting that an increased supply of maize will decrease maize prices. The gross profit occurs because the benefits of GM maize outweigh the reduction in revenue associated with somewhat lower maize prices.

While a 14.1% increase in yield, and the corresponding increase in profit, would be very good for Indian farmers, there are reasons to believe this estimate is conservative. Pellegrino et al. (2018) found that stacked maize varieties were associated with larger increases in yield[30], however, Finger et al. (2011) considered only Bt maize, and therefore did not include any stacked varieties (or HT maize). Including these traits may have led to a larger estimated increase in yield for GM varieties compared to conventional maize. Further, there is some evidence in Finger et al. that countries with lower yields receive larger yield increases from adopting GM maize[31]. This would align with later research that suggested GM maize had a stronger impact on lower yielding farms (Chavs et al., 2014)[32]. Klümper & Qaim (2014) also found that developing countries received larger increases in yield and gross profit from adopting GM crops.

[29] See Figure 3.

[30] With yield increases of up to 24.5% for quadruple stacked varieties (though double stacked varieties had lower yield increases regular “single GM event” varieties).

[31] In South Africa, GM maize increased yields by 24.6% (from a base of 7,124 kg/ha) compared to 5.6% in Spain (from a base of 11,840 kg/ha).

[32] Chavas, J.; Shi, G.; Lauer, J. The Effects of GM Technology on Maize Yield. Crop. Sci. 2014, 54, 1331–1335

Pellegrino et al. specifically assessed GM maize performance toxicological traits and found GM maize contained lower concentrations of mycotoxins (-29%), fumonisin (-31%), and thricotecens (-37%). The reduced toxicity was related to lower incidence of insect attack, because damage inflicted by pests creates entry points for fungal infections. Improving maize quality by reducing toxicity would decrease the likelihood that maize is unable to be sold or could only be sold at a lower price, and therefore increase farmer profits by improving the saleability, and the average price received, of maize.

During the 2022-23 crop year, the average return per hectare for maize produced in India was ₹24,126[33]. This made maize the fourth most profitable kharif crop. (In the kharif season, cotton, the only GM crop cultivated in India, had the highest return.) Based on two meta-analyses, GM maize increases farmer profits by 62% (Table 2), which translates to an increase in gross profit of ₹15,031 to ₹39,158 per hectare.

## 3.2 *Impacts on national maize production*

While farmers cultivating GM maize would benefit from higher yields and increased profit, the extent to which GM maize impacts the wider economy would depend on the speed and scale of GM adoption. In countries where cultivation of GM maize is allowed, it usually reaches very high levels of market share, frequently accounting for 90% of the total maize area planted (Figure 3). On average, GM maize reaches 50% market share in major producing countries after 7 years and 90% after 16 years[34].

[33] Gross returns after accounting for farm labour. *Price policy for Kharif Crops, The marketing Season 2024-25. Commission for Agricultural Costs and Prices*, Dept of Agriculture & farmers welfare, Ministry of Agriculture & farmers welfare, Government of India, March 2024.

[34] See Appendix 2.

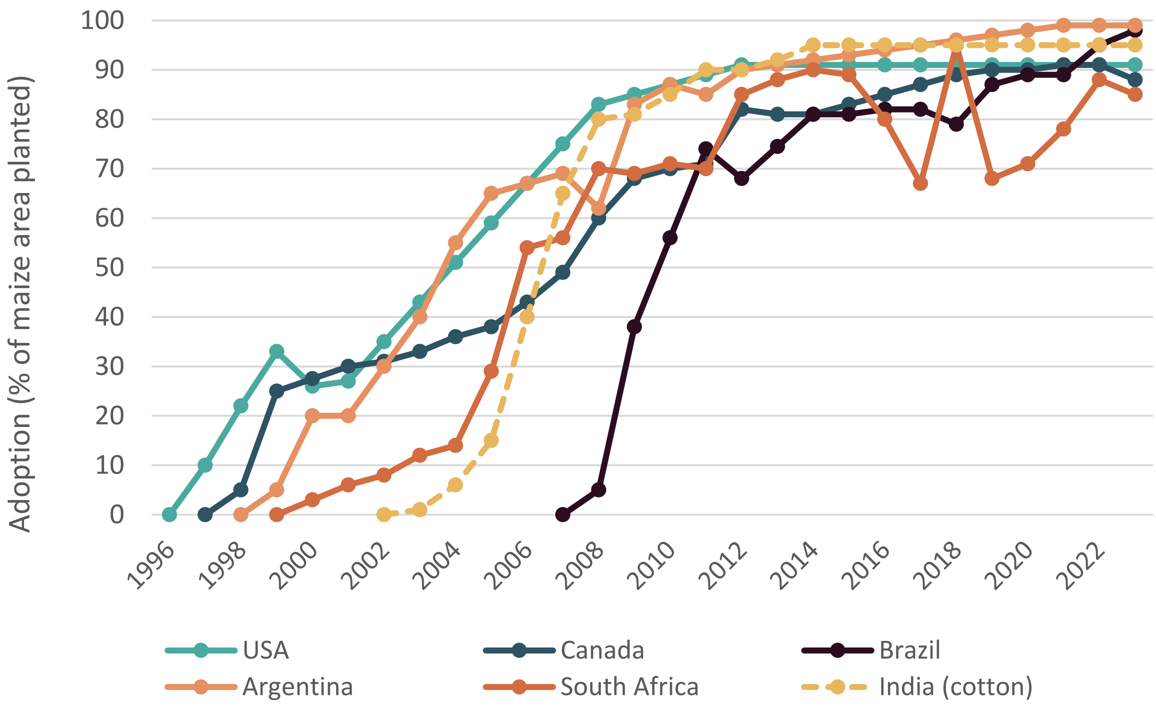


*Figure 3: Adoption profiles of GM maize (based on % of area planted) for major producing countries and for GM cotton in India only.*

Compared to GM maize elsewhere in the world, GM cotton was adopted very quickly in India, reaching 90% market share after only 9 years. The fast speed and high levels of adoption confirm the positive impact of GM crops on profitability. Reddy and Nandula (2012)[35] noted that "Farmers… must have seen some economic and weed control benefits; otherwise, the rapid increase in area planted to [GM crops] in recent years would not have occurred".

We forecasted[36] the potential impact of GM maize cultivation on national production in two future scenarios:

1. A "standard" scenario, where yield increased in line with the average of all three meta-analyses (+14.1% compared to the status quo yield) and where adoption was based on the average adoption of GM maize globally (see corresponding adoption profile in Figure 6), and
2. An "optimistic" scenario, where yield increased in line with the highest result observed across all meta-analyses (+18.0% compared to the status quo yield) and adoption was based on the adoption of GM cotton observed in India (again, see Figure 6).

[35] Reddy, K. N., and V. K. Nandula. "Herbicide resistant crops: History, development and current technologies." Indian Journal of Agronomy 57.1 (2012): 1-7.

[36] For detailed methodology see Appendix 2

The forecasted impact of GM maize cultivation, under standard and optimistic impact scenarios, relative to the status quo trend in production (with only conventional maize varieties) and relative to predicted future demand are shown in Figure 4.

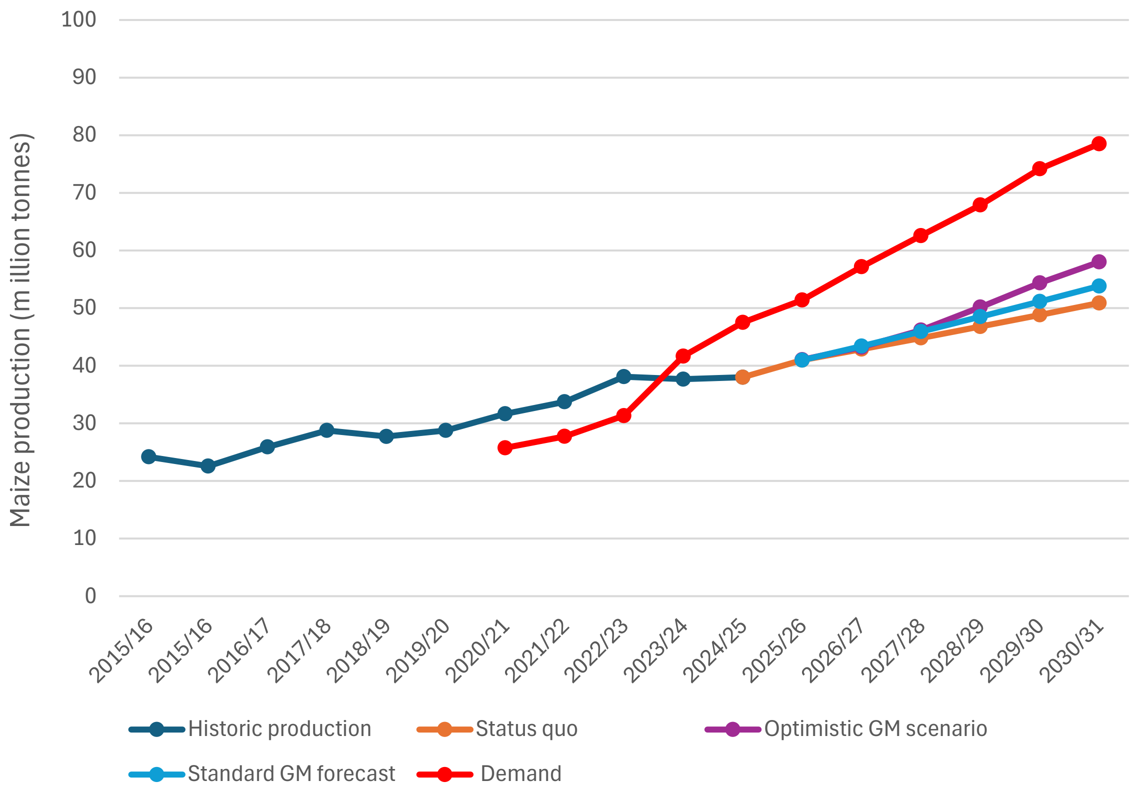


*Figure 4: Forecast impact of GM maize cultivation under standard and optimistic scenarios, relative to the current production trend and to predicted future demand. (Source: See Appendix 2 and Figure 3.)*

Allowing GM maize cultivation would increase domestic production by 6% to 14% in 2030-31, under standard and optimistic scenarios, respectively, if commercialisation begins in 2025-26 (Table 3). GM maize cultivation would deliver significant benefits to farmers, increasing total farmer profitability throughout India by ₹75 to ₹170 billion in 2030-31. The cumulative benefit of increased profits from the period between 2025-26 and 2030-31 is ₹228 to ₹438 billion.

*Table 3: Forecast production, change in production (tonnes and %), farmer profit, change in profit (billion ₹ and %), land use, and demand shortage in 2030-31, under standard and optimistic GM maize scenarios.*

| | *Forecast for 2030-31* | | |
|---|---|---|---|
| | **Base** | **Standard GM** | **Optimistic GM** |
| Production (million tonnes)[1] | 50.9 | 53.8 | 58.0 |
| *Change (million tonnes)* | - | 2.9 | 7.1 |
| *Change (%)* | - | 5.8% | 14.0% |
| Annual farmer profit (billion ₹)[2] | 293.3 | 368.3 | 466.4 |
| Change (billion ₹)[3] | - | 75.0 | 170.3 |
| *Change (%)* | - | 25.6% | 59.0% |
| Equivalent area saved ('000 hectares)[4] | - | 703 | 1,700 |
| Demand shortage (million tonnes)[1] | 27.6 | 24.7 | 20.5 |
| *% of demand not met* | - | 10.7% | 25.8% |

[1] See Figure 4. Demand shortage relative to demand forecast of 78.5 MT.
[2] Based average profit per/ha of ₹24,127 ().
[3] Increase in profit per ha under the standard scenario is ₹15,031 (see 3.1: Impacts for Indian farmers). The increase in profit per ha under the optimistic scenario was scaled relative to proportional increase in yield: ₹15,031 x 18/14.1 = ₹18,037.
[4] Area saved is based on the additional area which would be required to produce the additional output without GM (i.e., at base forecast yield in 2030-31: 4.19 tonnes per ha).

Critically, allowing GM maize cultivation would reduce the amount of land required to achieve a given level of production, by increasing yields. Without GM maize, to achieve the same level of production in 2030-31 as the standard GM scenario, an additional 703,000 hectares would be required (a 5.8% increase in the total maize area). In the long-term, the impacts of increased productivity can be much more important than the impact of changes in land use. For example, since 1961 the area used for cereal production in Argentina has increased by 76%, however, production has increased by 531%[37].

Despite the benefits to farmers and reduced land use, GM maize is not enough to meet rapidly increasing demand (Figure 4; Table 3). Without GM maize there is expected to be a maize shortage of 28 million tonnes in 2030-31, however, GM maize could potentially reduce this shortage by up to 26%. To address this shortage without significantly increasing land use would require imports (addressed in the next section).

While there is significant potential for GM maize to increase production to contribute to demand in 2030-31, it only reflects the benefits of GM maize at partial adoption. By 2030-31

[37] https://ourworldindata.org/grapher/index-of-cereal-production-yield-and-land-use?country=~ARG

GM maize would represent 41% of the total maize area planted[38] in the standard scenario and 79% in the optimistic scenario (Figure 6).

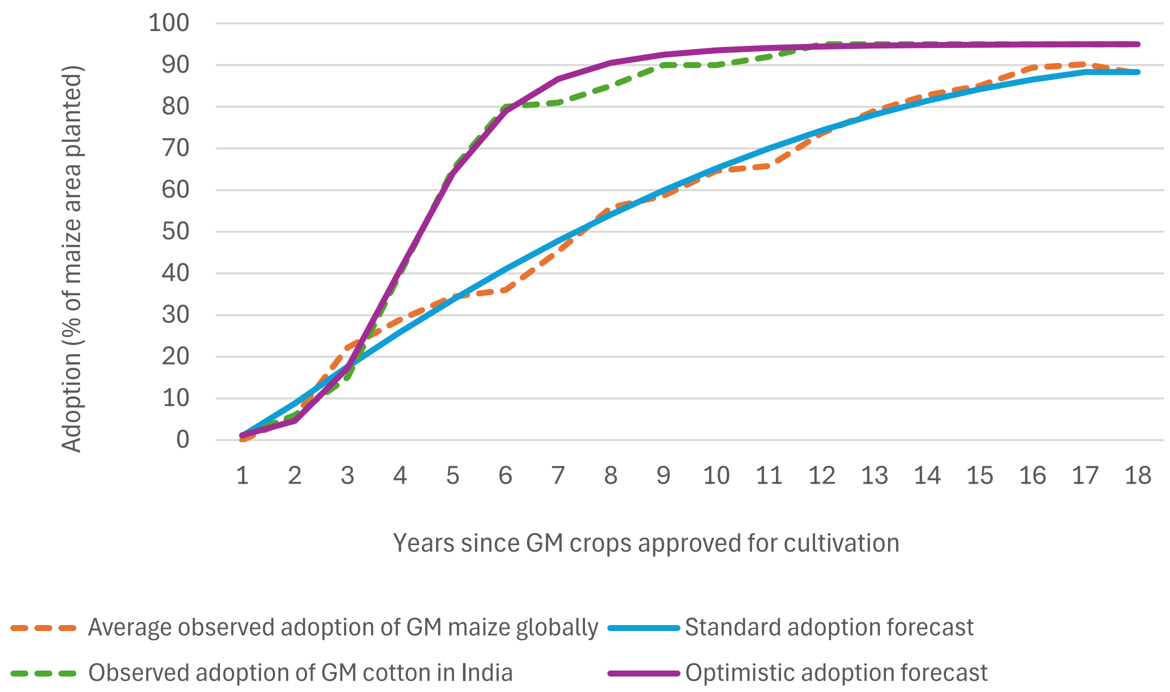


*Figure 5: Fitted adoption profiles and observed adoption data for standard and optimistic GM scenarios.*

Adoption is forecast to reach a maximum level (i.e. plateau) of 88%, by 2041-42, in the standard scenario[39], and 95%, by 2036-37, in the optimistic scenario, even though adoption in the optimistic scenario will reach 90% several years earlier. Even with no further increase in the total maize area planted after 2030-31, GM maize will eventually increase total farmers profits by ₹161 to ₹208 billion per year by 2041-42 (Figure 6).

[38] The total maize area of planted is forecast to increase to 12.1 million hectares (from 10.8 million ha in 2024/25) by 2030-31 (based on recent growth).

[39] While on average, GM maize reached 90% market share in major producing countries after 16 years, the longer-term average is slightly below this because some countries adoption rates decreased afterwards.

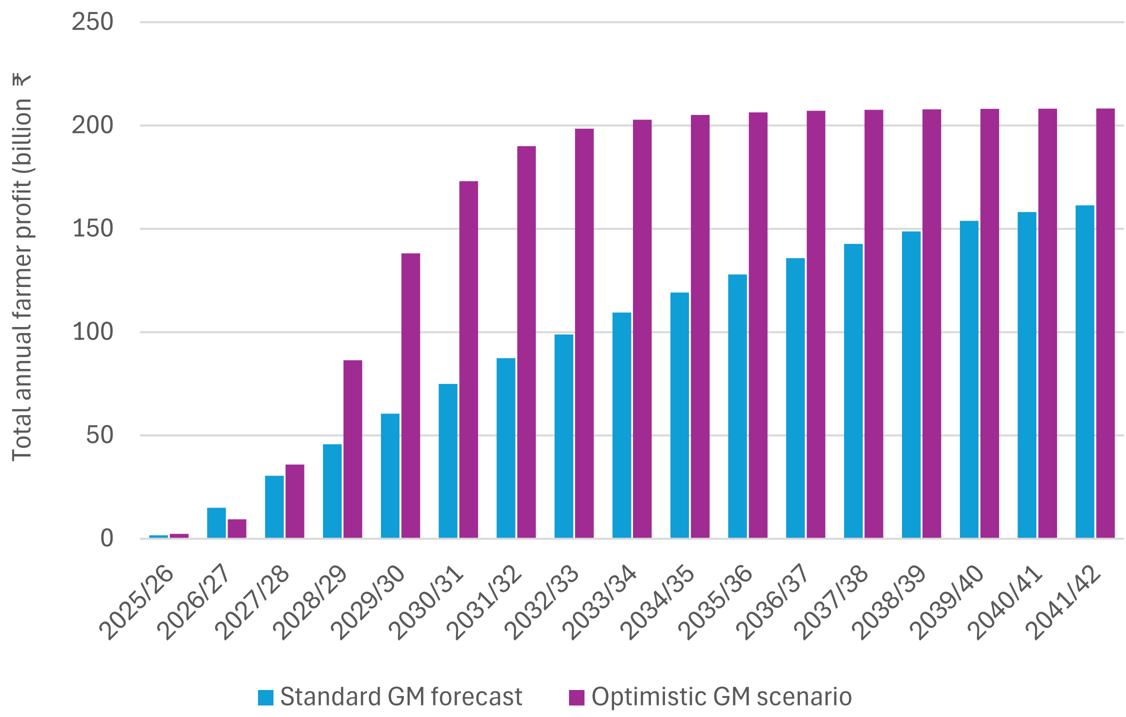


*Figure 6: Change in total annual farmer profit under standard and optimistic GM forecasts up to 2041-42.*

Ultimately, after accounting for adoption, GM maize will increase yields in India by 12.5% to 17.1%, in standard and optimistic scenarios, respectively, relative to the status quo (i.e. current productivity growth with only conventional maize)[40].

## 3.3 Imports and exports

Over the last decade India has usually exported 2-4 million tonnes of maize per year, while usually importing less than 0.3 million tonnes, however, in the next crop year India is set to become a net maize importer[11]. This change is due to the domestic shortage, which is likely to increase. To address this shortage without significantly shifting land use towards maize production, which would have negative consequences for other crops and for food security, will require more imports of maize.

The current ban also means that GM maize cannot be imported from other countries where GM maize is cultivated. Because many of the largest maize producers in the world (e.g., Brazil, Argentina, and the USA) produce predominantly GM maize (Figure 3), this restricts opportunities for Indian importers to source maize. As a result, most maize imported into India comes from Ukraine and Myanmar, which produce only conventional maize[11].

[40] See Appendix 2:

Allowing the import of GM maize would enable industries in India to access much greater quantities of maize and from a greater number of countries. Increasing the available supply of maize will result in lower maize prices. Within India, maize consuming industries would benefit, although increased competition from foreign imports may reduce prices for maize farmers, somewhat reducing the benefits of increased yields and profit margins.

# 4. Indirect impacts of allowing GM maize

The direct impacts of allowing cultivation of GM maize are increased domestic production and increased farmer profits (previous section). The direct impact of allowing the import of GM maize is that domestic industries have access to much greater quantities of maize. Both policies would increase the available supply of maize in India. Indirect impacts are the consequences of greater access to maize at lower prices for domestic industries.

First, domestic industries that consume large quantities of maize will be able to increase production. Increased production from all sectors (e.g., agriculture, starches, ethanol) would result in increased employment and stimulate economic activity. Increased domestic production which is exported (particularly from the starch sector, but also dairy and poultry products), will boost India's trade balance and increase reserves of foreign currencies.

Increased production from the agriculture sector specifically is expected to lead to increased availability of dairy and poultry products, relative to a scenario where GM maize is not allowed, lowering food prices and improving food security in a country with ever-increasing demand. It is important to note however, that some benefits arising from allowing GM maize would come from *avoiding negative outcomes* (e.g. avoiding price increases and associated economic distress). In some case, access to cheaper maize could mean that some poultry and dairy producers currently operating at a loss will become profitable and continue production and expansion. Without GM maize they may go out of business. Poultry feed prices, for example, have increased the cost to grow a broiler to above the price received for selling the animal[11]. Unless maize prices (which account for 39% of poultry production costs[41]) decrease, production of chicken is likely to decrease as poultry farmers are forced out of business. This example shows how GM maize restrictions reduce the human food supply and keep food costs high, despite only a small amount of maize being consumed by humans. In this example, poultry producers going out of business would also create unemployment (the poultry sector alone employs 6 million people directly or indirectly[42]).

[41] Poultry Federation of India
[42] https://www.onehealthpoultry.org/where-we-work/india/poultry-in-india/

An additional benefit of GM maize, to the poultry sector specifically, is that GM maize is associated with lower toxicity (discussed above). Poultry are highly susceptible to toxins in their feed, so maize which exceeds a certain toxicity threshold is not suitable for poultry feed. This makes a significant amount of maize produced in India unsuitable for poultry feed and would potentially exacerbate any future maize shortage. Reducing the toxicity of maize used for cattle feed, which is often not tested for quality (unlike poultry, which are more susceptible to mycotoxins), will also result in lower levels of aflatoxins in dairy products.

One of the main drivers of increasing demand for maize is ethanol, due to the government's National Policy on Biofuels (see above). Currently rice and sugarcane are major contributors to ethanol production, however, both are very water-intensive, particularly rice which is produced in paddy fields. Rice is also consumed mainly as a food crop in India, unlike maize. Shifting ethanol production towards maize and away from rice and sugarcane is therefore likely to result in less competition for human foods and improve water-use efficiency. The latter is particularly important, given the potential impacts of climate change on water availability.

As mentioned previously, the long-term impacts of increased productivity can be much more important than changes in land use. This is especially important because climate change is reducing the amount of suitable land available for crop production. Increasing the intensity (i.e., yield) of land which remains suitable for cultivation is therefore essential for maintaining a climate resilient agriculture sector.

Most analyses of the environmental impacts of GM maize and other GM crops focus on the direct reduction in pesticide uses. One indirect environmental benefit of GM crop usage is a reduction in greenhouse gas emissions due to reduced fuel use and tillage changes (associated with lower land use)[43]. An environmental risk associated with cultivation is the possibility of "outcrossing", which is when GM crops breed with closely related plants[44]. This creates the possibility that herbicide resistant weeds are produced if HT maize were to cross with nearby weeds. This risk is only associated with GM crop cultivation, so is not a concern in the many countries which do allow the import of GM crops but not the cultivation of GM crops (e.g., much of the European Union, Turkey, and Indonesia, among others).

[43] Brookes G, Barfoot P. Environmental impacts of genetically modified (GM) crop use 1996-2018: impacts on pesticide use and carbon emissions. GM Crops Food. 2020 Oct 1;11(4):215-241. doi: 10.1080/21645698.2020.1773198. PMID: 32706316; PMCID: PMC7518756.

[44] https://royalsociety.org/news-resources/projects/gm-plants/if-we-grow-gm-crops-will-they-cross-breed-with-other-plants/

# 5. Discussion and conclusion

In general, India's maize production has seen substantial growth over the past two decades, yet it still lags behind the global average yield. The majority of maize in India is used for animal feed, with the starch and ethanol industries also consuming a significant portion. Considering demand for maize is expected to grow faster than supply, India is likely to face shortages and higher prices in the future.

Based on review of the best available evidence, allowing cultivation and importation of GM maize in India is likely to increase productivity and profitability for farmers and to benefit other stakeholders in the maize supply chain, through access to greater quantities of maize at lower prices. Due to its trait attributes of pest resistance, herbicide tolerance, and lower toxicity, GM maize has the potential to address many current challenges faced by Indian maize farmers. The adoption of GM maize could lead to increased yields and reduced costs, significantly improving profitability for Indian maize farmers.

The broader supply chain, especially animal feed and ethanol producers, stand to benefit from access to more reliable and abundant sources of maize. This could incentivize further economic development in these sectors. Forecasts from this report suggest that allowing GM maize cultivation could increase domestic production by 6% to 14% by the 2030-31 crop year, depending on the speed of adoption. This increase in production would help meet the growing demand for maize, which is expected to reach 78.5 million tonnes by 2030-31. Nevertheless, even with GM maize cultivation beginning in 2025-26, the shortage in domestic maize production in 2030-31 is estimated at between 20.5 and 24.7 million tonnes

The adoption of GM maize is not without its challenges. The increased cost of GM seeds and increased pesticide use raises concerns, however, the literature is clear that GM maize increases farmer profits (despite higher seed costs) and that overall pesticide use decreases. This outcome is both economically and environmentally positive. The adoption of GM maize could have broader social implications, and there are concerns about the impact of GM crops on farmer autonomy. However, rapid adoption combined with large positive impacts on farmer profitability suggest farmers are choosing GM maize because it economically beneficial for them. Nonetheless, the perception of GM foods as unsafe by a significant proportion of consumers in India could pose a significant barrier to adoption. Feedback from a broad range of stakeholders has suggested that education about the scientific consensus on GM foods, for both consumers and farmers – some of whom will be sceptical – will be essential if GM maize were to be allowed.

In this context, it is critical to note that the dissemination of improved seeds should be accompanied with technical support to farmers to adjust their growing systems to adequately attend to crop input and management changes.

In 2030-31 there is expected to be a maize shortage of 27.7 million tonnes in India. This shortage would likely come with a major increase in the price of maize and other agricultural products, and with serious negative economic consequences for other sectors in the maize supply chain. Allowing the cultivation of GM maize could decrease this shortage by up to 26%, though allowing imports of GM maize would be required to fully address this shortage. GM maize will enhance domestic production and profitability for growers and provide a more reliable supply of maize for the broader industry. The case for GM maize is very strong. To realise these benefits, it is essential to address potential concerns associated with GM maize to ensure its successful adoption, which may depend on its societal acceptance.

We have prepared a set of recommendations aimed at harnessing the potential benefits of GM maize in India while addressing the associated challenges:

## 6.1 *Recommendations*

1. Define a framework in which cultivation and imports of GM maize would be allowed in India under a clear regulatory framework to manage its use, including guidelines for seed pricing, pesticide use, and environmental protection.

2. Conduct a comprehensive impact assessment to understand the potential economic, social, and environmental implications of GM maize cultivation and imports. In particular, the impact assessment should look at the distributional aspects of GM maize adoption, focusing on if and how GM maize is likely to be used by small-scale growers and less technology-savvy farmers, and identifying what challenges may need to be overcome to ensure they can realise benefits from GM maize (e.g., do they need better access to credit, markets, and technical assistance).

3. Following the impact assessment, design a comprehensive policy to support growers, by ensuring they receive appropriate technical support, education, and effective extension efforts.

4. Promote public awareness and education campaigns to educate consumers about important subjects such as safety, risks, and potential contributions of GM maize, addressing common misconceptions and concerns.

5. Monitor and mitigate environmental risks by developing strategies to inform the appropriate use of pesticides and other agricultural practices related to GM maize production and utilization. This should be done in partnership with companies and research centres through a collective effort.

# 6. Appendixes

## 6.1 Appendix 1: Maize production data

Table 4 shows global maize area, yield, and production, from the 10 biggest producing countries, along with the rest of the world, for the 2022 to 2023 crop season.

*Table 4: Area, yield, and production, and share of global production by country for the 2022-23 crop season[1,2].*

| Rank | Country | Area ('000 Ha) | Yield (MT/Ha) | Production ('000 MT) | Share of output | Cumulative share |
|---|---|---|---|---|---|---|
| 1 | United States[3] | 31,851 | 10.89 | 346,739 | 29.9% | |
| 2 | China | 43,070 | 6.44 | 277,200 | 23.9% | 54% |
| 3 | Brazil[3] | 22,400 | 6.12 | 137,000 | 11.8% | 66% |
| n/a | European Union | 8,799 | 5.95 | 52,329 | 4.5% | 70% |
| 4 | India | 10,744 | 3.55 | 38,085 | 3.3% | 73% |
| 5 | Argentina[3] | 7,200 | 5.14 | 37,000 | 3.2% | 77% |
| 6 | Mexico | 6,891 | 4.07 | 28,077 | 2.4% | 79% |
| 7 | Ukraine | 4,050 | 6.67 | 27,000 | 2.3% | 81% |
| 8 | South Africa[3] | 2,945 | 5.81 | 17,100 | 1.5% | 83% |
| 9 | Russia | 2,640 | 6 | 15,832 | 1.4% | 84% |
| 10 | Canada[3] | 1,444 | 10.07 | 14,539 | 1.3% | 85% |
| - | Rest of world | 59,056 | 2.87 | 169,769 | 14.6% | 100% |
| - | **Total** | **201,090** | **5.77** | **1,160,670** | **-** | **-** |

[1] Source: Foreign Agricultural Service, Official USDA Estimates.
[2] The 2022-23 crop season was used so accurate data was available for all countries.
[3] GM maize is allowed commercial in these countries. In some other countries (e.g. China) GM maize is allowed for commercial trials but is not yet harvested at scale.

Table 5 compares nation-wide identical production figures from two sources, the USDA (disaggregated into yield and land use) and Government of India (disaggregated by season) for the last 10 years.

*Table 5: Production figures disaggregated by components (area harvested and yield)[1] and by season (kharif, rabi and summer)[2] for India from 2014-15 to 2023-24 crop seasons.*

| | USDA[1] | | | Government of India[2] | | | |
|---|---|---|---|---|---|---|---|
| | **Area ('000 Ha)** | **Yield (MT/Ha)** | **Prod. ('000 MT)** | **Kharif** | **Rabi** | **Summer** | **Total** |
| 2014-15 | 9,185 | 2.63 | 24,173 | 17,145 | 7,114 | - | 24,173 |
| 2015-16 | 8,806 | 2.56 | 22,567 | 17,014 | 7,159 | - | 22,567 |
| 2016-17 | 9,633 | 2.69 | 25,900 | 16,053 | 6,514 | - | 25,900 |
| 2017-18 | 9,380 | 3.07 | 28,753 | 18,919 | 6,981 | - | 28,753 |
| 2018-19 | 9,027 | 3.07 | 27,715 | 20,118 | 8,634 | - | 27,715 |
| 2019-20 | 9,569 | 3.01 | 28,766 | 19,414 | 8,302 | - | 28,766 |
| 2020-21 | 9,892 | 3.20 | 31,647 | 19,429 | 9,337 | - | 31,647 |
| 2021-22 | 9,958 | 3.39 | 33,730 | 21,555 | 10,092 | - | 33,730 |
| 2022-23 | 10,744 | 3.54 | 38,085 | 22,681 | 11,049 | - | 38,085 |
| 2023-24 | 11,241 | 3.35 | 37,665 | 23,674 | 11,690 | 2,721 | 37,665 |
| 2024-25 | 10,800 | 3.52 | 38,000 | n/a | n/a | n/a | n/a |
| **Trend[3]** | **211** | **0.10** | **1,636** | **-** | **-** | **-** | **-** |
| *Change[4]* | 2.0% | 2.8% | 4.3% | - | - | - | - |

[1] Source: [1] Source: Foreign Agricultural Service, Official USDA Estimates: https://ipad.fas.usda.gov/countrysummary/default.aspx?id=IN&crop=Corn
[2] Source: Govt of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Final Estimate of Production of Food Grains, Oilseeds, and other commercial crops for the 2023-24 season (25-09-2024): https://agriwelfare.gov.in/en/AgricultureEstimates.
[3] Trend based on the previous 10 crop years.
[4] Change based on trend compared to the 2024-25 crop year.

Over the last 5 years (from 2019-20 to 2023-24) production has averaged 33.9 million metric tonnes.

Over the last 5 years, kharif and rabi seasons have contributed 62.8% and 29.7% of total maize production, respectively. Summer production was 1.6% of total maize production (but 7% in the 2023-24 crop year).

The production forecast in Figure 3 (from 2025-26 to 2030-31) is based on the trends for area and yield in Table 5. The assumptions for the demand forecast are in Table 6:

*Table 6: Composition of demand for maize for 2023-24 and 2024-25 crop years[1].*

| | *Demand (million tonnes)* | | **CAGR** |
|---|---|---|---|
| | **2023-24** | **2030-31** | |
| Poultry feed | 20.5 | 39.5 | 9.8% |
| Dairy feed | 5.2 | 7.3 | 5.0% |
| Starch | 5.5 | 10.2 | 9.3% |
| Beverage (alcohol) | 0.7 | 1.4 | 10.0% |
| Human consumption | 2.0 | 2.0 | 0.0% |
| Ethanol (fuel) | 7.0 | 17.0 | 13.6% |
| Exports | 2.3 | 0.0 | -100.0% |
| Seeds / wastage | 0.8 | 1.1 | 5.0% |
| **Total demand growth** | **43.9** | **78.5** | **8.6%** |

[1] Source: Industry estimates, via Techpro India Pvt. Ltd, 06/11/2024.

Table 7 shows the average maize area, yield, and production, from the 10 largest producing states, along with the rest of India, from the 2017-18 to 2021-22 crop seasons.

*Table 7: Average annual maize area, yield, and production by state from 2017-18 to 2021-22[1].*

| Rank | State | Area ('000 Ha) | Yield (MT/Ha) | Production ('000 MT) | Share of output | Cumulative share |
|---|---|---|---|---|---|---|
| 1 | Karnataka | 1,478 | 3,039 | 4,490 | 15% | |
| 2 | Madhya Pradesh | 1,366 | 2,962 | 4,046 | 13% | 28% |
| 3 | Maharashtra | 1,110 | 2,501 | 2,776 | 9% | 38% |
| 4 | Tamil Nadu | 370 | 7,190 | 2,659 | 9% | 46% |
| 5 | Telangana | 481 | 4,832 | 2,324 | 8% | 54% |
| 6 | Bihar | 666 | 3,479 | 2,319 | 8% | 62% |
| 7 | West Bengal | 305 | 6,452 | 1,967 | 7% | 68% |
| 8 | Andhra Pradesh | 309 | 6,198 | 1,916 | 6% | 75% |
| 9 | Rajasthan | 910 | 2,024 | 1,842 | 6% | 81% |
| 10 | Uttar Pradesh | 741 | 2,228 | 1,651 | 5% | 86% |
| - | Rest of India | 1,829 | 2,259 | 4,131 | 14% | 100% |
| **-** | **India** | **9,565** | **3,149** | **30,122** | **-** | **-** |

[1] Source: Govt of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Economics & Statistics Division, Agricultural Statistics Division, May 2023: https://desagri.gov.in/wp-content/uploads/2023/05/Normal-Estimates-2017-18-to-2021-22-2-1.pdf.

Note the average nation-wide production figure from Table 7 (30,122) aligns with the average production figure from the same 5-year period (2017-18 to 2021-22) taken from Table 5 above.

## 6.2 Appendix 2: Production forecasts and adoption profiles

Domestic production (in Figure 4) was forecasted based on underlying linear trends in land harvested and yield, observed between the 2014-15 and 2024-25 crop-years (Table 5).

The predicted impact of GM maize cultivation under each scenario was calculated for each crop-year from 2025-26 to 2035-36 based on:

a) the yield increase from GM maize (14.1% and 18% for standard and optimistic scenarios, respectively) relative to the base forecast, and
b) adoption (the proportion of maize area cultivated), which for the standard scenario is based on the average adoption of GM maize observed globally, and for the optimistic scenario is based on the adoption of GM cotton observed in India.

It was assumed that legalising GM maize in the 2025-26 crop year would allow for adoption to begin that year (1% in each adoption scenario). Adoption profiles (models fitted to "smooth" adoption data) and observed adoption data are compared in Figure 7.

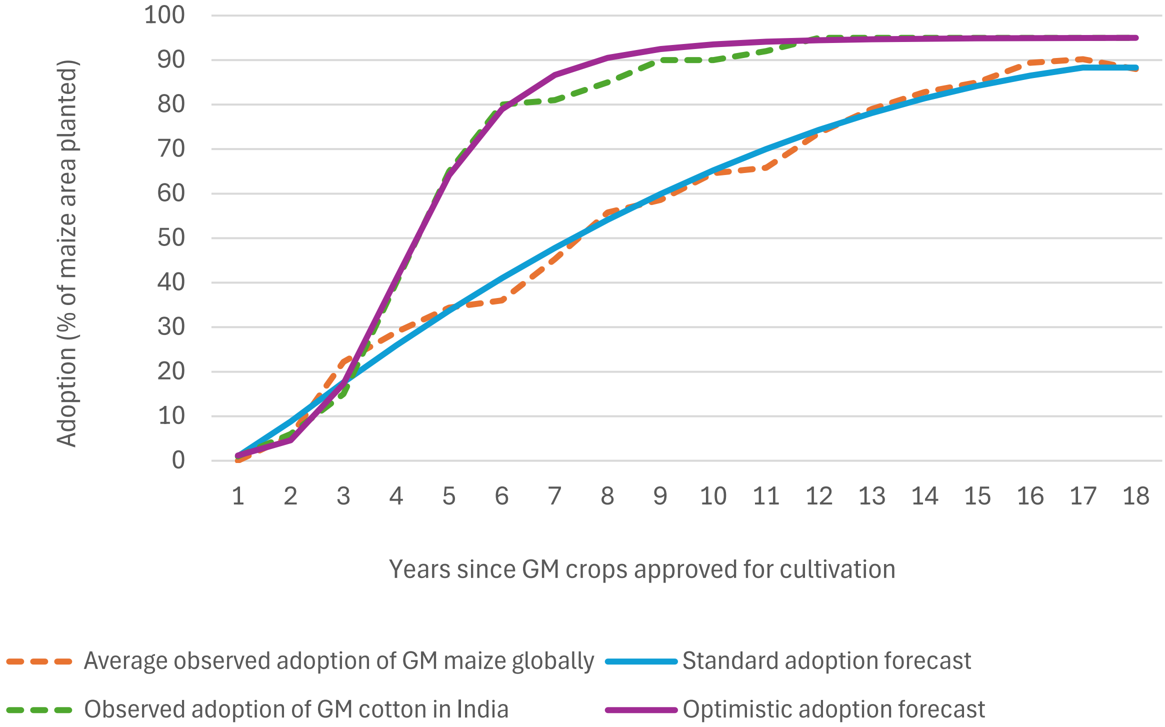


*Figure 7: Fitted adoption profiles and observed adoption data for standard and optimistic GM scenarios.*

Figure 8 shows a forecast of GM maize production relative to the status quo extended out to 2041-42. After accounting for "final" adoption rates (88% and 95% in standard and optimistic scenarios, respectively), the impact of GM maize cultivation is a 12.5% to 17.1% increase in yield, relative to the status quo of cultivation with only conventional maize.

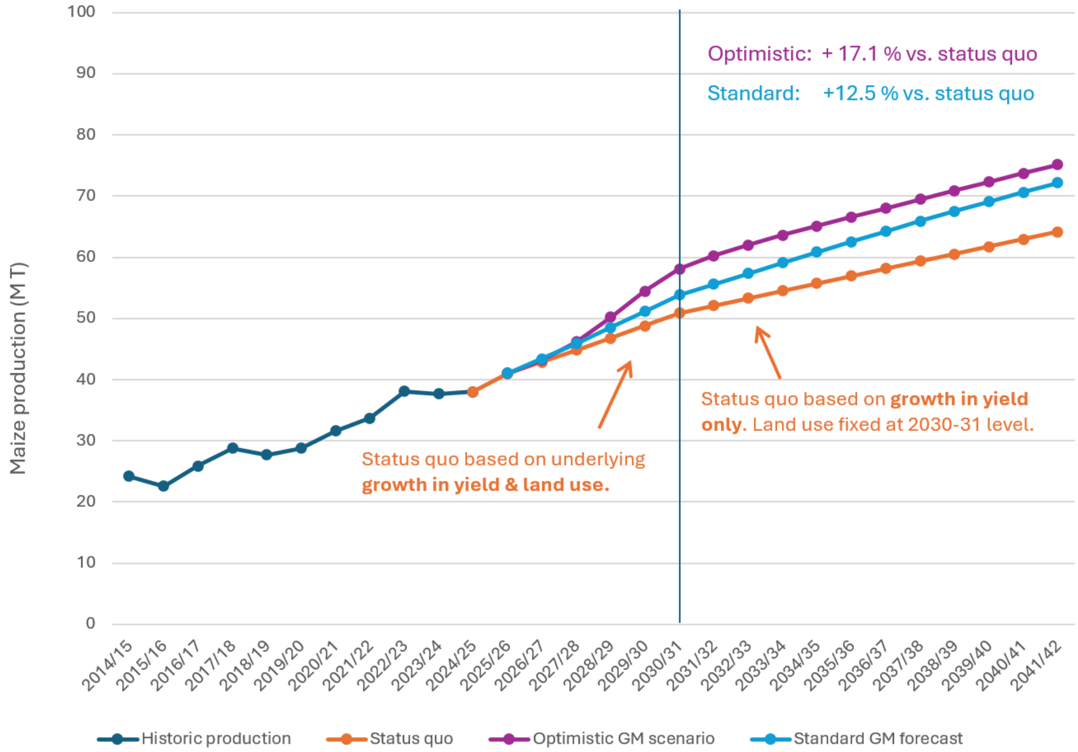


*Figure 8: Forecast impact of GM maize cultivation under standard and optimistic scenarios up to 2041-42.*