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U.S. DEPARTMENT OF AGRICULTURE

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March 2025

# The Growing Demand for Animal Products and Feed in India: Future Prospects for Production, Trade, and Technology Innovation

Jayson Beckman, Michael Johnson, Kayode Ajewole, James Kaufman, and Ethan Sabala

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## Abstract

India's population and income are expected to grow steadily through the year 2050, which could lead to increased domestic demand for animal food products (e.g., meat, dairy, and eggs). While India has largely been self-sufficient in animal feed, with imports of major feed commodities remaining under 2 percent of consumption since 2000, a large amount of soybean meal was imported in 2021 when domestic prices increased relative to global prices. Other changes in relative prices could have similar effects on net imports of feed. For this study, the authors developed feed demand and supply projections for India through 2050. The projections indicate that India's animal product demand will increase more quickly than supply and that India will have difficulty in meeting domestic feed demand if productivity is not increased above historical patterns. By the early 2030s, India will need imports to meet its growing animal feed demand, and imports will continue to grow through 2050. Use of genetically engineered seeds offer one potential opportunity to increase supply.

**Keywords:** feed, poultry, India, genetically engineered, imports

## About the Authors

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# Contents

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*A report summary from the Economic Research Service* *March 2025*

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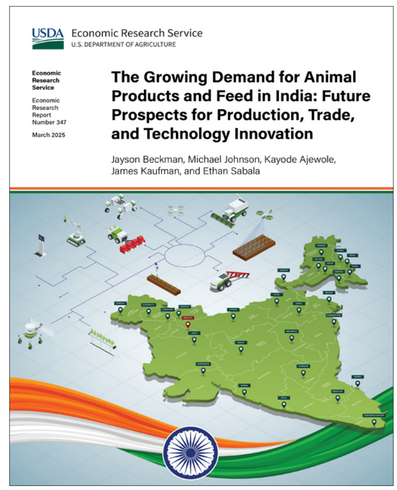



## What Is the Issue?

India became the most populated country in the world in 2023, and its population is expected to continue growing at least until 2050. During the same period, incomes are expected to grow rapidly. In a scenario of moderate income growth, the population could increase by 0.7 percent per year and Gross Domestic Product (GDP) per capita by 3.8 percent. In a scenario of more rapid income growth, these changes become 0.4 percent and 6.2 percent per year, respectively. Combined, these two effects could increase food demand, especially for animal products. India has a limited amount of arable land to expand production of food and feed, which could put pressure on domestic prices if demand increases. In 2021, some of this pressure was evident when the country imported soybean meal due to high domestic prices. These imports were genetically engineered (GE) despite a previous ban on such products. If demand for animal products continues to grow, more imports (including imports of GE products) might be needed.

## What Did the Study Find?

India's demand for animal products has increased over time due to macroeconomic changes. This growing consumption drives the demand for feed.

- India's nonmilk animal product consumption has increased from less than 6 kilograms (kg) per capita in 1960 to 17 kg in 2021. However, the consumption rates for several products (poultry, beef, sheep and goat, and pork) are below the average for low-income food-deficit countries.
- India's population of 1.4 billion in 2023 is expected to grow to at least 1.5 billion by 2050. Income is also projected to double by 2050.
- India is becoming more urban, and projections indicate that by 2046, more than half of the population will be in an urban setting.

The production and supply of animal products in India has increased, and India has become the world's third-largest exporter of beef, namely carabeef, which derives from the domestic Asian water buffalo.

- Beef production and productivity (meat per cow) in India lag behind major producers (Australia, Brazil, China, and the United States).
- Poultry meat productivity (meat per bird) also lags the global average; although it has increased since 2000. Production has increased by 8.5 percent per year from 2000 to 2022.
- In addition to meat products, India also produces and exports large amounts of fish and seafood, exporting 9.44 percent of its domestic value of production.

The feed production sector in India has grown over time.

- Almost two-thirds of India's consumption of animal feed in marketing year (MY) 2022/23 was made up of corn, wheat, and soybean meal.
- The share of corn in total animal feed consumption was 40.5 percent in MY 2022/23.

Projections indicate that India will need more feed to meet the growing demand for animal products, with imports needed by the early 2030s. The growth in imports will depend on the rate of income growth and the ability of the domestic production sector to meet the incremental increases in feed demand over time.

- Corn imports, for example, are projected to reach 122 million metric tons by 2050 under a scenario of rapid income growth. Under this scenario, imports are expected to pass 20 million metric tons by 2034. Note that if income growth is more moderate, India's corn imports are estimated to only reach 14 million metric tons (if they were to adopt GE production technologies) or 26 million metric tons (without GE adoption) in 2050. Hence, the income growth assumption is vital in determining estimated imports.
- For soybean meal, imports are projected to increase from 2.1 million metric tons in 2020 to more than 10 million metric tons in 2030 under rapid income growth. Ultimately, these imports reach 49.4 or 52.9 million metric tons (depending on GE adoption) in 2050. Projections under moderate income growth are 3.2 or 4.1 in 2030 and 9.3 or 12.8 million metric tons in 2050 (depending on GE adoption).

## How Was the Study Conducted?

The authors used data from the Food and Agriculture Organization of the United Nations (FAO), USDA, and household surveys from India to examine India's animal product demand and supply, as well as the current feed situation. Macroeconomic projections for two Shared Socioeconomic Pathways (SSP2 and SSP5) are then used to project future population and income for India. The authors also used total supply and demand balance sheets with feed conversion ratios based on projected meat demand and income (or expenditure) elasticities of demand to estimate India's future supply and demand for feed.

# The Growing Demand for Animal Products and Feed in India: Future Prospects for Production, Trade, and Technology Innovation

## Introduction

India has recently become the world's most populous country, and projections indicate that its population will continue to increase. In addition, urbanization and per capita incomes are projected to increase rapidly, suggesting that India may consume more food in the future. Although India consumes fewer animal products than most countries, demand for products such as poultry, aquaculture, and dairy could rise in the future from higher incomes (Makkar, 2018). An increase in demand for animal products would mean that more feed is needed. Estimates show that although India is the fourth-largest producer of feed in the world (in 2022, China, the top producer, produced 260.74 million metric tons of feed, while India produced 43.4 million metric tons), India already has a feed deficit of 11.4 percent (Trade Promotion Council of India (TPCI), 2023).

In terms of production of feedstuffs, India is the third-largest producer of field crops.[1] Using data from USDA, Foreign Agricultural Service (FAS) (2024c), the authors calculated that China produced 6.3 billion metric tons of field crops during 2013–22. In the same period, the United States produced 5.7 billion metric tons, and India produced 3.1 billion metric tons. India has the most cropland in the world (168.59 million hectares), and the United States is second (154.6 million hectares).[2] Thus, the difference in cropland and production is because India's yields tend to be below the global average (especially for corn and soybeans).

Imports could help India fulfill any future increase in either animal products or feed demand, but there are policies that keep imports below their potential. Beckman et al. (2022) noted that India is a net agricultural exporter because of its degree of protection. Beckman and Scott (2021) noted that India has the highest average tariffs on agricultural goods globally, while the Office of the U.S. Trade Representative (USTR) (2023) noted India's tariff rates are the highest of any major economy,[3] with an average applied tariff rate of 39.2 percent for agricultural goods. India also has nontariff barriers (NTBs) on several products, such as tallow, fat, and oils of animal origin, and tariff-rate quotas (TRQs) on corn. Additionally, India effectively bans imports of most genetically engineered (GE) food and agricultural products.

Given the potential demand growth for animal products and the difficulties for domestic production to meet it, the authors examined what India's future animal product markets might look like. They first analyzed the growing demand for feed and the underlying macroeconomic changes that are driving this growth.

[1] These crops are wheat, corn, barley, rice, sorghum, rye, mixed grain, cotton, copra oilseed, cottonseed oilseed, palm kernel oilseed, peanut oilseed, rapeseed oilseed, soybean oilseed, and sunflower oilseed.

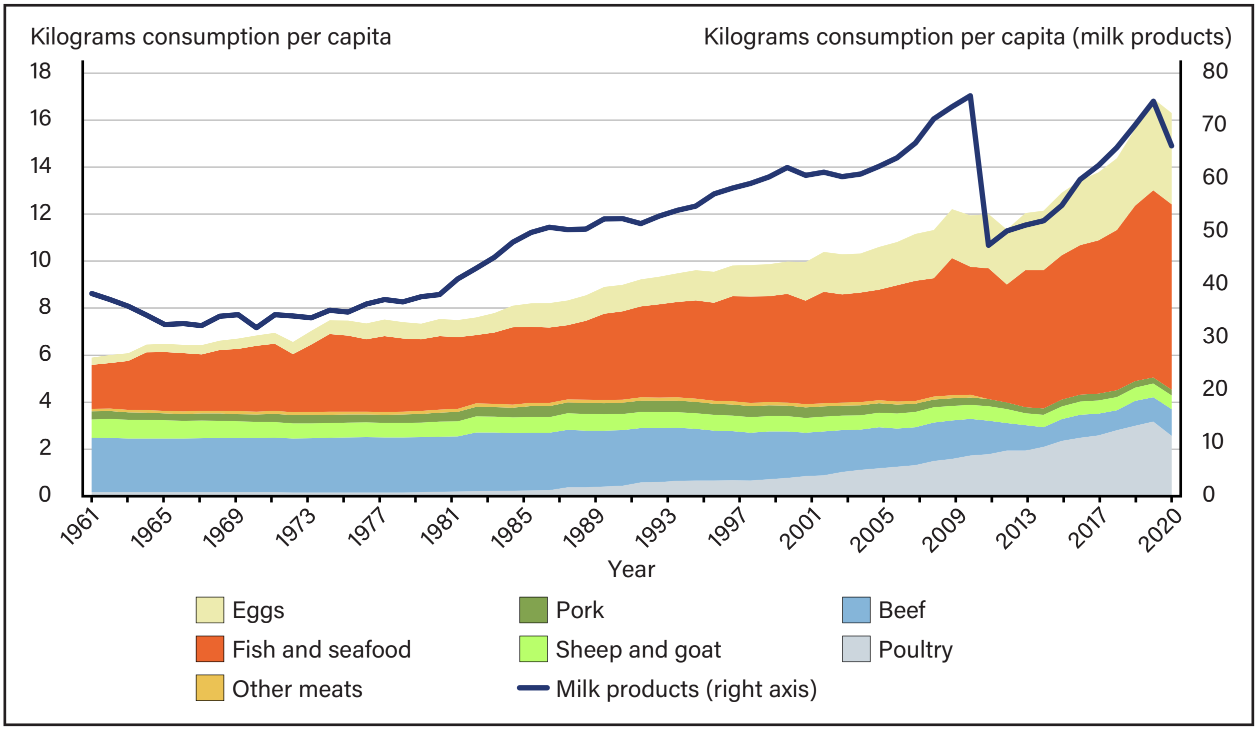
[2] Note that in terms of total agricultural land, India is behind other major agricultural producers.

[3] India's bound rates on agriculture, averaging 113.1 (and as high as 300.0) percent, are among the highest in the world (USTR, 2023).

# India's Growing Demand for Animal Products/Feed

India's consumption of animal products increased over time, in total and by type (figure 1). Milk products accounted for 80.3 percent[4] of total animal product consumption in 2019. In terms of meat products, poultry consumption has increased recently. In 2000, consumption was 0.9 kilograms (kg); in 2019, it was 3.2 kg. Fish and seafood consumption increased from 1.9 kg in 1961 to 7.9 kg in 2020. In 1961, beef was the animal product consumed the most (other than milk products), but beef consumption steadily declined.

Figure 1
**India's per capita consumption of animal products by kilogram, 1961–2020**




Note: The data indicates a large drop in milk product consumption in 2010, but this is because the Food and Agricultural Organization of the United Nations (FAO) changed the methodology for the data.

Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

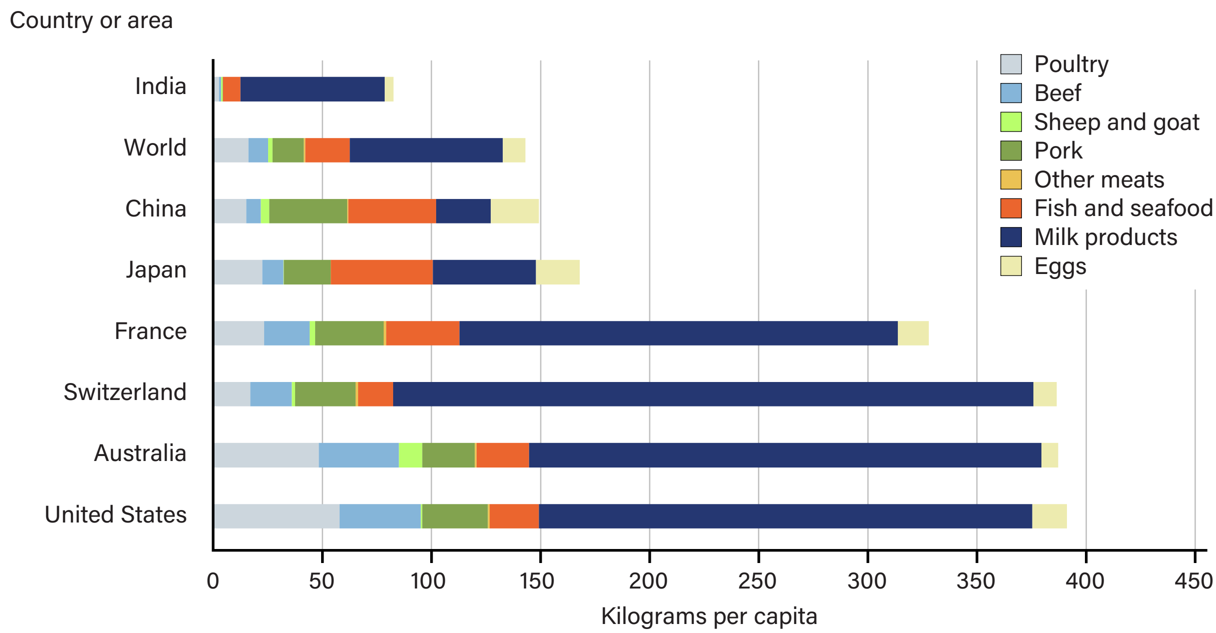
Despite the increase in animal product consumption, India lagged the world average in 2020 (figure 2).[5] The United States was the second-largest consumer of animal products (Montenegro was first with 441 kg per person, but this was skewed by 337 kg of milk-product consumption per person). World average per capita consumption was 143 kg for all animal products; India's consumption was 82.6 kg, but as with Montenegro, this was skewed by a milk product consumption of 66.3 kg per person. Fish and seafood consumption was the next-largest type of animal product consumed in India at 7.9 kg per person, followed by eggs at 3.9 kg. Poultry (2.6 kg), beef (1.1 kg), sheep and goat (0.6 kg), and pork (0.2 kg) were below the world average per

[4] The data indicate a large drop in milk product consumption in 2010, but this is because the FAO changed the methodology for the data. The FAO noted that the key difference is the absence of a balancer variable that would have taken on the outstanding unbalanced amount from the food balance sheet.

[5] Note that milk products are also the animal products most consumed globally, but the average share of total animal product consumption (49.1 percent) is lower than that for India. Of the countries listed in figure 2, Switzerland has the highest share of milk products in total animal product consumption (other than India) at 75.1 percent.

capita consumption (16.2, 9.0, 2.0, and 14.5 kg, respectively). India's total was slightly above the average of 74.89 kg per person consumed by countries the United Nations defines as being low-income food deficit (LIFD). However, India's consumption of poultry, beef, sheep and goat, and pork was below the average for LIFD countries. Scudiero et al. (2023) noted that poultry consumption in India was relatively low compared with its neighbors. Some of this was because Indian consumers typically prefer to buy from live-bird markets and because of cultural differences, such as widespread vegetarianism (table 1) (see box, "Religion and Animal Product Consumption in India"). Gulati and Juneja (2023) also noted that the poultry market is limited because of a lack of infrastructure.

Figure 2
**Average per capita consumption of animal products in select countries, 2020**




Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

## Religion and Animal Production/Consumption in India

A majority of people in India belong to a religion, such as Hinduism, that has strict dietary laws. Hindus make up 79.8 percent of India's population, and Muslims account for 14.9 percent. The remaining 6 percent are Christians (2.3 percent), Sikhs (1.7 percent), Buddhists (0.7 percent), Jains (0.4 percent), and others/not specified (0.9 percent) (Kramer, 2021). Hindus, Sikhs, and Jains restrict meat in their daily diets, especially beef, while Muslims are prohibited from eating pork. Vegetarians are prominent in India, with 39 percent of the population saying they follow a vegetarian diet (Sahgal et al., 2021).[1] However, Natrajan and Jacob (2018) stated that the percentage of vegetarians has been overstated and is between 20 to 30 percent. Future growth of the Indian population posits Muslims growing by 76 percent, Hindus by 33 percent, Christians by 18 percent, and others by 5 percent (Kramer, 2021).

[1] Note that the survey did not define vegetarian but left the definition up to the respondent.

Table 1
**Percent of Indian adults who are vegetarian, 2019–20**

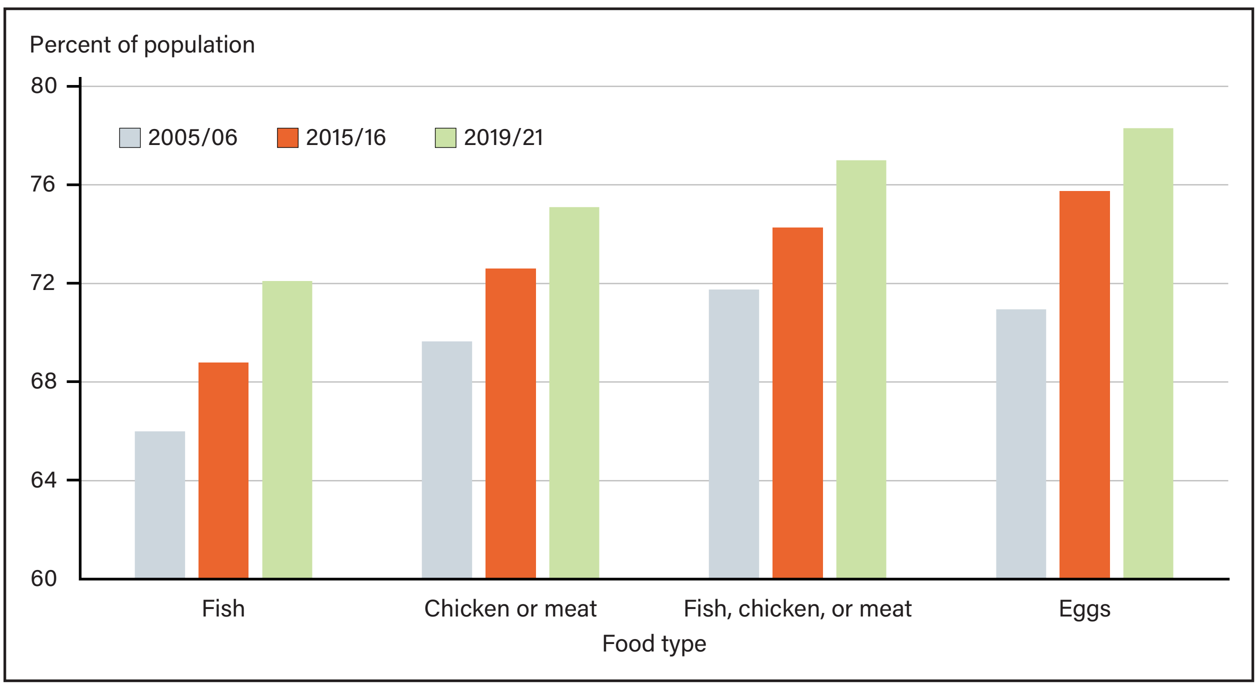
| | Restrictions on meat (percent) | Vegetarian (percent) | Not vegetarian | | | |
|---|---|---|---|---|---|---|
| | | | Abstain from eating meat on certain days (and from ever eating certain meats) (percent) | Only abstain from eating meat on certain days (percent) | Only abstain from eating certain meats (percent) | No restrictions on meat (percent) |
| General population | 81 | 39 | 30 | 6 | 5 | 18 |
| Hindu | 83 | 44 | 29 | 6 | 4 | 16 |
| Muslim | 67 | 8 | 39 | 7 | 14 | 32 |
| Christian | 66 | 10 | 30 | 10 | 16 | 33 |
| Sikh | 82 | 59 | 16 | 3 | 4 | 16 |
| Buddhist | 84 | 25 | 38 | 14 | 8 | 15 |
| Jain | 97 | 92 | 4 | 1 | 0 | 3 |

Note: The survey was conducted November 17, 2019–March 23, 2020, among adults in India.

Source: USDA, Economic Research Service using data from Religion and Food, Pew Research Center.

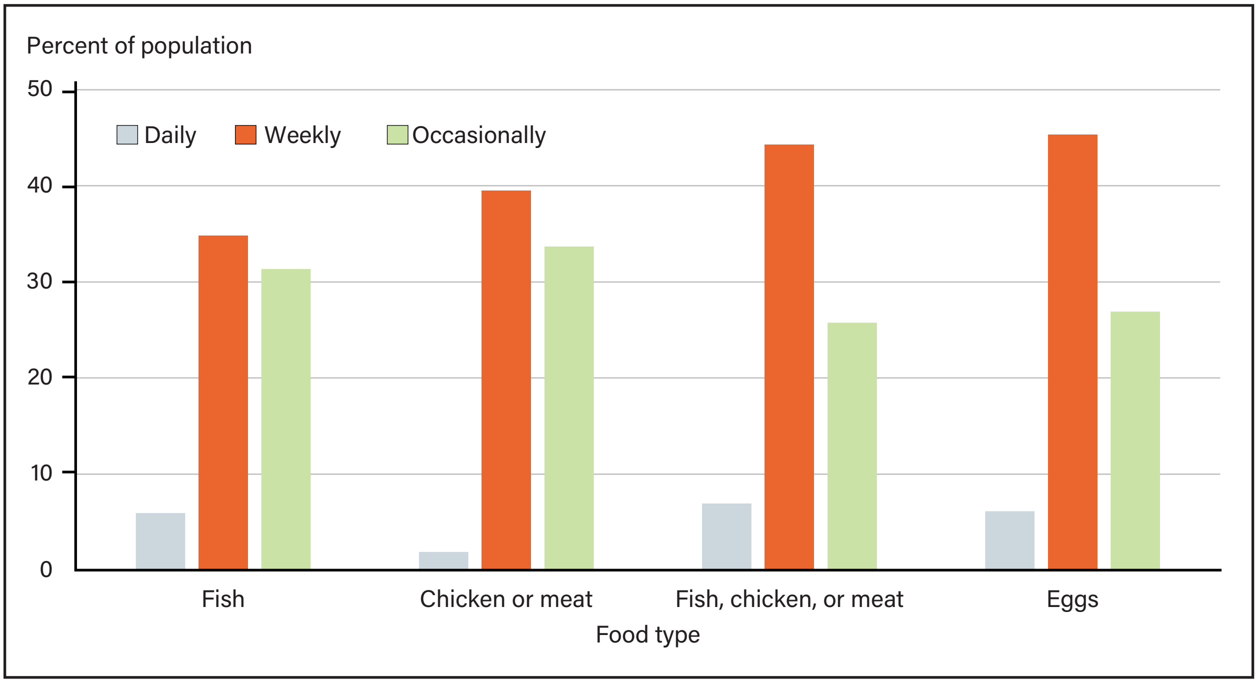
India's fish and seafood consumption is partially masked by vegetarianism. Padiyar et al. (2024) noted the 2021 consumption of fish and seafood was 8.89 kg per person, but among people who eat fish, it was 12.33 kg. Further, the number of people who are eating fish has increased over time (figure 3). But the number of people eating fish, chicken, or meat every day is very small (6.95 percent) (figure 4). Rather, most people consume one of the three products weekly (44.3 percent).

Figure 3
**Fish, chicken, meat, and egg consumption in India by percent of population**




Source: USDA, Economic Research Service calculations using data from Fish Consumption in India: Patterns and Trends, WorldFish.

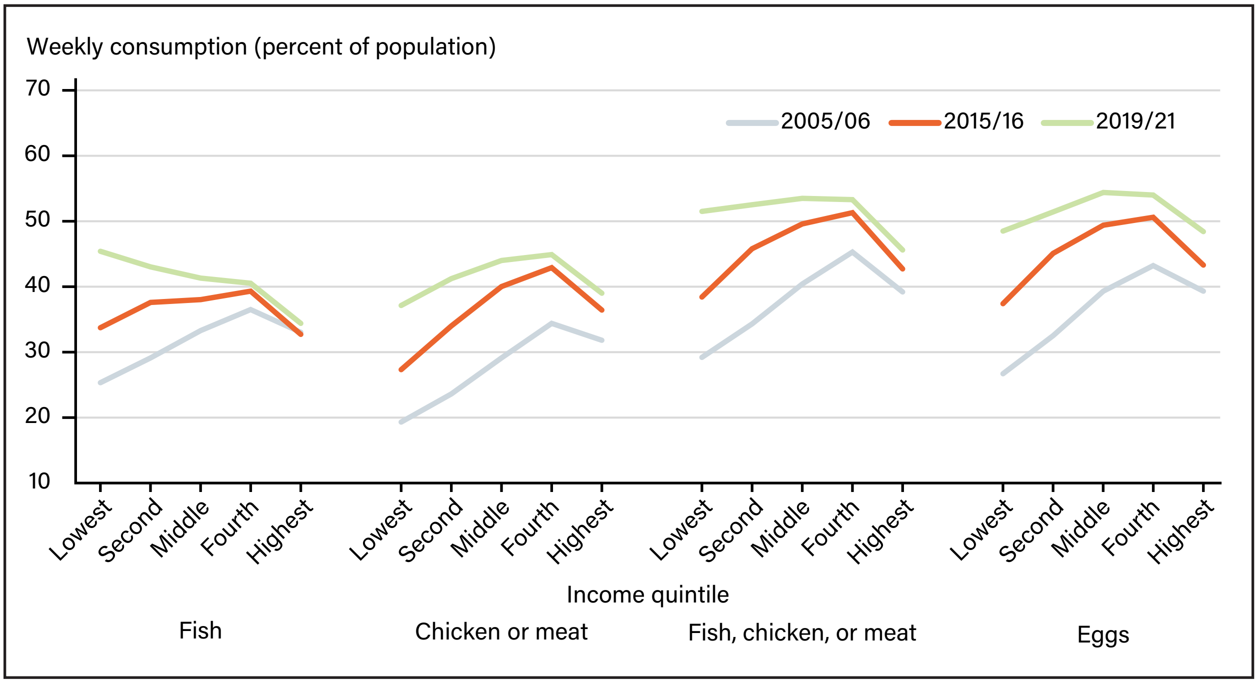
Figure 4
**Frequency of fish, chicken, meat, and egg consumption in India by percent of population, 2019–21**




Source: USDA, Economic Research Service calculations using data from Fish Consumption in India: Patterns and Trends, WorldFish.

Figure 5 shows the weekly consumption of these products by income quintiles across three survey periods, drawing from Padiyar et al. (2024). Several implications can be drawn from that work. First, the consumption of each category has increased over time and across all income quintiles. Second, eggs were the protein consumed by the poorest quintile, although fish was very close (25.3 percent of the population for fish and 26.7 percent for eggs). Third, for all proteins in the figure, the consumption percentage increased as income increased, up to the highest quintile when the percentage declined. Padiyar et al. (2024) noted that this could be because wealthier people may prefer to eat different varieties of fresh fish or processed fish, such as single-bone or live fish. This statement could also be extended to chicken and meat. See box, "Higher Incomes and Animal Product Consumption."

Figure 5
**Weekly fish, chicken, meat, and egg consumption by income group**




Source: USDA, Economic Research Service calculations using data from Fish Consumption in India: Patterns and Trends, WorldFish.

**Higher Incomes and Animal Product Consumption**

As incomes increase, there is evidence that consumers move away from staple grains (such as wheat, rice, and corn) to a more diversified diet (Bennet, 1941). Evidence also shows consumers shifting to higher protein diets, such as those including animal products (USDA, Economic Research Service (ERS), 2023). Already, there has been an increase in the demand for animal products worldwide, especially in developing countries experiencing rising incomes and urbanization (Latino et al., 2020). In Africa, for example, the region has quickly become the leading importer of chicken meat as urbanization and incomes have grown (Johnson et al., 2022). Komarek et al. (2021) considered how future demand for animal products might change across different future growth scenarios. Results from their model indicated that demand for animal products could increase by 49 percent in South Asia, including an increase of 4.3 percent for poultry demand in India.

# Underlying Macroeconomic Changes

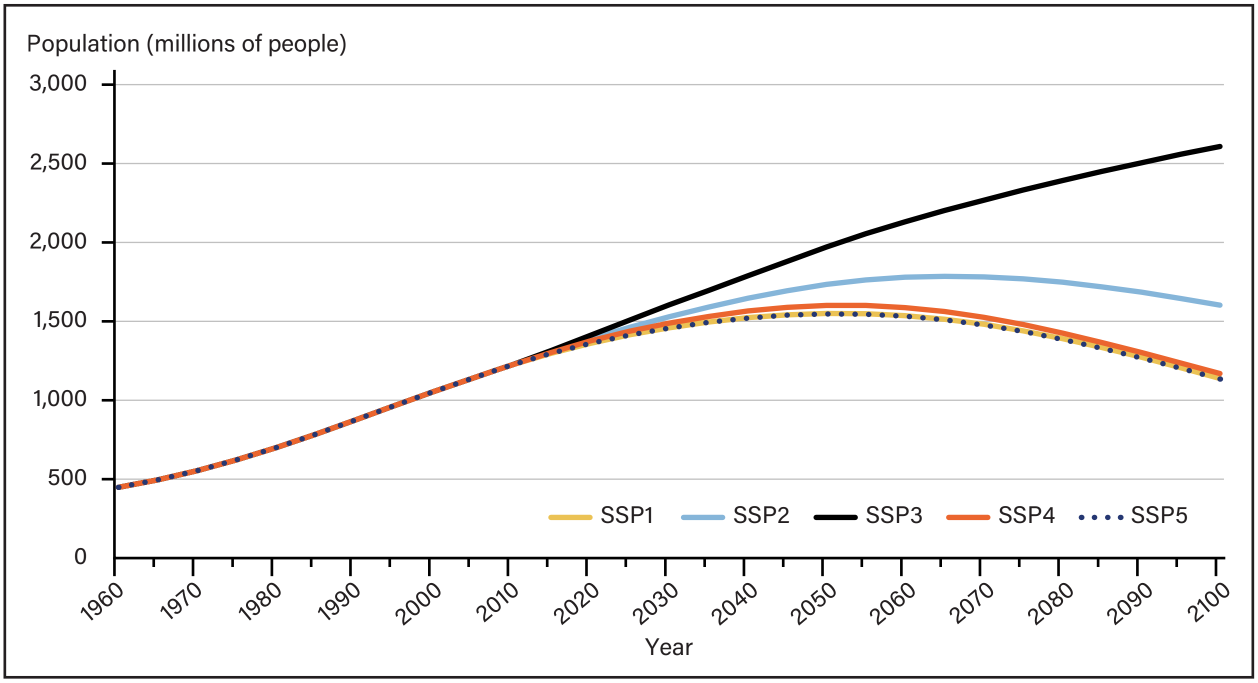
## Population and Urbanization

India's population is expected to keep growing, as figure 6 shows, at least until 2050 under most of the Shared Socioeconomic Pathway (SSP) scenarios.[6] Under the SSP3 scenario, the population is projected to continue climbing beyond 2050 to more than 2.5 billion by 2100. It is important to note, however, that even

[6] SSPs refer to various Shared Socioeconomic Pathways (SSPs) that are climate-change scenarios of projected socioeconomic global changes. See Hausfather (2018) for information on SSPs.

under SSP5—with the smallest projected population increase—India's population is projected to grow by as much as 13.7 percent between 2020 and 2050 (an addition of about 186 million people to feed).

Figure 6
**India population projections under the five Shared Socioeconomic Pathway (SSP) scenarios, 1960–2100**

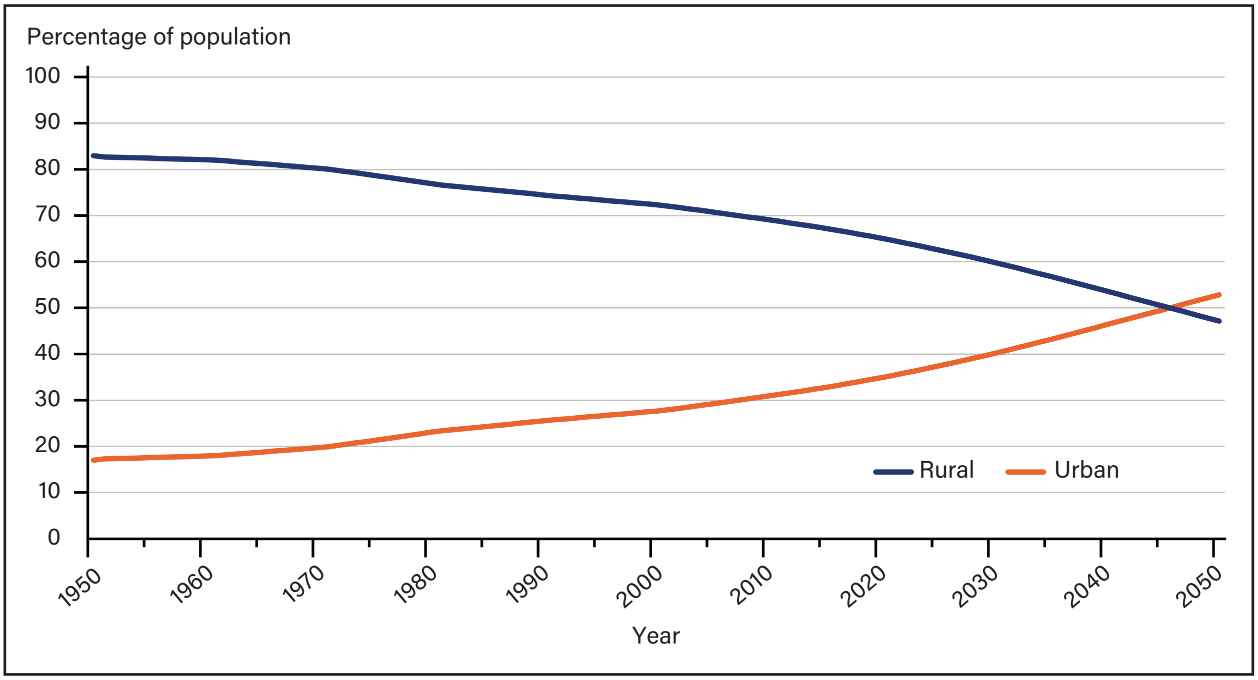



Note: SSPs refer to various Shared Socioeconomic Pathways (SSPs) that are climate-change scenarios of projected socioeconomic global changes. For information on SSPs, see Explainer: How 'Shared Socioeconomic Pathways' Explore Future Climate Change, Carbon Brief.

Source: USDA, Economic Research Service calculations using data from The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview, Global Environmental Change.

Along with a notable increase, India's population is also shifting to urban centers. Data from the World Bank's Urban Population figures indicate that in 2022, 36 percent of India's population was urban, an increase from 18 percent in 1960. Projections from the United Nations (2024) indicate that people residing in urban areas in India will be the majority population in the country by 2046 (figure 7). An increase in urbanization has been associated with a rise in retail and food service demand (Barrett et al., 2022).

Figure 7
**Percentage of India's population by urban/rural location, 1950–2050**



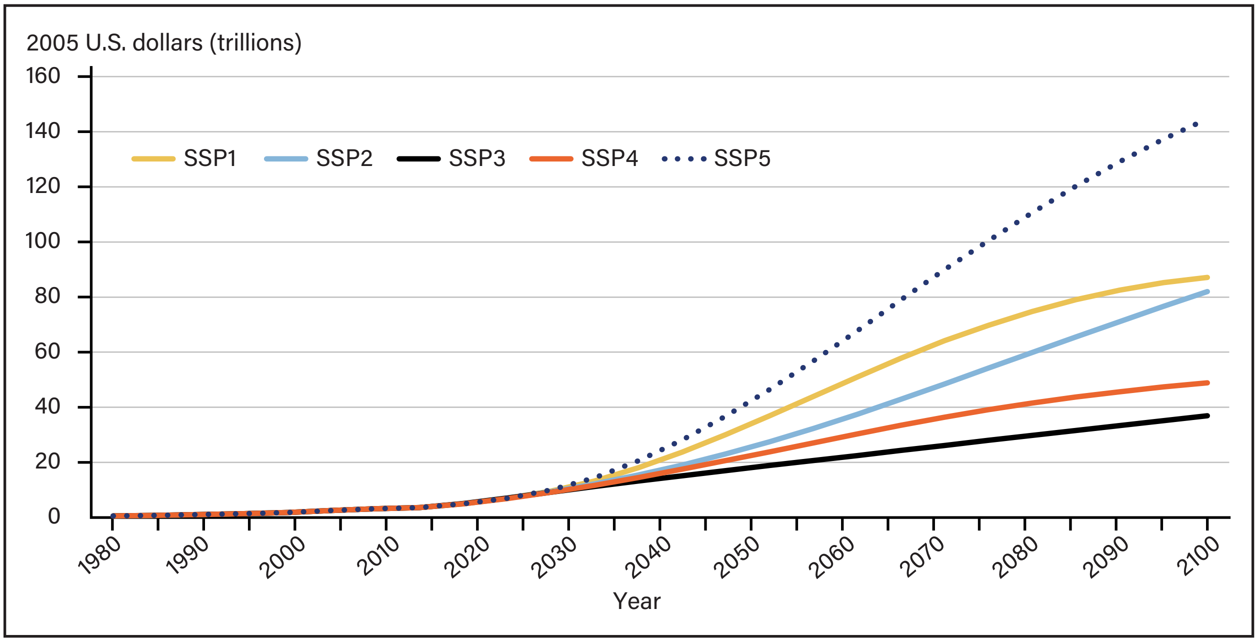

Source: USDA, Economic Research Service calculations using data from United Nations Country Profiles-India.

## Incomes

Incomes in India are also projected to grow, as figure 8 shows. In purchasing power parity (PPP) terms, incomes are projected to increase over time across all five SSP scenarios. SSP5 has the most rapid income growth, with a projected increase of 6.6 percent per year to 2050 (relative to 2020). SSP2, discussed later in this report, has an increase in incomes of 4.6 percent per year.[7] Note that the rate of growth in incomes in these SSP projections tends to be negatively correlated with population growth. For example, SSP3 has the highest projected population growth but the smallest income growth. The assumption is that rapid population growth puts greater demands on limited social and economic resources (such as access to education, health services, and jobs) and thus results in lower incomes overall.

[7] To estimate these changes, the authors used the log estimate approach to account for the change over the long time period in the figure.

Figure 8
**India's income projections (purchasing power parity) under the five Shared Socioeconomic Pathway (SSP) scenarios, 1980–2100**



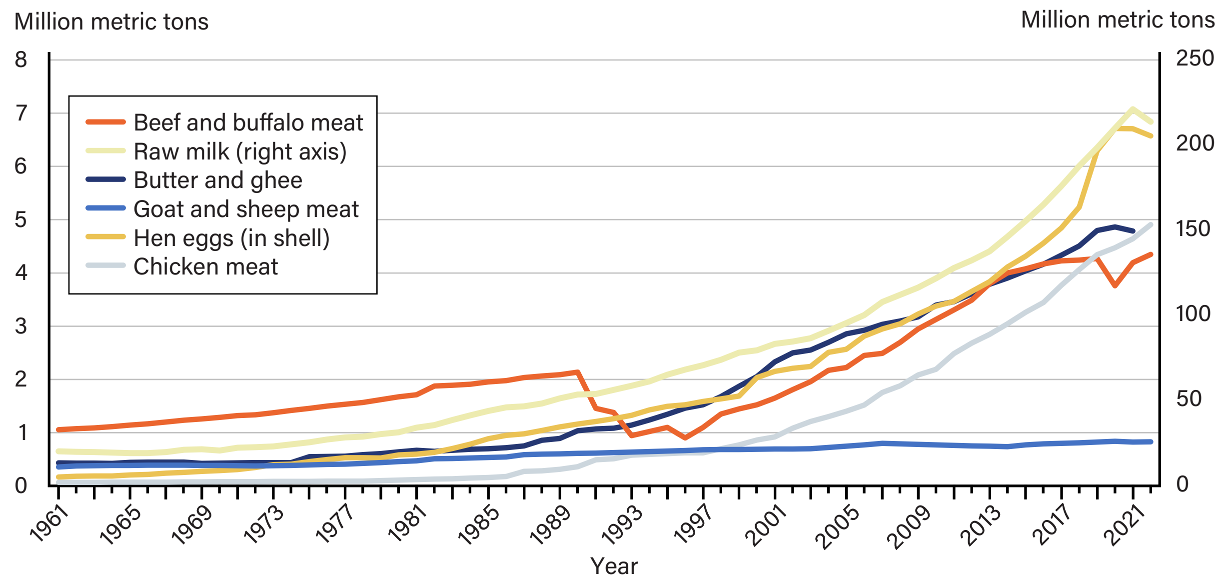

Note: SSPs refer to various Shared Socioeconomic Pathways (SSPs) that are climate-change scenarios of projected socioeconomic global changes. For more information on SSPs, see Explainer: How 'Shared Socioeconomic Pathways' Explore Future Climate Change, Carbon Brief.

Source: USDA, Economic Research Service calculations using data from The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview, Global Environmental Change.

## Production and Supply of Animal Products

Production of animal products in India grew in response to the increase in demand (figure 9). Notably, production for each of the animal products grew faster than population growth (except for sheep and goat meat). Production for buffalo (and beef) meat has grown at 5.1 percent per year on average since 2000. Chicken meat production grew at 8.5 percent per year on average over the same period. Raw milk (especially from buffalo) and hen egg production also increased much faster than population growth.

Figure 9
**India's production of livestock products, 1961–2022**




| Average annual growth rates (percent) | 1961–79 | 1980–99 | 2000–22 |
|---|---|---|---|
| Butter and ghee | 1.8 | 6.0 | 3.9 |
| Buffalo (and beef) meat | 2.4 | -3.3 | 5.1 |
| Chicken meat | 2.1 | 11.9 | 8.5 |
| Hen eggs (in shell) | 7.4 | 5.9 | 5.8 |
| Goat and sheep meat | 0.6 | 2.1 | 0.8 |
| Raw milk | 2.5 | 4.5 | 5.0 |
| Population | 2.2 | 2.1 | 1.4 |

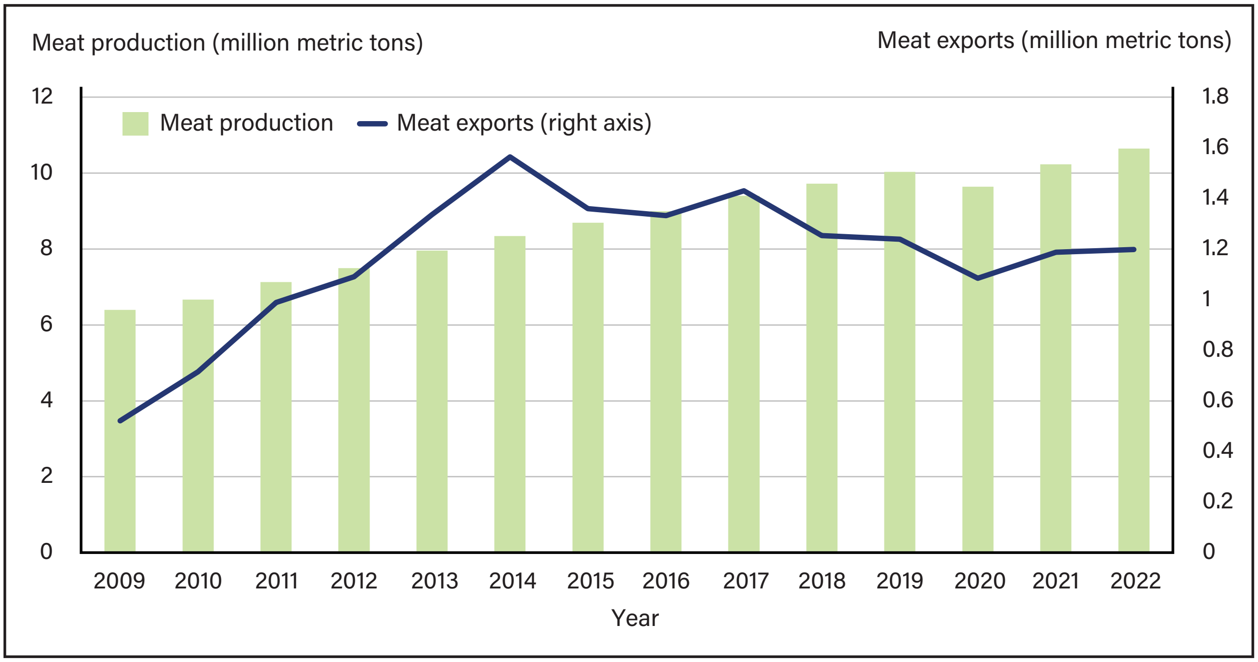
Note: Data for butter and ghee are not available for 2022.

Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

The increase in animal product production has also enabled India to become a major exporter of meat products (figure 10). In 2022, 10.20 percent of meat production was exported—note that India's meat imports are minuscule.[8] The vast majority of India's meat exports were buffalo meat/carabeef (89.42 percent), followed by edible offal of cattle (9.21 percent). India's buffalo meat exports are considered low-cost to produce relative to those of other major exporters (e.g., the United States) as they are typically from culled (or nonproductive) dairy animals (Landes et al., 2016). The total dollar value of India's meat exports in 2022 was $3.25 billion. Most of India's buffalo meat exports are destined for Asian and African markets. Malaysia imported 16.5 percent of the total value, followed by Egypt (15.9 percent) and Vietnam (14.5 percent) (Bhogal & Beillard, 2023).

[8] India imported only 1,200 thousand metric tons in 2022, for example (Trade Data Monitor (TDM), 2024).

Figure 10
**India's meat production and meat exports, 2009–22**



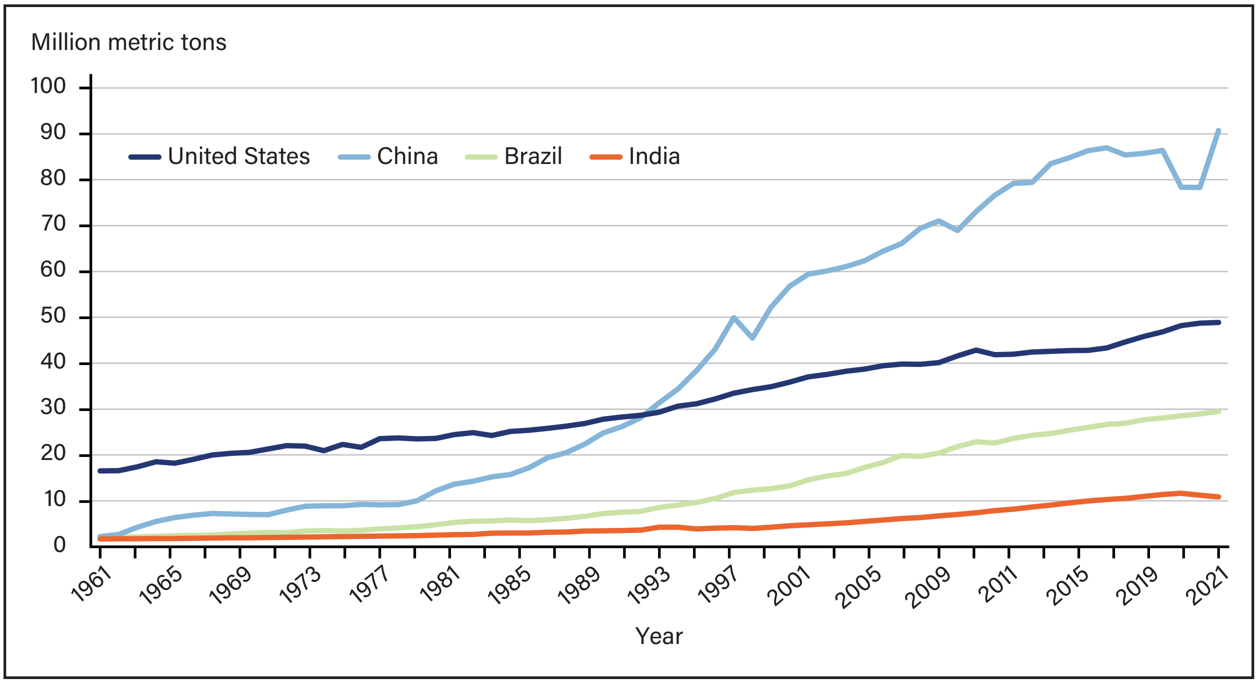

Note: Meats included are buffalo, cattle, poultry, duck, goat, pig, and sheep, along with other meat.

Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and Trade Data Monitor (TDM) (2024).

Meat production in India is lower than that of other major meat-producing countries, such as China, the United States, and Brazil (figure 11). While Brazil and the United States have maintained production levels over time, meat production in China has been increasing. In fact, China now imports feed grains for its growing livestock sector.[9] One reason for India's relatively lower production is lower productivity per animal. On average, for instance, cattle in India produce less meat per animal than other major cattle producers (table 2). Muthukumar et al. (2001) attributed poor animal productivity in India to a lack of quality genetics, but they also attributed it to inadequate availability of quality feed and fodder and high mortality rates. In addition, USDA, Foreign Agricultural Service (2023) noted that India's cattle production is largely a byproduct of the dairy sector, where cattle that no longer produce milk are slaughtered for meat, and there is little incentive to improve the country's productivity. Relatively lower productivity was the same for poultry (table 2), although India's poultry productivity has been increasing over the last 20 years. (India's poultry productivity did decrease in 2021 due to Coronavirus (COVID-19) pandemic market restrictions (Rahman et al., 2021)). There is potential scope to increase India's meat productivity through feed, which is the motivation for this study.

[9] China's grain imports rapidly increased from 2.37 million metric tons in 1976 to 16.12 million metric tons in 1982. Grain imports fell back to 5.79 million metric tons in 1985 as China became more self-sufficient in grain production (Carter & Zhong, 1991).

Figure 11
**Meat production by major producers, 1961–2021**




Note: Meat production includes cattle, poultry, sheep, goat, pork, and wild game, in addition to other meats.

Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

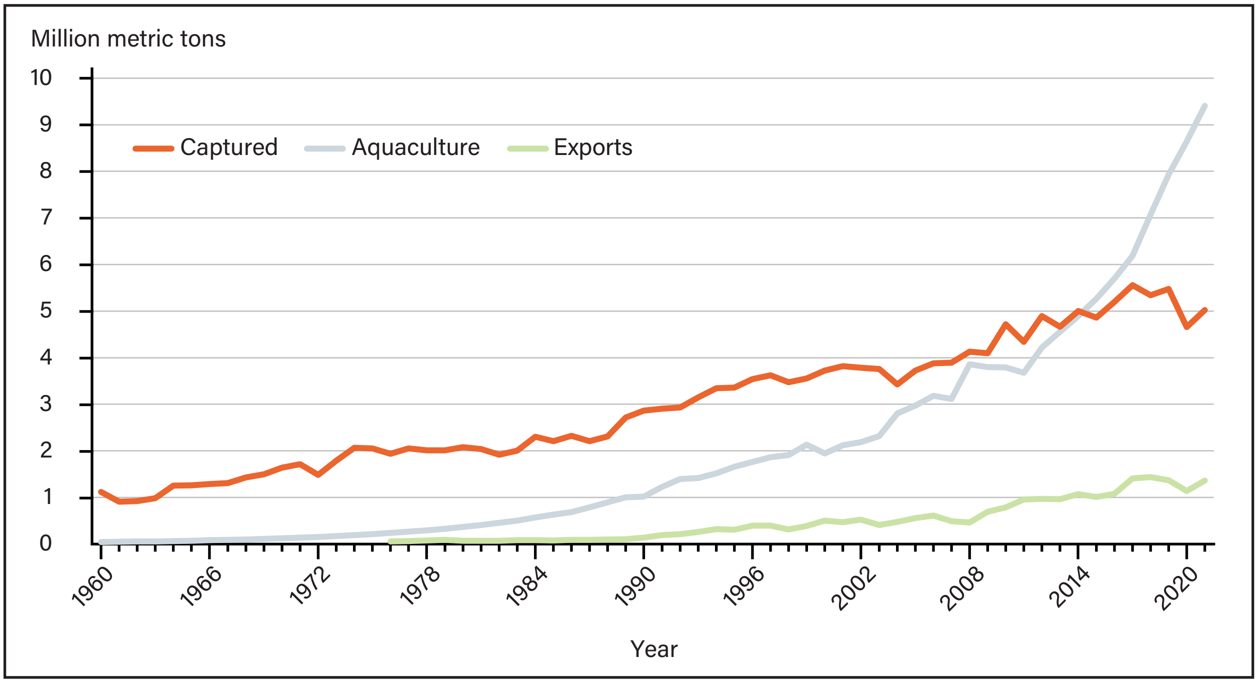
Table 2
**Productivity for poultry and cattle meat, 1980s–2020s**

| Poultry meat per animal (kilograms) | | | | | |
|---|---|---|---|---|---|
| | Brazil | China | India | United States | World |
| 1980s | 1.2 | 1.2 | 0.9 | 1.6 | 1.4 |
| 1990s | 1.5 | 1.4 | 0.9 | 1.8 | 1.5 |
| 2000s | 1.9 | 1.5 | 1.1 | 2.0 | 1.6 |
| 2010s | 2.3 | 1.5 | 1.4 | 2.3 | 1.7 |
| 2020s | 2.4 | 1.6 | 1.5 | 2.4 | 1.7 |
| **Cattle meat per animal (kilograms)** | | | | | |
| 1980s | 182.7 | 108.0 | 91.0 | 275.1 | 198.9 |
| 1990s | 208.4 | 145.0 | 102.8 | 301.1 | 204.7 |
| 2000s | 214.5 | 137.2 | 103.0 | 335.4 | 205.1 |
| 2010s | 259.3 | 146.6 | 103.0 | 358.7 | 209.1 |
| 2020s | 342.9 | 146.2 | 103.0 | 371.0 | 218.1 |

Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

Aside from buffalo, cattle, and poultry meat, India also produces fish and seafood (figure 12); the country is the second-largest producer globally after China. Although much of this is consumed in domestic markets, India has also become a major exporter of fish and seafood. In 2021, the country exported 9.44 percent of its fish and seafood production. A major destination for these exports was the United States, both in terms of value and volume (37.56 percent of the value). India has moved production toward aquaculture versus captured fish over time; in 2012, aquaculture made up 65.19 percent of India's total production of fish and seafood.

Figure 12
**India's production and exports of fish and seafood, 1960–2021**




Source: USDA, Economic Research Service calculations using data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

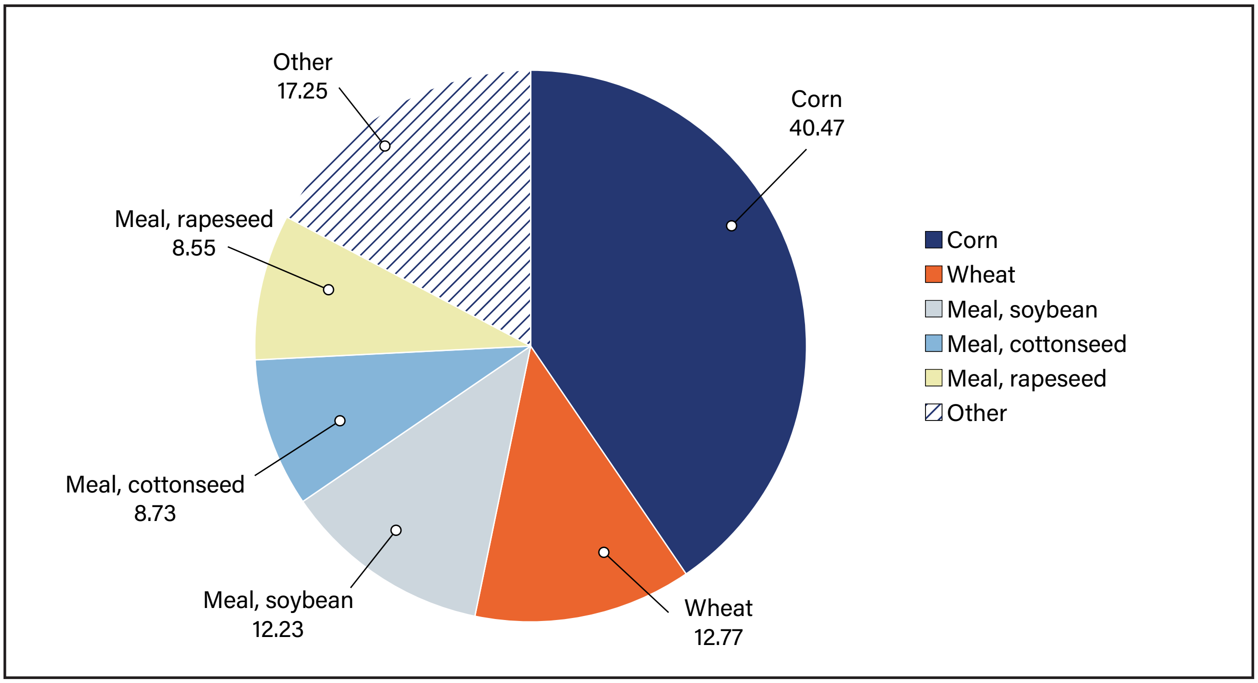
## India's Animal Feed Situation

### Overview of the Feed Sector

Almost two-thirds of India's consumption of animal feed in marketing year[10] 2022/23 consisted of corn, wheat, and soybean meal (figure 13). Corn was the commodity most consumed as animal feed, making up 40.49 percent (20.6 million metric tons) of total consumption, with wheat and soybean meal making up 12.77 and 12.23 percent (6.5 and 6.2 million metric tons), respectively. Rapeseed meal and cottonseed meal were the fourth- and fifth-largest animal feeds consumed in 2022/23, with shares of total consumption at 8.73 and 8.55 percent (4.4 and 4.4 million metric tons), respectively. The remaining 17.25 percent (8.8 million metric tons) of India's 2022/23 animal feed consumption was split among 13 different commodities, as shown in figure 13.

[10] Marketing years differ across commodities. For a comprehensive list of commodity marketing years, see USDA, FAS (2024a). Animal feed is the USDA, FAS definition for feed domestic consumption or food waste domestic consumption—presumably, this accounts for feed for fish.

Figure 13
**India's feed consumption by commodity (percent), 2022/23**

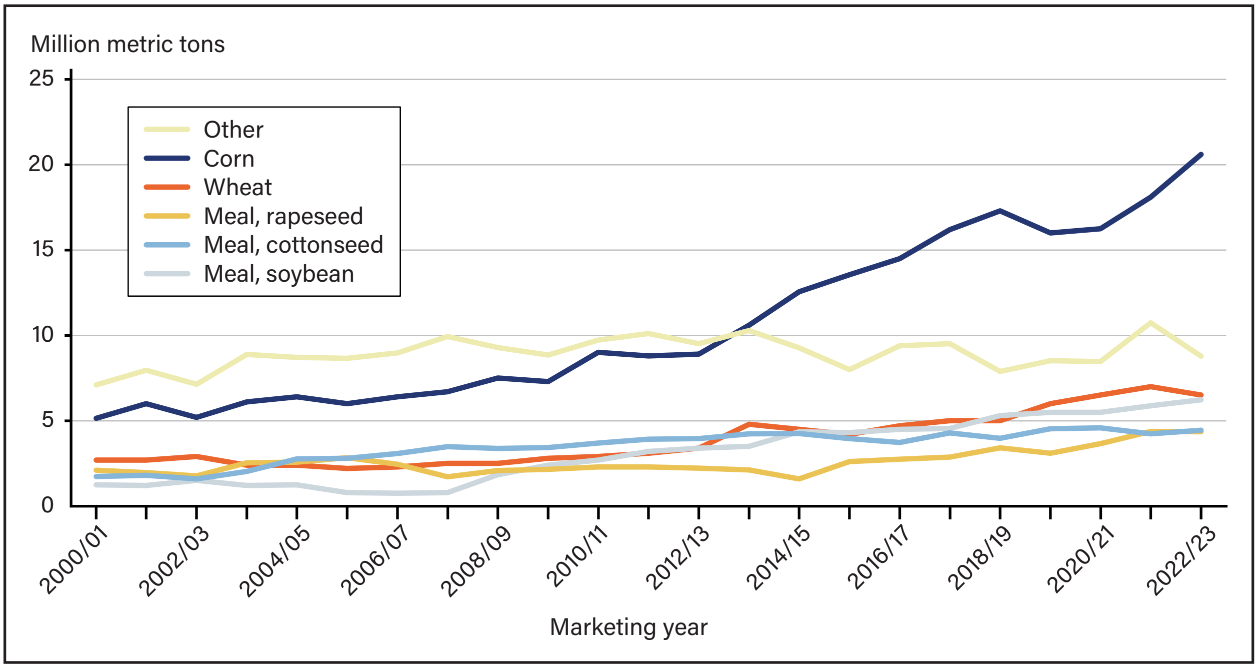



Note: The "other" category includes soybeans; cottonseed; millet; meal, peanut; rapeseed; sorghum; meal, copra; oilseed, peanut; meal, sunflower seed; barley; meal, palm kernel; sunflower seed; and copra. India's producers will sometimes substitute rice products, fish meal, and seed oils as additives into animal feed (USDA, Economic Research Service (ERS), India's Poultry Sector: Development and Prospects (Report No. WRS 04-03). However, the data report 0 usage throughout the period analyzed. USDA, Foreign Agricultural Service (FAS) does report between 7.0 to 7.5 million metric tons of broken rice use for 2023.

Source: USDA, ERS calculations using data from USDA, FAS, Production, Supply, and Distribution.

Corn has been India's top animal feed since 2000, increasing from 5.15 million metric tons in 2000/01 to 20.6 million metric tons in 2022/23 (figure 14). India's consumption of wheat, soybean meal, rapeseed meal, and cottonseed meal have all more than doubled from 2000/01 to 2022/23. Soybean meal had the fastest growth among all feed commodities, nearly surpassing wheat as the second-most-consumed animal feed in 2022/23. For cattle herds, Landes et al. (2017) stated that the largest feed category was crop residues (wheat, oilseeds, rice, pulses, sugarcane tops, etc.) at 64 percent of the feed supply, followed by cultivated green fodder (corn, sorghum, millet, alfalfa, clover, etc.) at 18 percent, pasture/grazing at 12 percent, and concentrates (coarse grains, oil cakes, and meals) at 6 percent.

Figure 14
**India's feed consumption trends, 2000/01–2022/23**




Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

Of the remaining commodities (labeled "Other" in figure 14 and comprising 17.25 percent of India's animal feed consumption in 2022/23), the majority is made up of soybeans, cottonseed, millet, and peanut meal.[11] Soybeans had the largest growth in consumption over the period. Consumption of cottonseed for animal feed grew from 2000/01 to 2013/14 but thereafter fell nearly back to 2000/01 levels and increased by only 39 percent overall. Consumption of millet as animal feed grew by 77.8 percent from 2000/01 to 2022/23, and peanut meal consumption fell by 8.4 percent.

Among feed grains, wheat and corn production outpaced other feed commodities, with more than 142 million metric tons of production between them in 2022/23 (table 3).[12] Though wheat production in India is greater than corn production, the portion of production consumed as animal feed is larger for corn than it is for wheat (table 3). India's production of wheat and corn increased from 2002/03 to 2022/23 but at a slower rate than consumption of these products as animal feed. The percentage of India's domestic consumption consumed as animal feed increased for both wheat and corn from 2002/03 to 2022/23. The share of corn consumed as animal feed was 43.33 percent of India's total domestic consumption in 2002/03 and increased to 59.37 percent in 2022/23, while wheat's share increased from 3.85 percent to 5.98 percent.

[11] Sorghum and broken rice have also been periodically used as energy-feed substitutes, especially whenever their relative prices are more favorable compared with other energy grains such as corn or wheat (Mehta & Nambiar, 2007).

[12] In recent years, there has been increasing use of broken rice and milling waste as energy supplements due to relatively lower prices compared with other energy feed ingredients (USDA, FAS, 2024).

Table 3
**Wheat and corn production, consumption, and animal feed share of consumption**

| | | 2002/03 | 2012/13 | 2022/23 |
|---|---|---|---|---|
| Wheat | Production (million metric tons) | 72.77 | 94.88 | 104.00 |
| | Feed consumption (million metric tons) | 2.90 | 3.40 | 6.50 |
| | Domestic consumption (million metric tons) | 75.25 | 83.82 | 108.68 |
| | Animal feed share of consumption (percent) | 3.85 | 4.06 | 5.98 |
| Corn | Production (million metric tons) | 11.15 | 22.26 | 38.09 |
| | Feed consumption (million metric tons) | 5.20 | 8.90 | 20.60 |
| | Domestic consumption (million metric tons) | 12.00 | 17.50 | 34.70 |
| | Animal feed share of consumption (percent) | 43.33 | 50.86 | 59.37 |

Note: Domestic consumption includes feed consumption.

Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

## Source of Feed Ingredients

The supply of India's animal feed is largely from domestic production. India's total feed use for 2022 was 46.36 million metric tons, and imports of feed commodities were 178,969 metric tons. Soybeans are India's largest imported feed product and are domestically crushed into soybean meal. Corn and wheat are produced in large amounts domestically in India, while soybean production is more limited. Figure 13 indicates that soybean meal represents (on average) 12 percent of animal feed, the third-largest source of feed after corn and wheat.[13] The largest percentage of India's soybean imports come from sub-Saharan African countries such as Togo and Benin (TDM, 2024). None of the major soybean producing countries (such as Brazil, the United States, and Argentina) that use genetically engineered (GE) soybeans are significant import sources due to India's effective ban on GE soybean imports. In 2021, India permitted GE soybean meal imports for a specified quantity and period to curb increases in feed prices in Indian markets. A large share of soybean meal was imported from Argentina, which is also the top exporter of soybean oil to India and permitted by India's authorization of GE-derived soybean oil imports starting in 2007.[14]

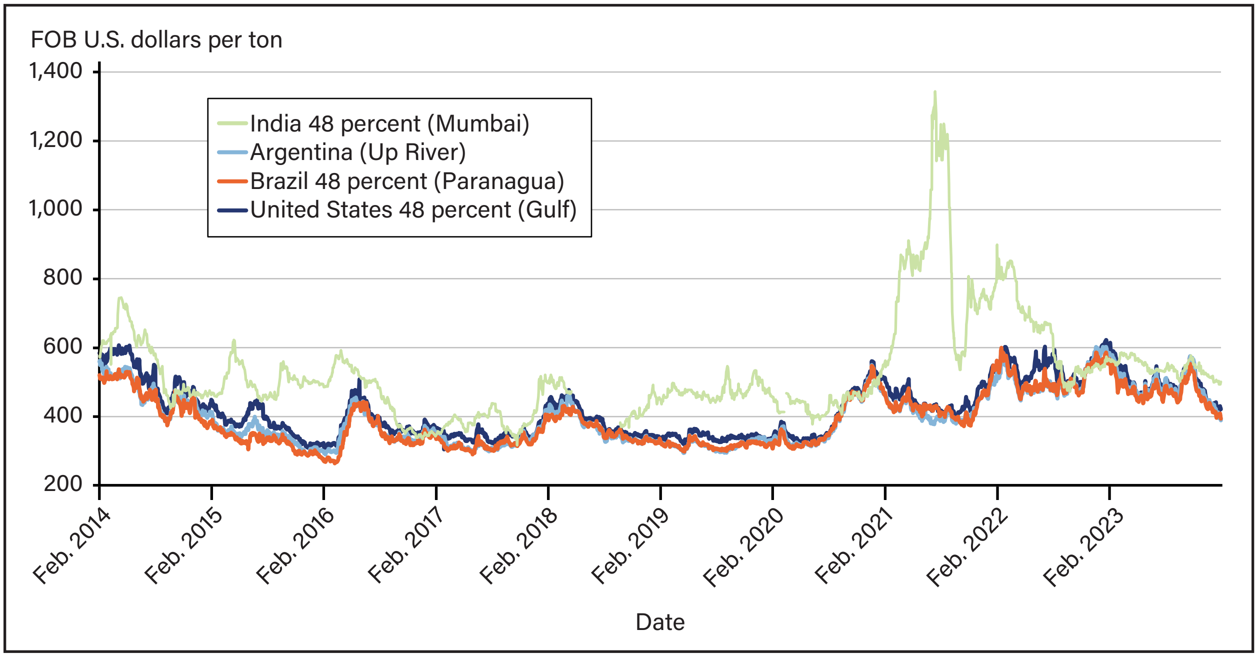
India's imports of feed ingredients, such as corn and soymeal, from the United States and Brazil have been limited. As a result, the livestock industry in India has faced a surge in feed ingredient prices in recent years, which raises feed (and livestock) production costs and limits India's competitiveness with other major livestock-producing countries.[15] Figure 15 shows that the freight-on-board (fob) export price for soybean meal produced in India was higher than that of other major exporters such as the United States, Argentina, and Brazil. Between 2021 and 2022, India's soybean meal prices were far higher than those of other exporters, while soybean meal prices in the United States, Argentina, and Brazil were relatively low during the same period.

[13] Cereal grains make up between 70 to 80 percent of feed mixes, depending on the growth stage in broiler chickens. The grains in feed serve as the primary source of energy, while oilseeds and other additives make up the rest of the feed mix (20 to 30 percent) and provide a source of protein and other important nutrients (Bavaresco et al., 2020).

[14] Corn is imported occasionally by India. Between 2019 and 2023, Ukraine and Myanmar, neither of which produce GE corn varieties, were the major sources of corn imports (TDM, 2024). Rarely is corn imported by India from the United States, Brazil, and Argentina (which produce GE corn). India imports wheat predominately from Australia (TDM, 2024)

[15] Feed constitutes more than 70 percent of the cost of raising broiler chickens, the rest being operational costs such as labor, energy, water, veterinary services, and maintenance costs (Alhotan, 2021).

Figure 15
**Soybean meal price comparison by country, 2014–23**




FOB = free on board.

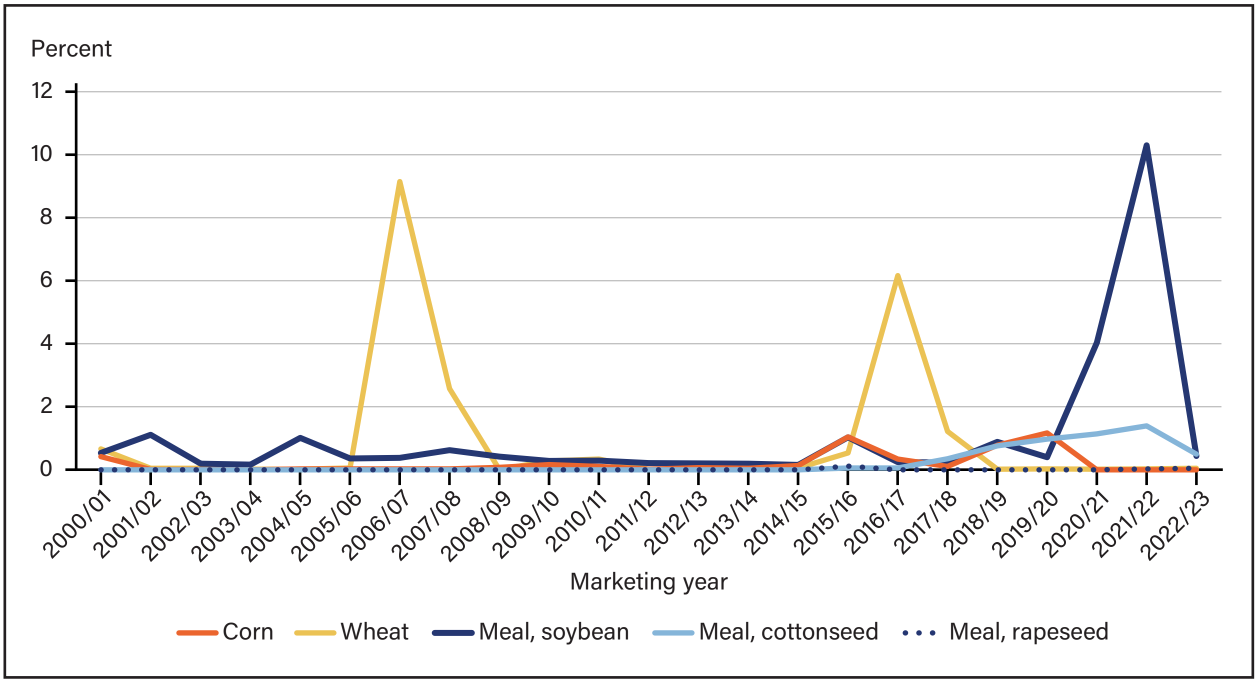
Note: The parentheses reference the location of soybean meal for export.

Source: USDA, Economic Research Service calculations using data from the International Grains Council (IGC).

India has traditionally been self-sufficient for commodities used as feed ingredients. As figure 16 shows, apart from two 1-year spikes in wheat imports and a 1-year spike in soybean meal imports, India's imports of its major animal feed commodities have remained under 2 percent of consumption since the turn of the century.[16] Of particular interest is the most recent spike in soybean meal imports, coinciding with the increase in domestic prices relative to international prices (figure 15). This was a result of a directive by India's Directorate General of Foreign Trade (DGFT), Ministry of Commerce and Industry, to allow imports of 1.2 million metric tons of soybean meal and cake potentially derived from GE soybeans through October 31, 2021 (Chandra et al., 2021). On May 2, 2022, this policy was extended to allow imports of an additional 550,000 metric tons through September 30, 2022 (Chandra, 2022). Most additional soybean meal imports came from Argentina and Bangladesh, while further sources included Vietnam, Brazil, and Thailand. Although small relative to the other sources, U.S. soybean meal exports to India increased during the same period.

[16] India's wheat imports are for food use, with some of the milling byproduct (bran) going for feed use.

Figure 16
**Ratio of India's imports to domestic consumption, 2000/01–2022/23**



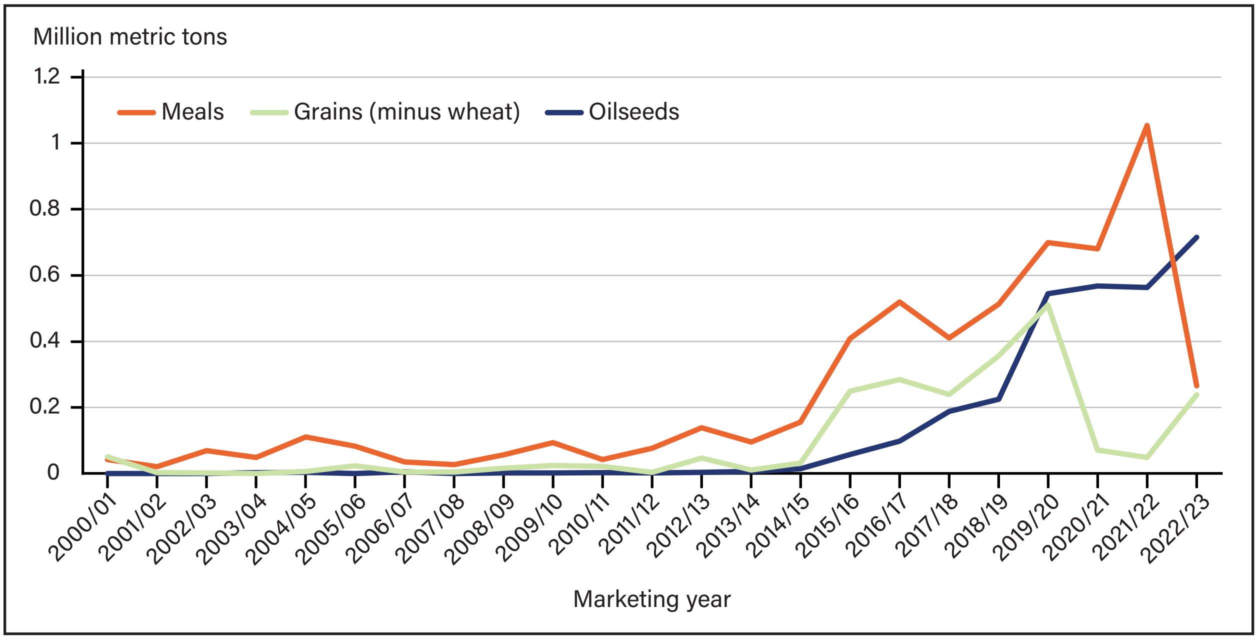

Note: India's imports of millet, cottonseed, sorghum, rapeseed, peanut meal, and rapeseed meal never exceeded 1 percent of domestic consumption.

Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

India's self-sufficiency in the production of grains and oilseeds is due to past policies and investments that have provided production incentives over time (see box, "Self-Sufficiency Production Goals, Producer Price Support, and Trade Policies"). Despite these efforts, however, the growing demand for feed ingredients, such as corn and soymeal, has not recently been met by domestic production (figure 17).[17] That is, there has been a gradual increase in imports of feed ingredients from the 2014/15 marketing year (figure 17). Soybean imports increased steadily from 2014/15 to 2022/23, peaking at over 718,000 metric tons in the most recent marketing year. In fact, soybeans comprised nearly all of India's oilseed imports. Meals, such as copra and sunflower seed meal, also had steady increases over the same period but decreased in the most recent 2022/23 marketing year. Soybean meal imports have also grown over time, reaching a peak of over 1 million metric tons in the 2021/2022 marketing year before decreasing in the most recent year. Among grains, corn has been the major imported grain and the primary driver behind the rise in total grain imports from 2015/16 to 2019/20, peaking at 318,000 metric tons in 2019/20 before dropping to zero from 2020/21 to 2022/23.

[17] Wheat was excluded from the figure because this crop was rarely imported by India except for the deficit marketing years of 2006/07 and 2016/17.

Figure 17
**India's imports of commodities used for feed, 2000/01–2022/23**




Note: India's imports of wheat spiked in marketing years 2006/07 and 2016/17 to over 6 million metric tons; thus, wheat is excluded from the figure.

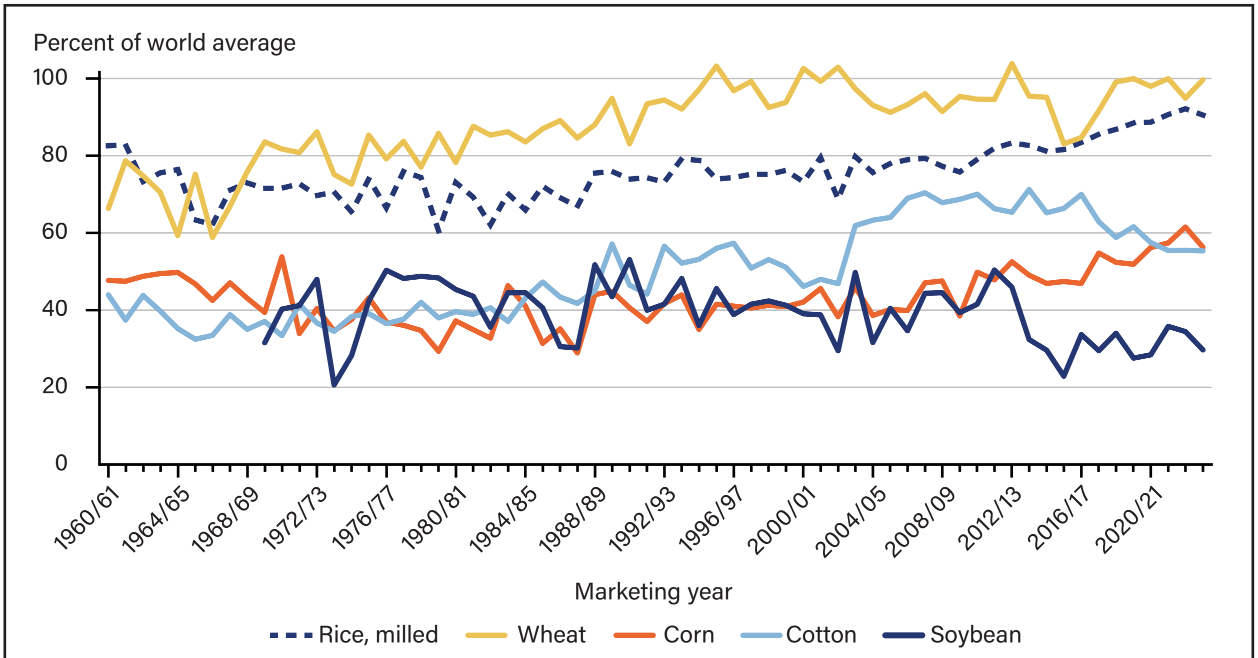
Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

# Increasing Supply of Feed and Options for Biotechnology

## India's Yield and Land Area

As India's future demand for food and feed continues to grow, it will need to be matched with either increased production or an increased reliance on imports. India has seen moderate yield growth for its major commodities, especially wheat and rice. Traditionally, the emphasis on rice and wheat production in India has been related to ensuring food self-sufficiency and food security. However, as noted, with sustained income growth and urbanization, consumption patterns could continue shifting toward a more diversified diet, especially for higher protein animal products, increasing the cultivation of feed crops. But India's crop yields of key feed ingredients, such as soybeans and corn, lag far behind the rest of the world. In 2022/2023, the country's corn yields were 62 percent of the global average, and soybean yields were only 30 percent (figure 18).

Figure 18
**India's crop yields compared to the global average, 1960/61–2023/24**




Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

Several reasons for the low yields have been posited, including the structure of India's agriculture in small-scale holdings and the inadequate investment for facilitating resources such as fertilizer, agrochemicals, and mechanization (Ramasamy, 2004). India's intellectual property rights may also limit investment in germplasm, especially for nonhybridized seeds (Kolady et al., 2012) and biotechnology (Sadashivappa & Qaim, 2009). Additionally, the pressures of climate change (e.g., Chandio et al., 2022) and natural resource depletion (Ramasamy, 2004) have the potential to further limit India's future yield growth.

Figure 19 shows where the production of feedstuffs tends to be located in India (using an average of 2020–22). The State of Madhya Pradesh has the most area under the crops considered for feedstuffs (cereals, wheat, oilseeds, and cotton), the majority of which are oilseeds (45 percent of the 16,671,500 hectares of area under feedstuffs). Wheat, with 36 percent of the area, also has a large amount of land (figure 20). Madhya Pradesh

## Self-Sufficiency Production Goals, Producer Price Support, and Trade Policies

The Government of India (GoI) has policies designed to maintain self-sufficiency in food production and ensure adequate rural incomes and food security. Some of these policies include guaranteed favorable prices to farmers. These support programs include the Prime Minister's Farmer Income Protection Scheme (PM-AASHA), the Price Deficiency Payment Scheme (PDPS), and the Private Procurement and Stockist Scheme (PPSS) (GoI, 2023). In addition, a scheme named the Prime Minister's Farmer's Tribute Fund (PM-KISAN) was introduced in 2019 to provide income support to all landholding farmers' families in India (GoI, 2023). The country's minimum support prices (MSPs) are aimed at giving farmers a minimum of 50 percent as a margin over the cost of production (GoI, 2023). In addition, there are policies that subsidize agricultural inputs such as fertilizers, fuel, seeds, irrigation water, and power at both the state Government and Central Government levels (Office of the U.S. Trade Representative (USTR), 2023; Jha et al., 2007).

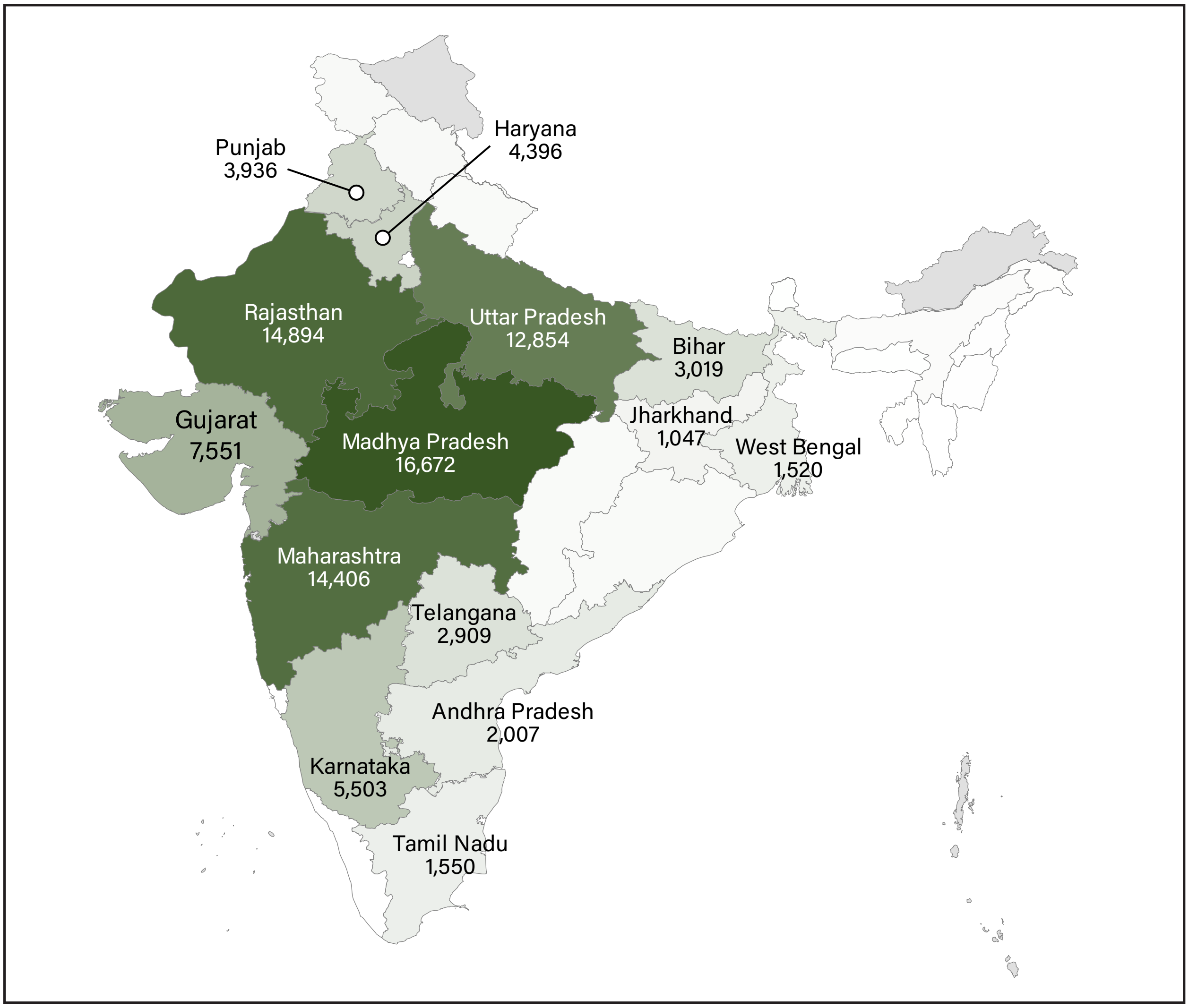
Beside supports to domestic production and prices of major crops, the GoI also has restrictive trade policies. These include import/export restrictions, tariffs, tariff rate quotas, and export subsidies (Hudson, 2022). For instance, India enforces import duties and export restrictions on several agricultural products, thereby protecting domestic markets from fluctuations in international prices. India's applied tariff on corn was 50 percent in 2021 (USTR, 2023). Note that India imports a very small amount (less than $1 million) of composite feed, which could be because of relatively high tariffs or restrictions on genetically engineered imports.

While domestic support encourages the expansion of agricultural production in India, it can also limit global competitiveness in terms of productivity. For instance, India has the largest area of land cultivated for cereals, rice, pulses, and groundnuts, but yields from these crops are far below their potential (GoI, 2023). India's domestic support could encourage inefficient allocation of resources because it enables farmers to produce commodities that may be more efficiently produced in other countries. India's Government regularly announces MSPs for crops before the planting season, thereby affecting planting decisions and providing a subsidy to the entire crop, which distorts market prices through overproduction and limited demand for imports (USTR, 2023). Similarly, import duties and export restrictions can create distortions in global markets.

has had an increase in the amount of land used for feedstuff production since 2017, although 2021/22 had a decrease relative to the previous year. Figure 20 shows the production of these feedstuffs since 2017 for the five largest producing states. The data indicate that acreage tended to increase in the 2019/2020 and 2020/2021 growing periods before falling slightly in 2021/22. Across these five states, the total area devoted to feedstuffs has increased since 2017, but at 5.58 percent, it is not enough to keep pace with the projected increase in demand due to changes in population and incomes.

Figure 19

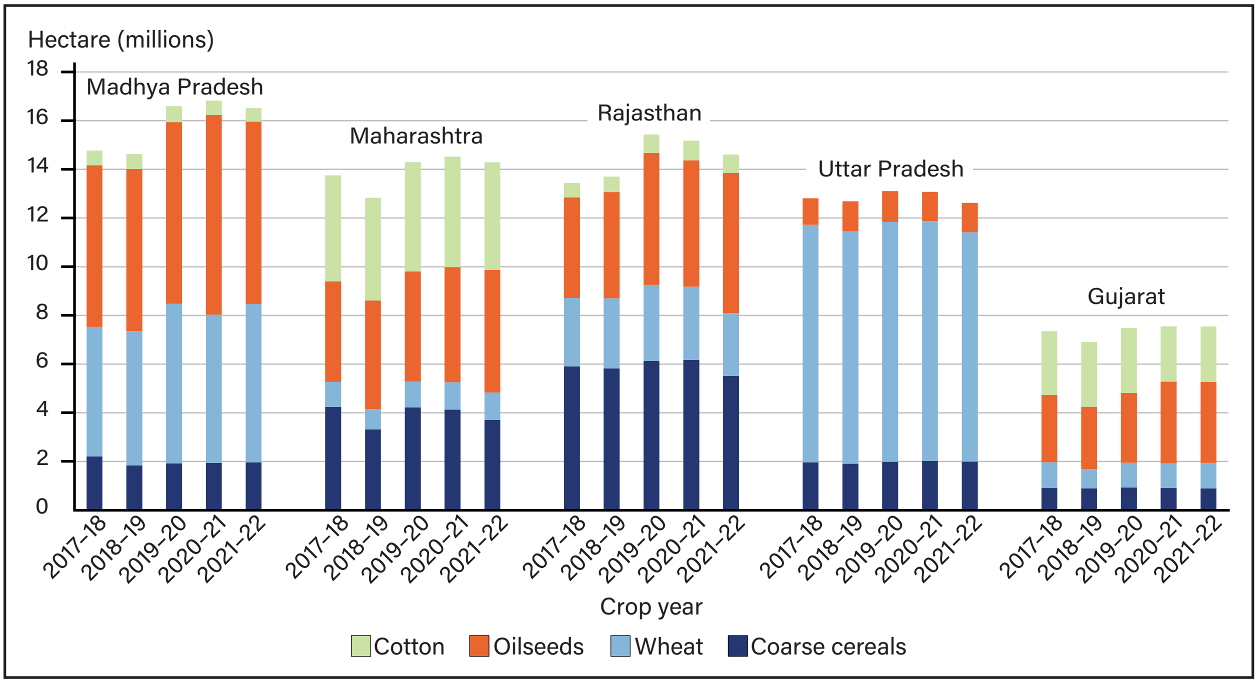
**Total feed crop area in India (1,000 hectares), 2020–22**




Note: Feedstuffs considered are cereals, wheat, oilseeds, and cottonseed. Total feed crop area represents 2020–22 average for each state. Only states with more than 1 million hectares planted are highlighted.

Source: USDA, Economic Research Service using data from the Reserve Bank of India.

Figure 20
**Feed crop area (million hectares), 2017–22**




Source: USDA, Economic Research Service using data from the Reserve Bank of India.

## India's Genetic Engineering (GE) Policy and the Adoption of GE Feeds

One possibility for addressing the gap in yields of feed crops is the adoption of improved germplasm, including the use of genetic engineering (GE). However, India's policies toward biotechnology have restricted the use of GE, both in terms of access to global markets for GE feed grains and for domestic production. While India has allowed the production and import of select GE crops and products, the country continues to be a hesitant adopter of the technology (See box, "India's Policy on Genetic Engineering"). To date, India has only allowed the production of cotton and the import of select products derived from GE crops that do not contain living modified organisms (LMOs). These products include vegetable oil derived from GE soybean and GE canola, as well as a temporary allowance for GE soybean meal.

## India’s Policy on Genetic Engineering

Before a new genetically engineered (GE) variety can be brought to market, the applicant must work with the respective Indian agencies to perform comprehensive food, feed, and environmental safety studies. The Environment Protection Act of 1986 provides the basis for India’s biotechnology regulatory framework for GE plants, animals, and their products and byproducts, along with the Rules for the Manufacture, Use/Import/Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells (1989), which is collectively known as the “rules of 1989.”

The biosafety approval of GE crops and products for research, development, and cultivation and processed nonfood products is handled by the Genetic Engineering Appraisal Committee (GEAC). The Food Safety and Standards Authority of India (FSSAI) has the authority to handle the food safety approval of GE food, including processed food and products. Ambiguity among different approving agencies and ongoing debate across legislators has slowed the authorization of new traits for production or trade (Singh & Beillard, 2023). Pray et al. (2005) suggested that the cost of regulation and long regulatory delays in India have likely limited firms’ willingness to introduce new traits. Likewise, the long regulatory delays can be costly in that they withhold the benefits of the technologies from producers and consumers.

India currently allows relatively few GE food or feed crops into the country, and those that are allowed are nonliving modified organisms (LMOs). The GEAC has granted import approval for vegetable oils derived from six GE soybean varieties and one GE canola variety. In 2021, the Ministry of Commerce and Industry (MOCI)/Directorate General of Foreign Trade (DGFT) issued a notification granting temporary authorization for imports of up to 1.2 million metric tons of soybean meal derived from GE soybeans, which expired on September 30, 2022 (Singh & Beillard, 2023). When policy allows the import of these GE commodities, a significant share of imports comes from GE-producing countries. For example, in 2022, India imported 85 percent of its soybean oil from countries that produce GE soybeans, such as Argentina and Brazil. Similarly, in 2021 and 2022, when soybean meal imports were allowed, the majority were sourced from GE-producing countries.

Cotton has been the focus of India’s experience with biotechnology. After the commercial release of *Bacillus thuringiensis (Bt)* cotton in 2002, India’s adoption rate quickly rose to 82 percent of its cotton-planted area in 2008 and has since stabilized at an adoption level of roughly 95 percent (figure 21). India has approved five separate transgenic varieties for commercial production that confer the *Bt* gene in cotton. *Bt* cotton adoption has been examined by a significant body of peer-reviewed research, with evidence showing positive yield gains, reduced pesticide applications, and higher profits (see box, “Impacts from India’s Genetically Engineered Cotton Adoption”).

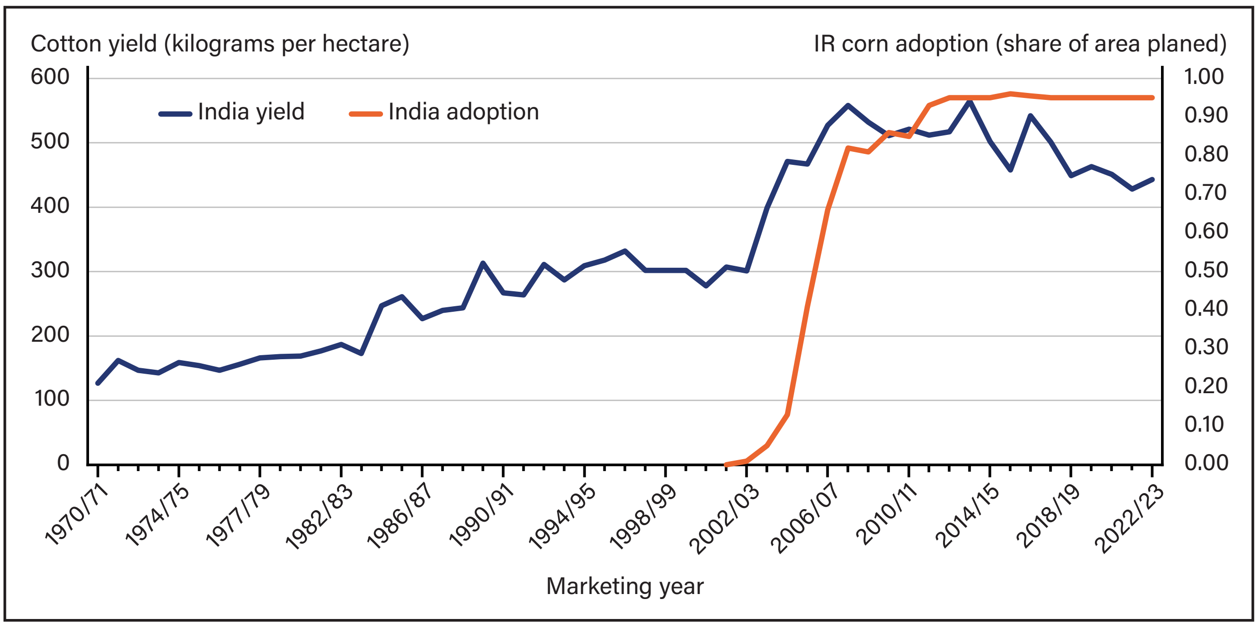
## Impacts From India's Genetically Engineered Cotton Adoption

Kathage and Qaim (2012) found that *Bacillus thuringiensis* (*Bt*) varieties had a 24-percent increase in cotton yield through reduced pest damage and a 50-percent gain in cotton profit among smallholders. This was found to result in a net increase of *Bt* cotton growers' annual consumption expenditures by 18 percent compared with nonadopters, suggesting improved living standards. *Bt* varieties were also associated with savings in chemical pest control (Qaim & Zilberman, 2003). In addition to productivity gains, the adoption of *Bt* varieties offered environmental and health benefits such as reduced incidence of acute pesticide poisoning among smallholders (Kouser & Qaim, 2011). *Bt* cotton adoption also contributed to poverty reduction (Subramanian & Qaim, 2010) and employment creation (Subramanian & Qaim, 2009; Nuthalapati & Dev, 2009).

The result of this adoption to genetic engineering (along with contributions of fertilizer and hybrid seed) has been significant increases in cotton production (Gruere & Sun, 2012). While India was a net importer of cotton in the 1990s, after the introduction of *Bt* cotton in 2002, the country emerged as the second-largest global cotton producer after China. This has been due, in part, to the significant productivity gains of Indian cotton yields, nearly doubling in less than a decade. Starting in 2002/2003, there was a distinct upward shift in yields that correlates with the commercial adoption of insect-resistant (IR) cotton varieties (figure 23). In the last 15 years, cotton yields have been declining due to several factors. Weather and pest incidence have both been problematic over the period. Resistance of pests to genetically engineered (GE) varieties has increased, partly due to imperfect resistance management programs and a lack of new GE varieties that are available in other countries, such as the United States (Subramanian, 2023).

Figure 21

**India's total cotton yield and adoption of insect-resistant (IR) cotton varieties**




Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service (FAS), Commodity Marketing Years, and Production, Supply, and Distribution; and Global Status of Commercialized Biotech/GM Crops, International Service for the Acquisition of Agri-biotech Applications, 2018.

Despite cotton being India's only commercialized GE crop, there is ongoing research and development in GE crops in both public and private research institutions in the country. Research activities span a range of crops and traits, according to Singh and Beillard (2023). Several crops have notably progressed through the development phase and have since advanced into the regulatory approval process. The first was *Bt* brinjal (eggplant), which was recommended by GEAC for commercial cultivation approval in 2009. However, its release was blocked the following year until further notice due to a lack of consensus among scientists and opposition among eggplant-growing States (Verma et al., 2021). Although it remains unapproved, field trials of separate transgenic *Bt* eggplant varieties are still ongoing (Singh & Beillard, 2023). A GE mustard variety was also recommended for approval by GEAC for environmental release in 2017 and again more recently (Singh & Beillard, 2023; Verma et al., 2021). A final determination is still forthcoming. Other transgenic varieties, such as HT (herbicide-tolerant) corn and stacked insect-resistant (IR)/HT cotton, are also in the regulatory pipeline (Verma et al., 2021; International Service for the Acquisition of Agri-biotech Applications (ISAAA), 2022).

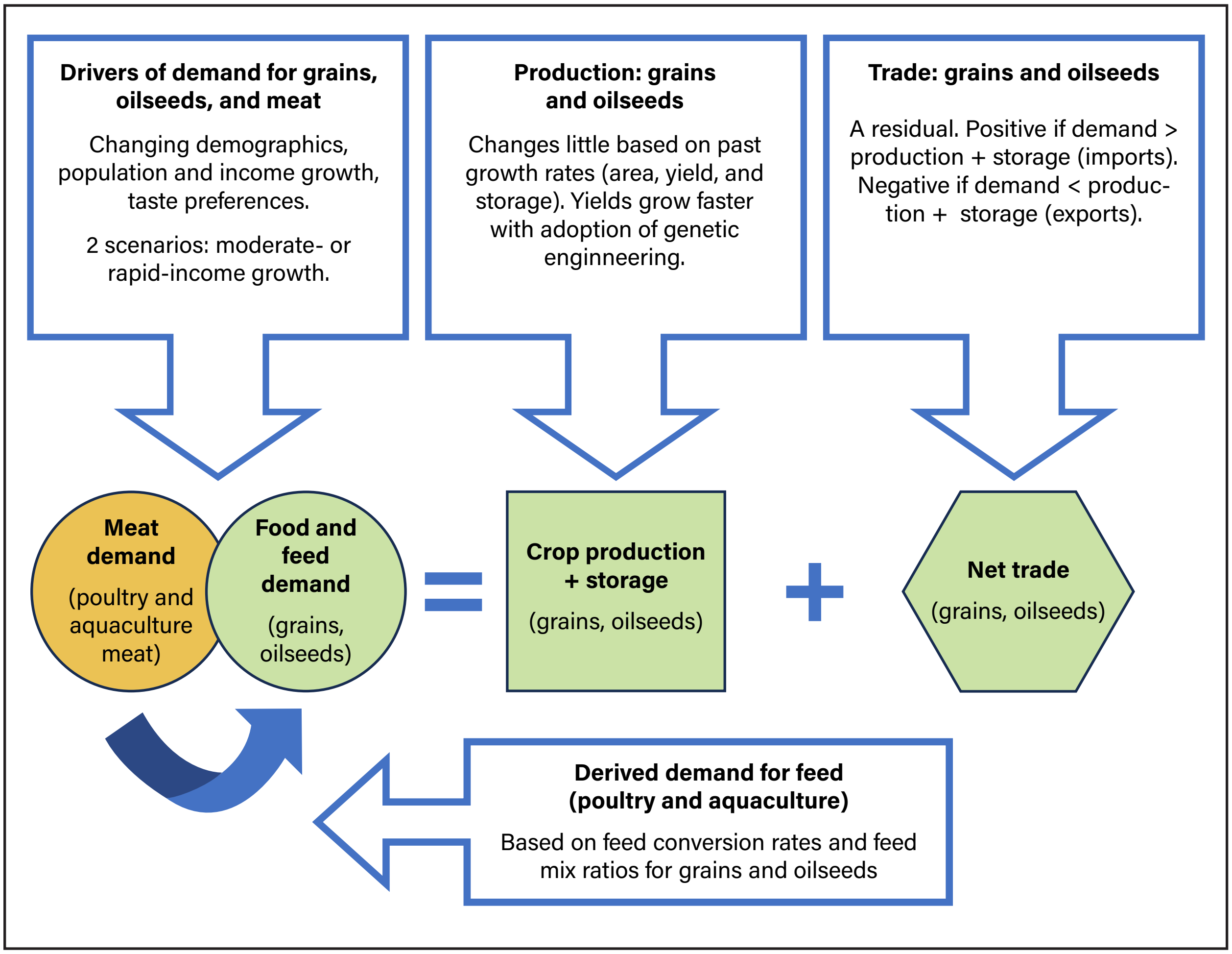
In addition to those crops that have already been approved, there have been ongoing discussions in India that suggest the potential for future approval of other GE products for importation. Most of these discussions have centered around non-LMO feed products but have not resulted in any clear paths for authorization. In 2021, the Ministry of Commerce and Industry (MOCI) announced that India and the United States had agreed to a framework for implementing market access for U.S. alfalfa hay, including GE varieties. However, India has not yet issued the notification authorizing the import of all alfalfa hay (Singh & Beillard, 2023). Feed manufacturers have applied for permission to import distillers' dried grains with solubles (DDGS) (Singh & Beillard, 2023).

## Projecting Future Demand and Supply of Feed in India to 2050

To project India's future demand and supply of feed, this report's authors followed Bhalla and Hazell (1997), who projected both food and feed demand for India to 2020 under alternative income growth scenarios.[18] Bhalla and Hazell (1997) chose an approach that analyzes total supply and demand balance sheets using feed conversion ratios based on projected meat demand and income (or expenditure) elasticities of demand. The present authors used the same approach in different income and crop yield growth scenarios to estimate future potential demand and supply of feed. Figure 22 illustrates their modeling framework, with further details on the approach and assumptions outlined in appendix A. A caveat of the approach is that it ignores any price effects that arise when supply and demand change over time, but the authors preferred this trackable approach that only considers feed demand. The absence of price effects also implies an absence of policy interventions, such as export taxes, import tariffs, and domestic subsidies. Critics also point to the assumptions based on income extrapolation with assumed fixed demand elasticities and feed requirements over time as not being as realistic by excluding dietary shifts as per capita incomes rise (Keyzer et al., 2005). The authors took some of this into account by adjusting demand elasticities as incomes rose above certain thresholds. Given the barriers that India has on imports of animal products, the authors assumed no additional imports of these products. Additionally, for fish and seafood, the focus was entirely on the demand for aquaculture products (aqua meat), as the study was only interested in the derived demand for feed.

[18] The authors compared the Bhalla and Hazell (1997) projections with actual data from 2020 to establish the robustness of their approach. The authors found that Bhalla and Hazell (1997) overestimated cereal consumption (they estimated a 126.3-percent increase, compared with a 95.1-percent actual) and underestimated poultry meat consumption (581.8 percent compared with an 812.2-percent actual).

Figure 22
**Modeling framework for estimating future feed demand in India**




Source: USDA, Economic Research Service illustration of modeling framework.

## Future Projections

The authors estimated total supply by making an adjustment to trade according to past trends (if exports and imports were small enough, which was mostly the case) using the projected domestic supply of feed grains and soybeans to 2050, as well as demand for human consumption and for livestock feed (as total feed), assuming a ratio of ending stock to total supply. Any surpluses or deficits that occurred would require the country to export or import, respectively. The analysis utilized two separate scenarios for both income and yield growth, resulting in a combined set of four scenarios:

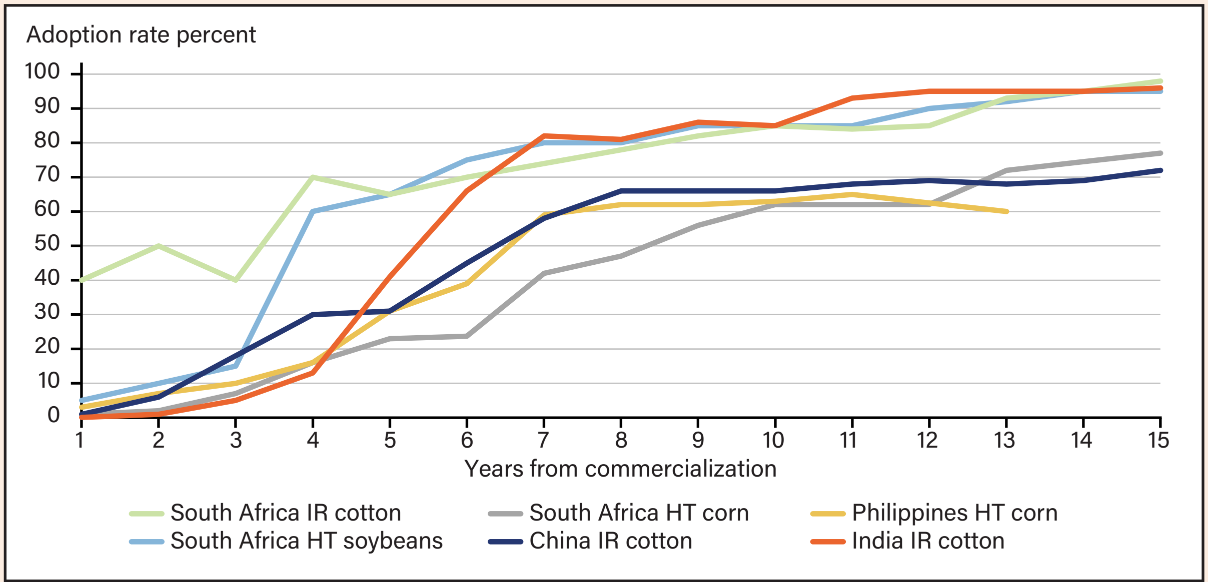
1. S1: Moderate income growth (SSP2) + current yield growth (status quo);
2. S2: Moderate income growth (SSP2) + rapid yield growth from GE adoption (corn and soybeans only) (see box, "Genetic Engineering Adoption Path for India");
3. S3: Rapid income growth (SSP5) + current yield growth (status quo); and
4. S4: Rapid income growth (SSP5) + rapid yield growth from genetic engineering adoption in corn and soybeans.

## Genetic Engineering Adoption Path for India

To develop a genetic engineering adoption path for India, the authors considered the case of *Bacillus thuringiensis* (*Bt*) cotton adoption. India first commercialized cotton in 2002, and adoption started slowly in the first few years until reaching 41 percent in year 5 and 82 percent in year 7 (box figure 1). China had a very similar adoption path, reaching 31 percent in year 5 and 66 percent in year 8. In contrast, South Africa had 40 percent adoption when it was first officially commercialized and reached over 65 percent in year 5. Globally, herbicide-tolerant (HT) corn has tended to be adopted at a slower rate. Countries with demonstrated adoption that may be relevant to India include South Africa and the Philippines, which reached 23 percent and 31 percent adoption, respectively, in year 5. With these representative adoption paths as guidance, the adoption scenarios shown in box table 1 were used for India.

Box figure 1

**Adoption of genetically engineered traits by select countries and crops**




HT = herbicide-tolerant. IR = insect-resistant.

Source: USDA, Economic Research Service calculations using data from Global Status of Commercialized Biotech/GM Crops, International Service for the Acquisition of Agri-biotech Applications, 2018.

Box table 1

**Scenario adoption path percent for genetically engineered feed crop production (years from commercialization)**

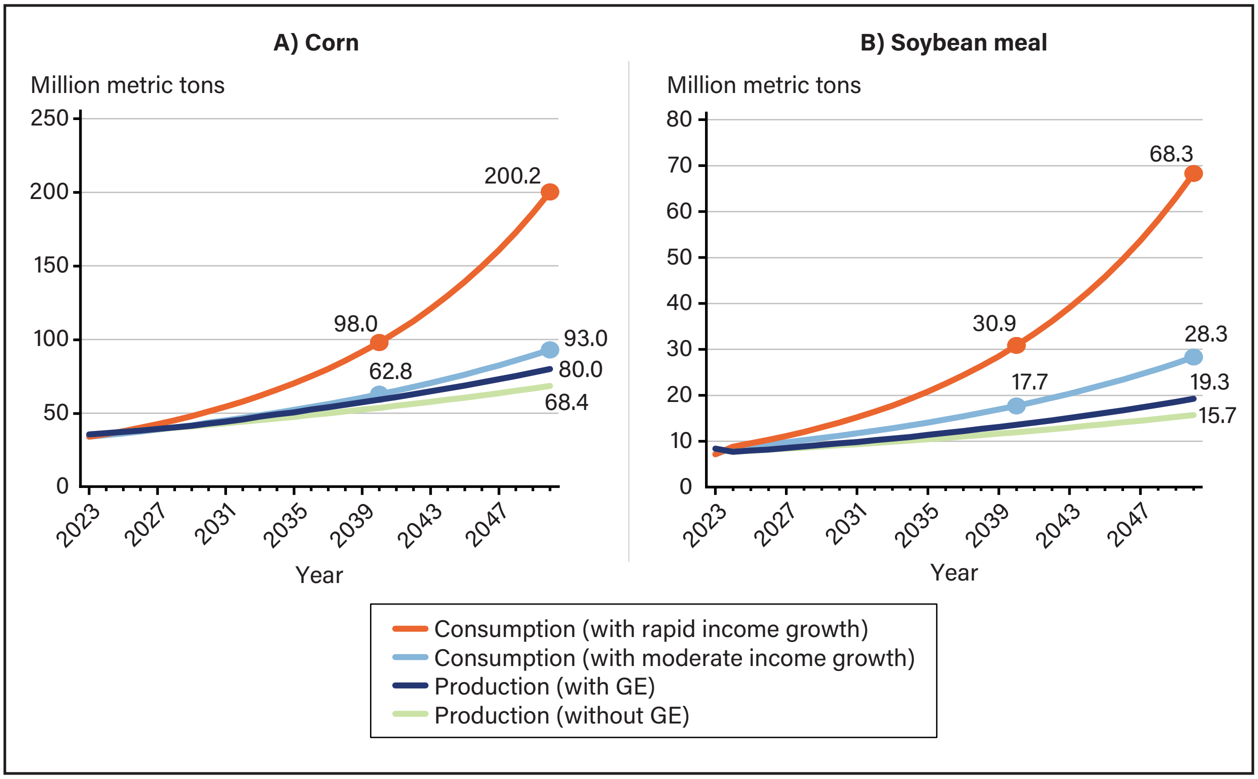
| Years after | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HT soy (percent) | 5 | 10 | 15 | 60 | 65 | 75 | 80 | 80 | 85 | 85 | 85 | 90 | 92 | 95 | 95 |
| HT corn (percent) | 2 | 5 | 9 | 16 | 27 | 31 | 51 | 55 | 59 | 63 | 64 | 62 | 66 | 75 | 77 |
| *Bt* corn (percent) | 2 | 5 | 8 | 15 | 14 | 13 | 35 | 44 | 52 | 67 | 67 | 65 | 72 | 71 | 73 |

HT = herbicide-tolerant. *Bt* = *Bacillus thuringiensis*.

Source: USDA, Economic Research Service calculations using data from Global Status of Commercialized Biotech/GM Crops, International Service for the Acquisition of Agri-biotech Applications, 2018.

Figure 23 shows results for total domestic consumption and production of corn and soybean meal. Total domestic consumption was made up of the estimated demand for feed using feed conversion ratios (FCRs) from appendix A, plus projected human consumption demand based on the study's assumed income elasticities and per capita income growth rates. Figure 23a shows total domestic consumption for corn growing from about 34 million metric tons in 2023 to 93 million metric tons by 2050 (almost tripling) for the moderate-income growth scenario (SSP2), but this rose even more—to 200 million metric tons in 2050—under the rapid income growth scenario. This was mostly driven by the feed demand component because corn is not as widely used for human consumption in India, and demand for feed grows much more rapidly with higher income growth rates. For soybean meal (figure 23b), consumption increased almost fivefold under the rapid income growth scenario because demand for poultry and aqua meats rose more quickly among a rising middle class. Wheat also experienced modest growth (figure 24), mostly for human consumption (it comprised about 15 percent of feed in the model, only slightly more than current shares). Wheat had a surplus for exports under the moderate-income growth scenario.

Figure 23
**Projections of corn and soybean meal consumption and production in India, 2023–50 (million metric tons)**

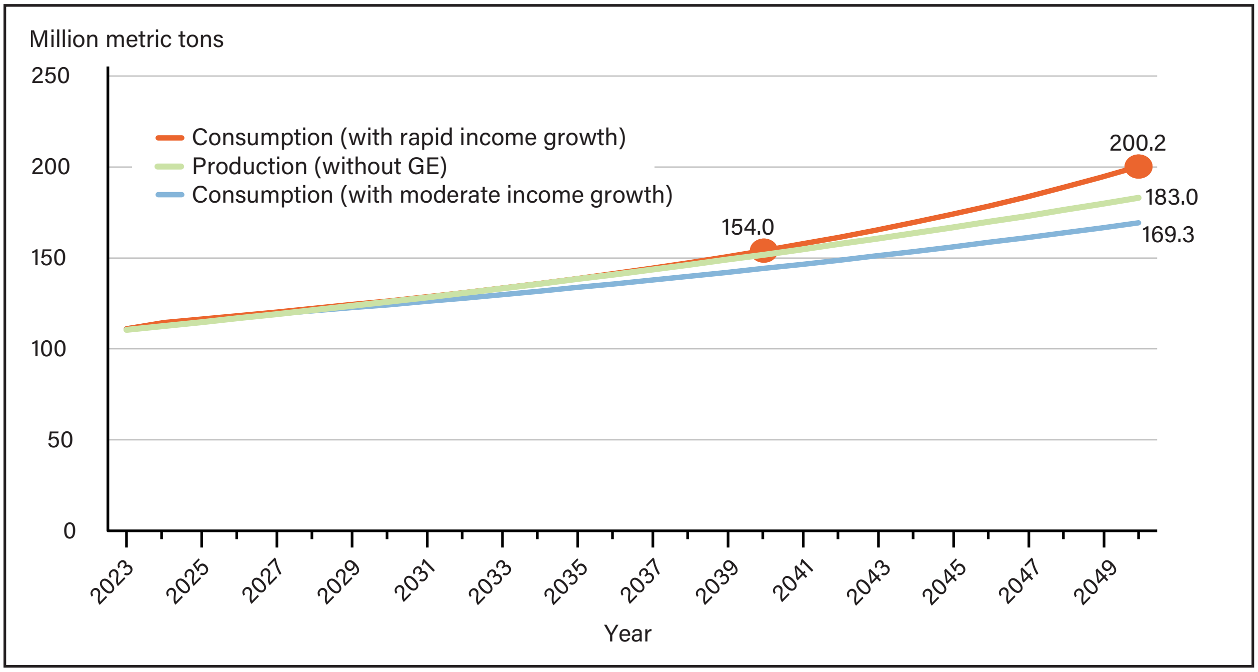



GE = genetic engineering.

Note: Consumption is affected by 2 income scenario assumptions about its future growth, while production is affected by yield scenario assumptions for future growth (a slow-growth assumption for area harvested is held constant across all yield scenarios).

Source: USDA, Economic Research Service model calculations using USDA, Foreign Agricultural Service's Production, Supply, and Distribution (PSD) database and the United Nations' Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

Figure 24
**Projections of wheat consumption and production in India, 2023–50**



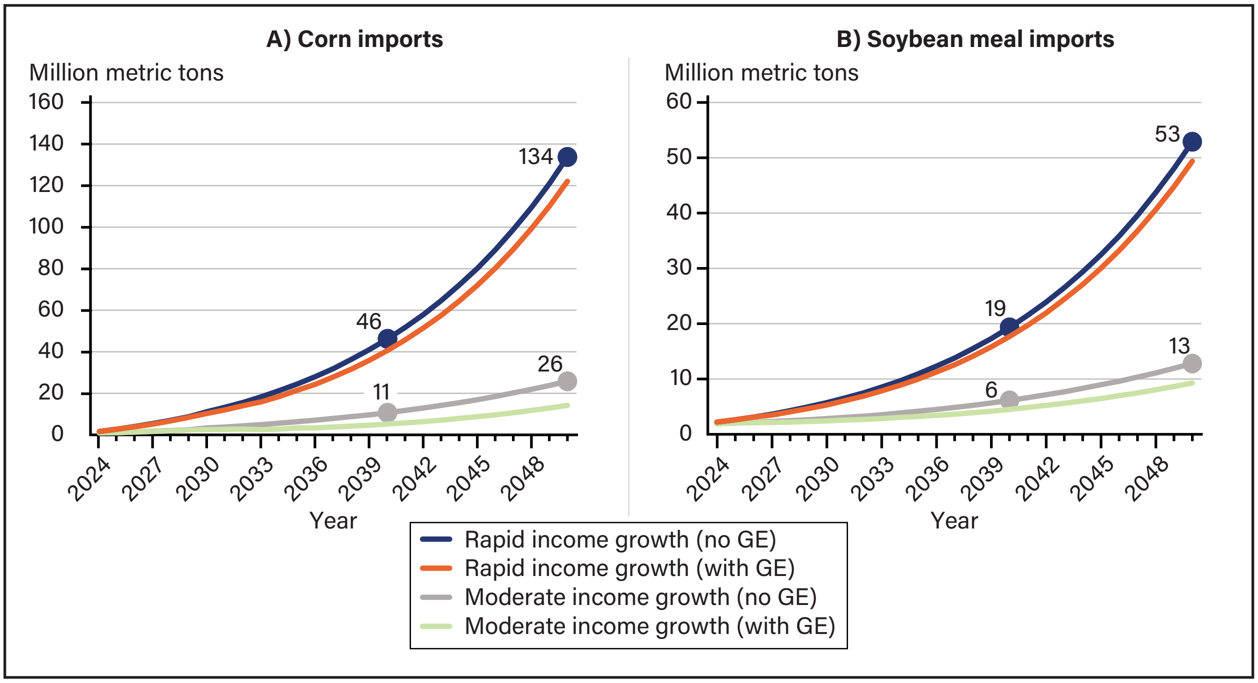

GE = genetic engineering.

Note: For wheat, there is no GE scenario.

Source: USDA, Economic Research Service calculations using USDA, Foreign Agricultural Service's Production, Supply and Distribution (PSD) database and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

In almost all cases, domestic production was not able to keep up with growth in demand under the rapid income growth scenario, even with genetic engineering to increase yields. Figure 25 illustrates the resulting growth in imports to 2050. Imports rose faster under the rapid income growth scenario as demand for chicken meat grew, and therefore, demand for feed ingredients also rose, especially for corn and soybean meal (figure 25). Imports rose to as high as 134 million metric tons under the rapid income growth scenario. This figure would only be reduced slightly to 122 million metric tons if genetically engineered seeds were approved for use in India (figure 25). This emphasized the accelerated growth in demand for feed as more and more consumers diversified their diets away from starchy staples. The effects of genetic engineering adoption were more pronounced under the moderate growth scenario, with imports potentially declining from 26 million metric tons to only 14 million metric tons by 2050. All in all, neither scenario prevented India from importing corn and soybean meal (or in soybean equivalents).

Figure 25
**Projections of corn and soybean meal imports in India by type of scenario, 2024–50**




GE = genetic engineering.

Source: USDA, Economic Research Service calculations using USDA, Foreign Agricultural Service's Production, Supply and Distribution (PSD) database and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

Finally, table 4 shows imports for both soybean meal and soybean oil under the authors' four scenarios.[19] All scenarios showed gradually increasing imports over time as production failed to keep up. Imports were reduced when soybean production increased with the adoption of genetic engineering (GE). For example, under the moderate income growth scenario, 12.8 million metric tons of soybean meal imports were projected without any consideration of GE technologies. This was reduced to 9.3 million metric tons with GE adoption. However, imports were only marginally reduced due to the GE effect with rapid income growth (two right columns in table 4), clearly showing how the resulting increase in demand for high value and more diversified products, such as chicken meat and soybean oil, cannot be met by domestic suppliers of soybean meal.

[19] These are two byproducts of soybean crushing that are expected to increase in demand as per capita incomes rise.

Table 4

**Projections of imports of soybean products (meal and oil) in India, 2010s to 2050 (million metric tons)**

| Income growth | SSP2 (moderate income growth) | | SSP5 (rapid income growth) | |
|---|---|---|---|---|
| Yield growth | No GE | With GE | No GE | With GE |
| Scenario (S) | S1 | S2 | S3 | S4 |
| a) Soybean meal | | | | |
| 2010s | 0.0 | 0.0 | 0.0 | 0.0 |
| 2020s | 1.4 | 1.4 | 2.2 | 2.1 |
| 2030s | 4.1 | 3.2 | 10.8 | 9.9 |
| 2040s | 8.8 | 6.4 | 32.0 | 29.6 |
| 2050 | 12.8 | 9.3 | 52.9 | 49.4 |
| b) Soybean oil | | | | |
| 2010s | 2.5 | 2.5 | 2.5 | 2.5 |
| 2020s | 4.3 | 4.3 | 4.6 | 4.6 |
| 2030s | 6.7 | 6.5 | 8.9 | 8.7 |
| 2040s | 10.1 | 9.6 | 16.4 | 15.8 |
| 2050 | 12.6 | 11.8 | 22.5 | 21.7 |

SSP = Shared Socioeconomic Pathway. GE = genetic engineering.

Note: SSPs refer to various Shared Socioeconomic Pathways (SSPs) that are climate-change scenarios of projected socioeconomic global changes. For information on SSPs, see Explainer: How 'Shared Socioeconomic Pathways' Explore Future Climate Change, Carbon Brief, 2018.

Source: USDA, Economic Research Service calculations using USDA, Foreign Agricultural Service's Production, Supply and Distribution (PSD) database and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

## Conclusion

Much like China 20 years ago, India's per capita income is growing and is expected to keep growing at a fast rate in the future. In addition, urbanization is spreading, which could increase the demand for animal products and processed foods through restaurants and grocery stores. A greater demand for animal products and processed foods could drive further investments and efficiencies in agrifood value chains in India (Awokuse & Reardon, 2018). While India has largely been self-sufficient in feed supply for animal meat production, it is increasingly having to rely on some imports (importing a large amount of soybean meal in 2021, for example), especially when domestic prices increase relative to global prices. However, India continues to maintain some of the world's most restrictive trade barriers, including high import tariffs, and outright bans on imports of genetically engineered (GE) products.

Given future potential growth in the demand for animal products due to increased incomes and urbanization, this study examined the constraints and opportunities for meeting this growing demand.[20] The authors began by first examining the growing demand for meat products, including the demand for animal feed, driven by changing macroeconomic factors, such as population, income, and urbanization growth. The

[20] At the time of this writing, a recent report examining India's ability to meet its future food needs (NITI Aayog, 2024) noted how population growth would lead to more food demand, with income growth driving the demand for animal products. However, the report focused on food only, including animal products, not the availability of feed to produce the animal products as this report does.

authors then examined the degree to which agriculture has been able to respond to supply the increased demand for animal products, especially in terms of the feed supply. Options to meet the supply needs, such as through biotechnology (or genetically engineering) innovations, both domestically or as imports from global markets, were then considered. Finally, the authors presented some future projections through 2050 under alternative income growth scenarios and the potential effects on animal product demand and the ability of the domestic agricultural sector to meet that demand over time. The projections showed that India's animal product demand and, therefore, demand for feed will increase significantly, especially under a rapid income growth scenario such as China experienced over the last few decades. The growth in demand for feed will far outpace domestic supply. As soon as the early 2030s, India could become hard-pressed to meet its growing animal feed demands without resorting to imports. Note that dietary restrictions based on religion play a large role in India. Although this study presents some background on these effects, the estimates of future consumption do not explicitly consider changes from religion (beyond the baseline that considers consumption from India's overall religious composition).

Given India's activities over the last decade, it is possible to conceive several future scenarios where GE feedstuffs could be authorized for import by India. One scenario is where soybean meal is authorized for importation, which could be an expansion of the country's 2021 temporary approval. While this could be implemented in perpetuity, it could alternatively be implemented on an ad hoc basis during periods of feed shortage. A second scenario could authorize distillers' dried grains with solubles (DDGS) and/or alfalfa in a similar fashion to soybean meal. It remains unlikely that living modified organism (LMO) feed crops, such as corn, soybeans, and canola, would be authorized for import under the current situation. However, there has been interest from the Indian feed industry in allowing the importation of herbicide-tolerate (HT) soybeans. This would have the benefit of supporting the Indian crushing industry and supplying both soybean oil and soybean meal, which are in high demand.

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# Appendix: Projecting Feed Demand and Supply

The starting point of this study was the viewpoint that the demand of grains for food is likely to increase less rapidly than the demand of grains for feed. This is because as per capita incomes rise, the demand for starchy staple grains diminishes as consumers shift to more diversified diets with meat, dairy, and aquaculture products. The research focused mainly on chicken and aquaculture meat because both are among the most common and fastest growing meat sectors in India. For feed grains, the focus was on corn and wheat (the most common grains for feed ingredients in the country).[21] For oilseeds, the analysis was focused on soybean and its processed products, soybean meal and soybean oil, which can drive the demand for soybeans just as feed does. The authors looked at the entire balance sheet of total grain and soybean supply, stocks, production, consumption, imports, and exports, drawing from USDA's Production, Supply, and Distribution (PSD) database (U.S. Department of Agriculture, Foreign Agricultural Service, 2024c) and the United Nations' Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).

The authors began by estimating growth in demand for both grains and soybeans for feed and human consumption from 2023 to 2050. Demand of grains for human consumption competes with the livestock sector's demand for feed, which the authors derived from the livestock sector's supply response to consumer demand for animal products (for the study, chicken and aqua (seafood) meat). Similarly, demand for soybeans is derived from the same supply response by the livestock sector. Feed mixes are typically composed of 70 percent grain (for energy), 20 percent soybean meal or other oilseed substitute (for protein), and the rest as nutrient additives. Soybean meal is extracted together with soybean oil from crushed soybeans. The conversion rate is typically that 1 kilogram (kg) of crushed soybeans will produce 0.8 kg of soybean meal and 0.15 kg of soybean oil. Crushed soybeans are about 85 percent of the original weight of soybeans. Once the authors had their demand estimates, they estimated production growth by projecting future growth in yields and area harvested, which provided a base for alternative yield growth scenarios.

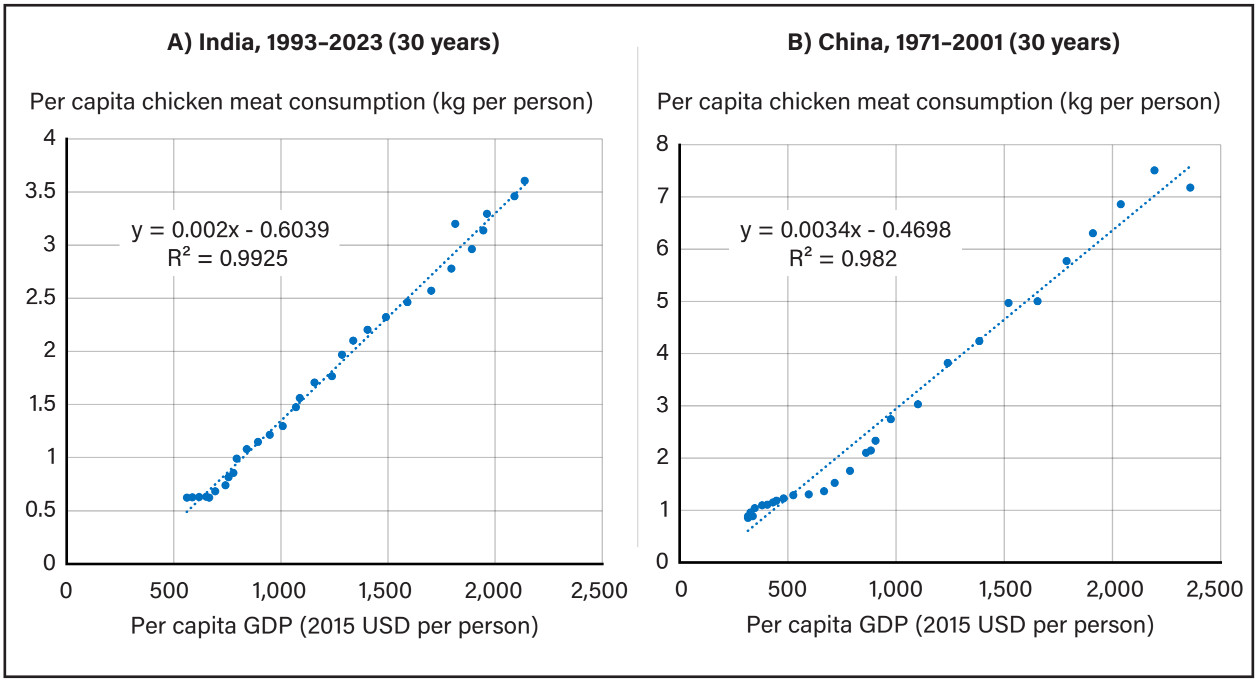
## Demand

Consumer demand for high-value animal products has a high-income elasticity, especially among poorer households. This means that as incomes rise, people will likely consume more animal products. This can be illustrated for chicken meat by comparing China and India over certain 30-year periods unique to each country when per capita incomes were about the same (figure A.1). First, in comparing the growth in per capita meat consumption versus per capita Gross Domestic Product (GDP), there was dramatic growth in China where per capita GDP grew significantly in the 1980s to 2001, when the country's per capita income was close to $2,500 per person, as it was in India in 2023. There is a strong correlation between the growth in per capita chicken meat consumption and per capita GDP in China and India as figure A.1 shows. What is interesting is the rapid growth of chicken meat consumption in China versus that of India (i.e., a steeper line) at similar levels of per capita GDP growth. Per capita, chicken meat consumption in China increased almost sevenfold over a 30-year period (1971–2001), from about 1 kilogram (kg) per person to 8 kg per person. In contrast, India has only seen a twofold to threefold increase over the last 30 years (1993–2023), from about 1 kg per person to 3.5 kg at the same per capita levels. In fact, per capita consumption remains very low in India relative to China where it is now close to 12 kg per person compared with India's 3.5 kg per person. Part of this may be due to the higher prevalence of vegetarian diets in India, as pointed out earlier in this report.

[21] Although it should be noted that broken rice is also being increasingly used as a feed grain substitute, relative prices have changed in favor of rice after the Russia-Ukraine war.

Figure A.1

**Simple correlation between per capita GDP (USD per person) and chicken meat consumption (kg per person) over time in India, 1993–2023, and China, 1971–2001**




GDP = Gross Domestic Product. USD = U.S. dollars. kg = kilograms.

Note: In the linear regression equation, y = per capita broiler meat consumption and x = per capita GDP; R2 = is the goodness of fit or correlation coefficient between y and x. The equation for A) is y = 0.002x – 0.6039, and the R2 is 0.9925. For B), the equation is y = 0.0034x – 0.4698, and the R2 is 0.9820.

Source: USDA, Economic Research Service calculations using GDP data from the World Development Indicators database of the World Bank and per capita broiler consumption data from the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

To estimate the derived demand for feed based on growth in per capita GDP, and thus the demand for chicken meat, the authors used data from the USDA PSD database and the United Nations' FAOSTAT on chicken meat consumption, and World Development indicators for per capita GDP.[22] The authors calibrated income elasticities per decade (as constant) based on these two values to ensure the resulting change in per capita consumption of chicken meat based on per capita income growth closely resembled the actual data. Allowing the elasticities to change over time recognized the presence of declining elasticity values at higher levels of per capita income. Mathematically, this can be shown as:

$$\Delta x^d = \varepsilon * \Delta y,$$

where $x^{\mathrm{d}}$ is the per capita demand for chicken meat and y is per capita income, $\Delta$represents the percent change in incomes, and $\varepsilon$ is the income elasticity of demand.

The authors used two per capita income projections to 2050 based on the Shared Socioeconomic Pathways (SSPs) database (Riahi et al., 2017). They chose the SSP2 and SSP5 income growth scenarios to compare results between a moderate (middle of the road) and a rapid per capita income growth scenario. Population growth estimates were taken from the same source under both scenarios. Estimates of meat consump-

[22] United Nations' FAOSTAT was used to fill any data gaps on poultry in India.

tion were then calculated for each year based on the annual growth in per capita incomes under these two scenarios and assumed income elasticities of demand for chicken and aqua meat.[23] As noted, income elasticities of demand are first calibrated to actual per capita GDP growth and meat consumption rates. The authors assumed little change until 2050 except for the rapid growth scenario for chicken meat because the elasticities would be expected to decrease with higher incomes. Table A.1 summarizes the results of the calibrated income elasticities of demand for both chicken and aqua meat.

Table A.1
**Calibrated income elasticities of demand for chicken meat by decade, 1973–2050**

| | Moderate income growth scenario (SSP2) | | Rapid income growth scenario (SSP5) | |
|---|---|---|---|---|
| Decade | Chicken meat | Aqua meat | Chicken meat | Aqua meat |
| 1970s | 2.600 | 4.000 | 2.600 | 4.000 |
| 1980s | 3.120 | 4.000 | 3.120 | 4.000 |
| 1990s | 3.120 | 1.600 | 3.120 | 1.600 |
| 2000s | 2.496 | 1.120 | 2.496 | 1.120 |
| 2010s | 1.498 | 0.896 | 1.498 | 0.896 |
| 2020s | 1.498 | 0.806 | 1.498 | 0.806 |
| 2030s | 1.498 | 0.806 | 1.498 | 0.806 |
| 2040s | 1.498 | 0.806 | 1.348 | 0.806 |

SSP = Shared Socioeconomic Pathway.

Note: The assumption is that the income elasticities will stay the same in the future, except in the rapid income growth scenario.

Source: USDA, Economic Research Service calculations based on model scenario runs for different periods to reflect actual chicken meat demand (for years before 2023) and adjusted for future years. The data used in the model were from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

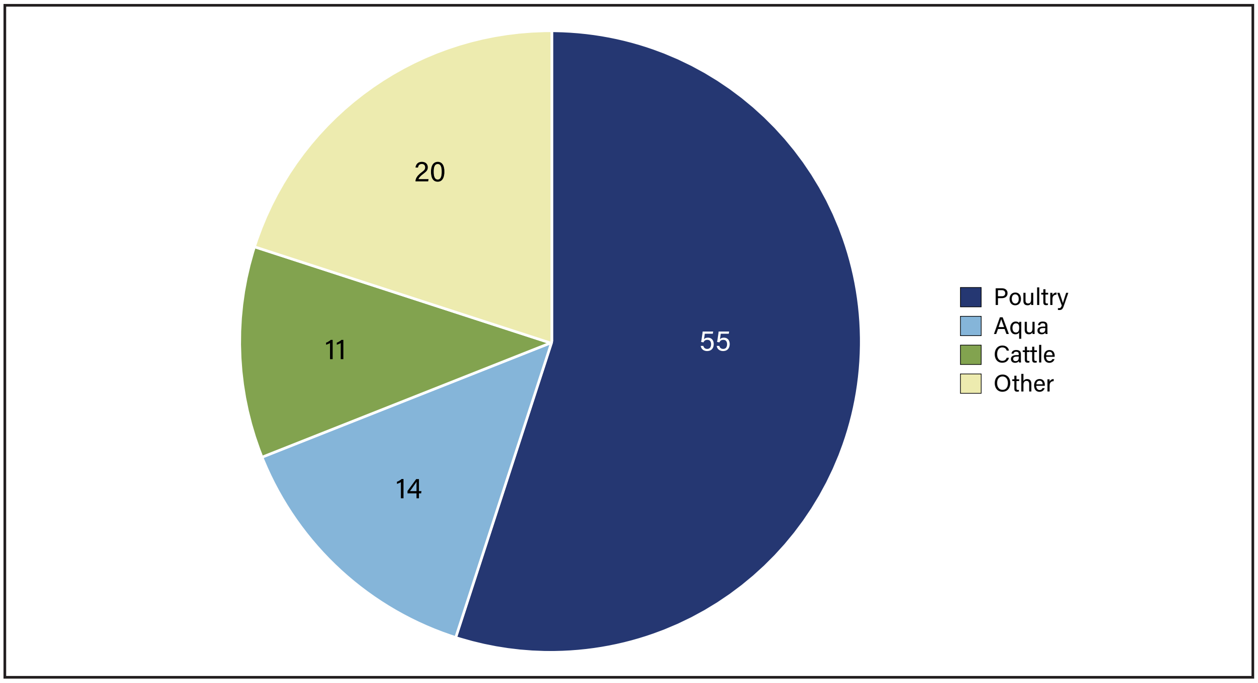
The projections of chicken and aqua meat demand through 2050 enabled the authors to calculate how much feed will be required to meet that demand for both chicken and aqua meat. This was accomplished by using a feed conversion ratio (FCR) of feed weight to meat weight. The authors selected a value that appeared reasonable given the data on total feed for the most recent period—3.03 kg for chicken meat (which is typical in many developing countries, i.e., 3.03 kg of feed produces 1 kg of chicken meat) and 2.4 for aqua meat.[24] Many factors can influence FCRs, including biological, environmental, and production practices. Because of limited data on these ratios over time and recognizing these ratios can change over time with improved production practices, improvements in feed compositions, and even genetic improvements in chicks, the authors allowed the FCRs to be calibrated in the model according to the share of total feed going to chicken and aqua meat production. The shares were set close to the current allocations by 2023 of 55 percent of total feed for chicken feed, 14 percent for aqua feed, and the rest for cattle and other livestock (figure A.2). The shares were allowed to only grow marginally up to about 70 percent for chicken meat and 18 percent for aqua feed, with the remainder going to other livestock. The final FCR values, which appeared reasonable, are shown table A.2. Finally, feed demand for both meat sectors was then projected based on the demand for meat under the two income growth scenarios: (1) moderate (or middle of the road) scenario (SSP2), with GDP growth of 4.6 percent per year (or 3.8 percent in per capita terms with population growth set at 0.7

[23] The authors limited their analysis to the growth in demand for aquaculture products because they were interested in assessing how the supply from production (and, hence, feed demand as in poultry production) can meet this growing demand.

[24] See, for example, Andam et al. (2017) for Ghana.

percent per year), and (2) a rapid income growth scenario (SSP5), with GDP growth of 6.6 percent per year (or 6.2 percent in per capita terms with population growth set at 0.4 percent per year).

Figure A.2
**Feed sector allocation (percent)**




Source: USDA, Economic Research Service using data from Meeting the Rising Demand: Strategies for Expanding India's Animal Feed Exports, India Business & Trade.

Table A.2
**Calibrated feed conversion ratios for chicken and aquaculture by decade, 1973–2050**

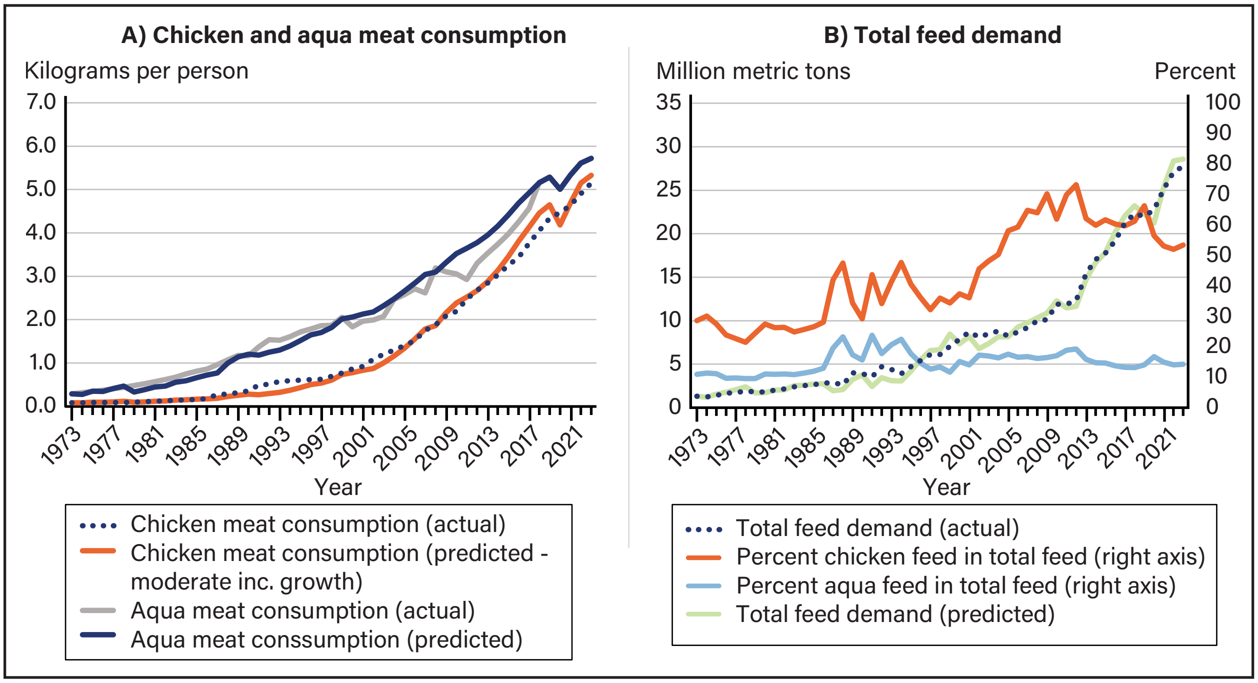
| Decade | Feed kg per chicken meat kg | Feed kg per aqua meat kg |
|---|---|---|
| 1970s | 4.370 | 2.400 |
| 1980s | 4.370 | 2.400 |
| 1990s | 3.933 | 2.400 |
| 2000s | 3.540 | 2.400 |
| 2010s | 3.186 | 2.400 |
| 2020s | 2.867 | 2.160 |
| 2030s | 2.580 | 1.944 |
| 2040s | 2.322 | 1.750 |

kg = kilograms.
Note: 1970s data began with data from 1973.

Source: USDA, Economic Research Service calculations based on model scenario runs for different periods to reflect actual total feed and chicken meat demand (for years before 2023) and adjusted for future years. The data used in the model was from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

Figure A.3 graphs the results showing actual against predicted values for chicken meat demand, including the corresponding demand for feed, based on actual per capita GDP growth rates. Predicted results appear to be reasonable, with the actual and predicted lines for both aqua and chicken meat relatively close.

Figure A.3
**Comparing original (actual) and predicted results of per capita chicken and aqua meat consumption and feed demand in India based on actual per capita GDP growth, 1973–2023**



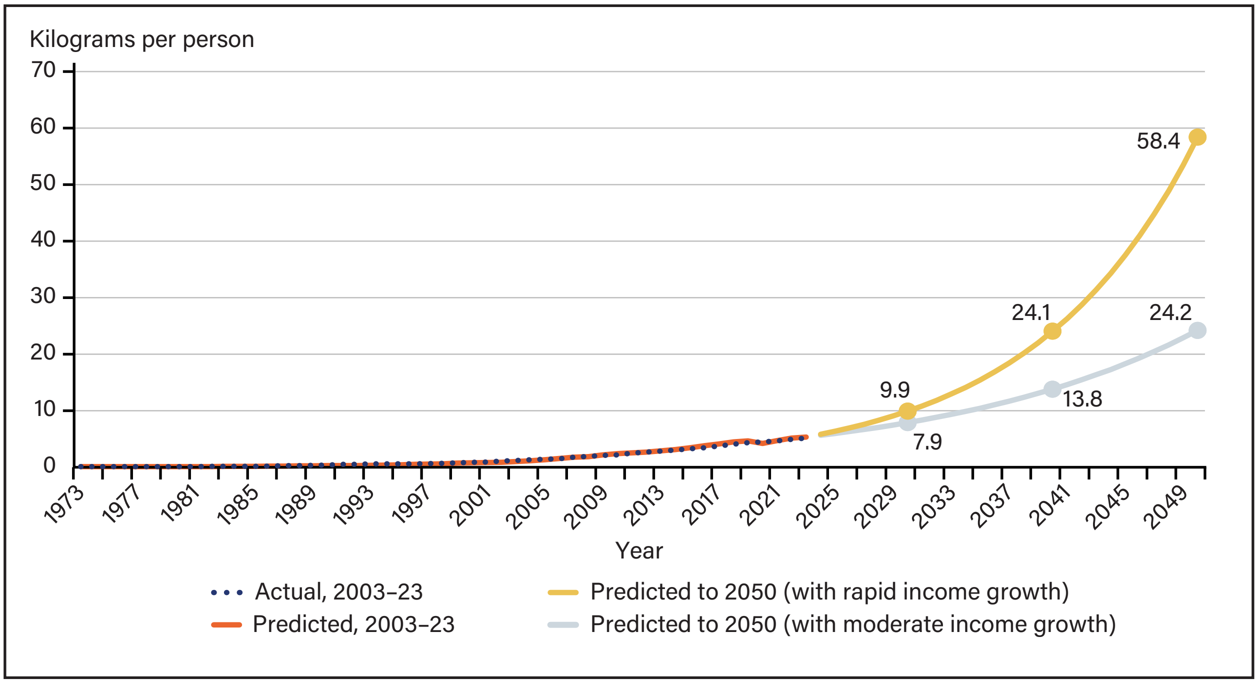

GDP = Gross Domestic Product. inc. = income.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

To project forward through 2050, the authors assumed income elasticities would not change from their 2020s values, except for the case under rapid per capita income growth. Figure A.4 shows the resulting projections for chicken meat and the resulting derived demand for feed in figure A.5. If a more rapid growth rate in per capita income is assumed, this results in a much higher growth in demand for both meats and corresponding feed, as one would expect. However, demand for chicken feed far outweighs that for aquaculture, as a large share of aquaculture is captured and not farmed.

Figure A.4

**Projecting chicken meat consumption in India to 2050 based on assumed future income growth scenarios (SSP2 - moderate and SSP5 - rapid)**

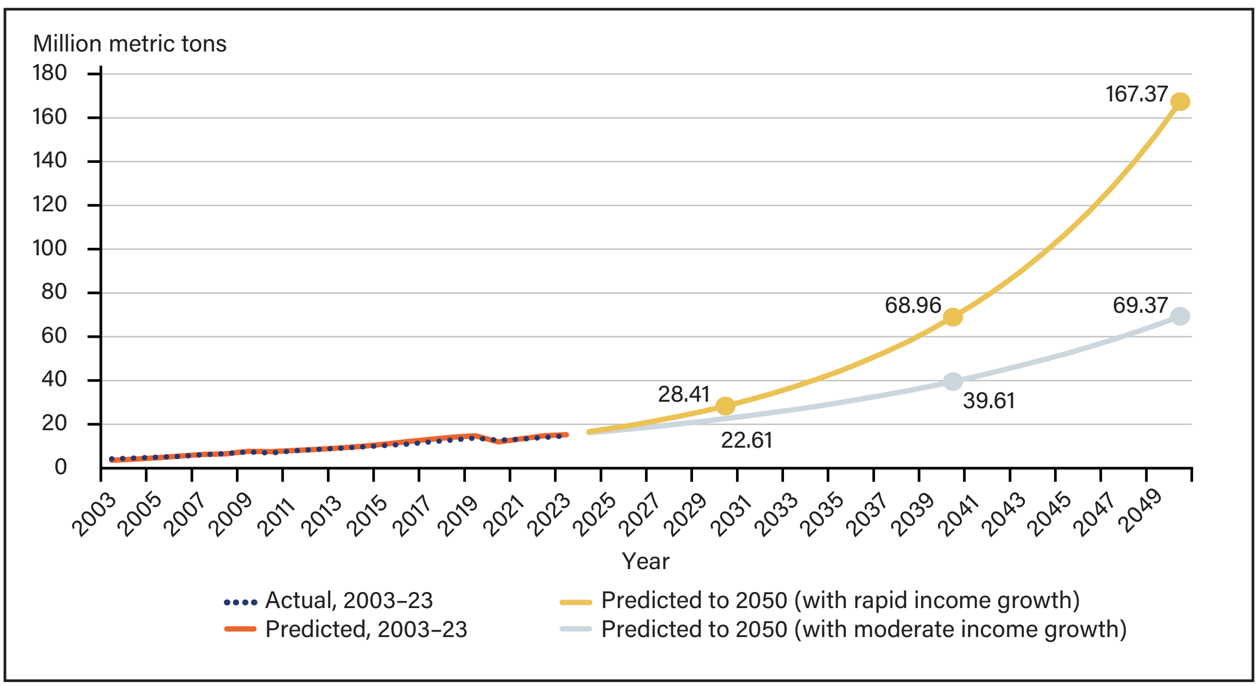



SSP = Shared Socioeconomic Pathway.

Source: USDA, Economic Research Service model projections and base data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

Figure A.5

**Derived feed demand in response to increased demand for chicken and aqua meat in India to 2050 under two income growth scenarios**




Source: USDA, Economic Research Service model projections and calculations using base data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the United Nations' Food and Agriculture Organization Statistical Database (FAOSTAT).

All three commodities (wheat, soybean oil, and corn) are not only consumed by the feed sector but also by humans, especially wheat and soybean oil in India (which is extracted together with soybean meal from soybean crush). The authors also estimated demand growth for corn, wheat, and soybean oil destined for human consumption based on population growth and the study's two per capita income growth scenarios. This will enable estimations of future demand growth using calibated income elasticties like those used for chicken and aqua meat estimates (table A.3).

Figure A.6 shows the authors' final projected growth in consumer demand to 2050 (in million metric tons) for the two grains and soybean oil. These also appear resonably conservative for corn and wheat but with growth much faster for soybean oil due to increasing per capita income (assuming this is a higher value commodity and that demand is likely to continue growing as incomes rise).

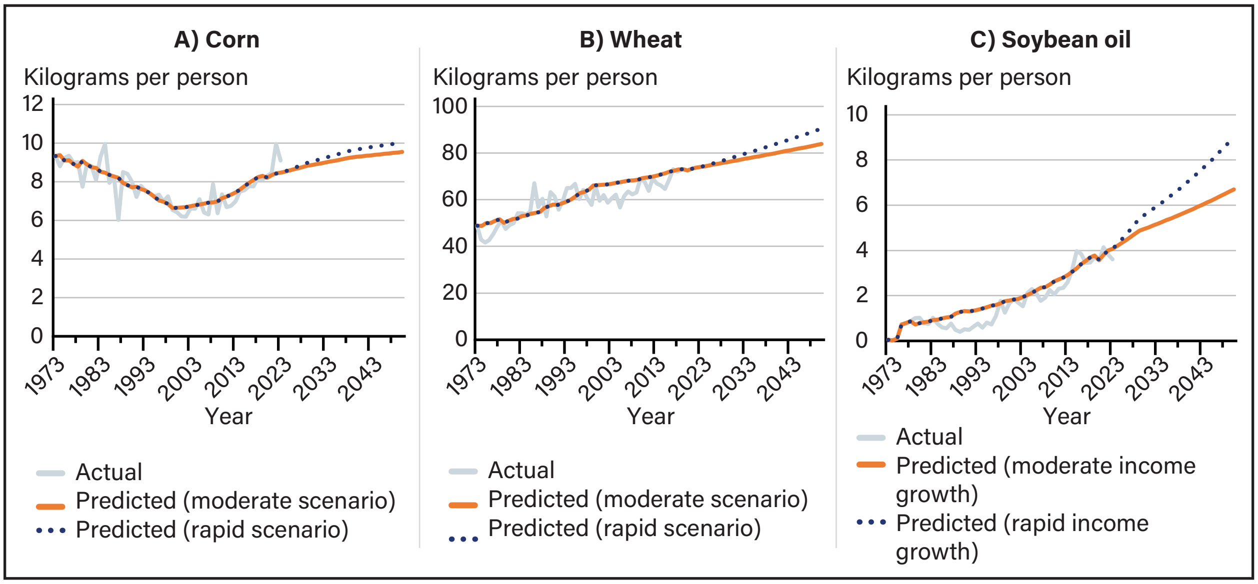
Table A.3
**Calibrated income elasticities of demand for corn, wheat, and soybean oil, 1973–2050**

| | Moderate income growth scenario (SSP2) | | | Rapid income growth scenario (SSP5) | | |
|---|---|---|---|---|---|---|
| Decade | Corn | Wheat | Soybean oil | Corn | Wheat | Soybean oil |
| 1970s | -0.440 | 0.400 | 2.200 | -0.440 | 0.400 | 2.200 |
| 1980s | -0.440 | 0.400 | 1.760 | -0.440 | 0.400 | 1.760 |
| 1990s | -0.440 | 0.400 | 0.880 | -0.440 | 0.400 | 0.880 |
| 2000s | 0.110 | 0.080 | 0.792 | 0.110 | 0.080 | 0.792 |
| 2010s | 0.330 | 0.120 | 0.792 | 0.330 | 0.120 | 0.792 |
| 2020s | 0.182 | 0.120 | 0.792 | 0.165 | 0.120 | 0.792 |
| 2030s | 0.127 | 0.120 | 0.792 | 0.116 | 0.120 | 0.792 |
| 2040s | 0.069 | 0.120 | 0.792 | 0.058 | 0.120 | 0.792 |

SSP = Shared Socioeconomic Pathway.

Source: USDA, Economic Research Service calculations based on model scenario runs for different periods in time to reflect actual consumer demand (for years before 2023) and adjusted for future years. The data used in the model is from USDA, Foreign Agricultural Service, Production, Supply, and Distribution, and the World Development Indicators database of the World Bank for per capita income.

Figure A.6
**Projected growth in consumer demand for corn, wheat, and soybean oil, 1973–2050**



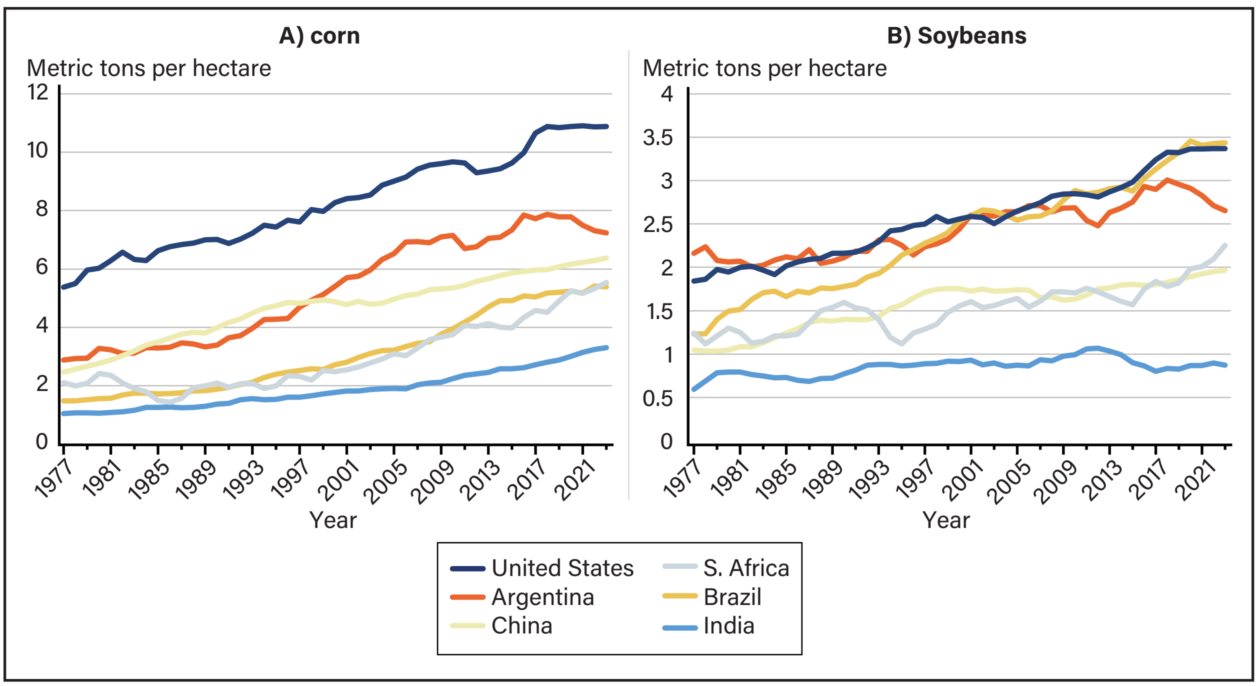

Source: USDA, Economic Research Service model projections and calculations using base data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

## Supply

The results for meat demand have implications on import demand for feed grains and soybean meal in the future, depending on how well India's agricultural sector can respond to the growing demand, which can be affected by many factors (e.g., risks of climate change) and technology access options to adapt and increase yields. Various futuristic production outcomes are projected in this report for feed grains and soybeans to 2050 under yield scenarios of (1) additional authorizations for GE grain seeds (affecting corn and soybeans only), and (2) without GE authorization (status quo moderate yield growth). Under the GE scenario, yields would essentially double for corn and soybeans by 2050. Under the status quo, they would increase by about 62 percent by 2050, with wheat increasing by about 60 percent. These projections are based on annual yield growth rates of 1.9 percent for corn, 1.7 percent for wheat, and 2.1 percent for soybeans. Additionally, the authors made important assumptions about the adoption of GE technologies for *Bacillus thuringiensis (Bt)* corn and herbicide-tolerate (HT) soybeans based on C. James (2018) and using adoption curves over a 15-year time horizon from table 2. Adoption occurs between the years 2024 and 2039 and sets at the maximum of 95 percent of the total area harvested for *Bt* corn and 73 percent for HT soybeans between 2040 and 2050. The authors were careful to validate potential yield gains over time by examining actual global yields for corn and soybeans in select countries that have adopted GE technologies, covering the era when biotechnology became widely used. Figure A.7 shows these yields over time between 1973 and 2023 for both corn and soybeans and highlights the biotechnology adoption era. The United States and Argentina have experienced some of the highest corn yields in recent years (11 metric tons per hectare and about 8 metric tons per hectare, respectively).

Figure A.7

**Five-year moving average corn and soybean yields during the biotechnology adoption era in select countries: Argentina, Brazil, China, India, South Africa, and the United States, 1977–2023**




Source: USDA, Economic Research Service based on data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

Table A.4 further analyzes these yields by calculating the percentage change in yield between the 1997–99 average and 2021–23 average. Changes between these two periods for corn (and therefore yield growth) was highest for Brazil and South Africa—two countries that also moved to adopting *Bt* corn at a rapid pace. While India almost doubled its corn yields (by 95 percent), this was due to an initial low average yield of only 1.8 metric tons per hectare in the 1997–99 period.

Table A.4
**Targeted yields for corn, soybeans, and wheat by 2050 (metric tons per hectare)**

| | Corn | | | Soybeans | | | Wheat | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1997-99 | 2021-23 | Percent change (24 years) | 1997-99 | 2021-23 | Percent change (24 years) | 1997-99 | 2021-23 | Percent change (24 years) |
| a) Current yields | | | | | | | | | |
| Argentina | 5.7 | 6.7 | 18.6 | 2.6 | 2.5 | -2.5 | 2.6 | 2.8 | 8 |
| Brazil | 2.6 | 5.7 | 117.8 | 2.5 | 3.4 | 36.0 | 1.7 | 2.9 | 70 |
| China | 4.9 | 6.4 | 31.8 | 1.8 | 2.0 | 10.9 | 3.9 | 5.8 | 49 |
| South Africa | 2.5 | 5.6 | 127.2 | 1.6 | 2.4 | 49.3 | 2.2 | 4.0 | 84 |
| United States | 8.3 | 11.0 | 33.6 | 2.6 | 3.4 | 32.6 | 2.8 | 3.1 | 11 |
| India | 1.8 | 3.5 | 95.3 | 0.9 | 0.9 | -1.8 | 2.6 | 3.5 | 35 |
| | 2021-23 | 2050 | Percent change (26 years) | 2021-23 | 2050 | Percent change (26 years) | 2021-23 | 2050 | Percent change (26 years) |
| b) Targets for India to 2050 | | | | | | | | | |
| Conv. | 3.5 | 5.6 | 62.2 | 0.9 | 1.5 | 61.9 | 3.5 | 5.6 | 60.8 |
| With GE | 3.5 | 6.9 | 100.0 | 0.9 | 1.9 | 100.0 | 3.5 | NA | NA |

GE = genetic engineering. NA = not applicable. Conv. = base conventional technologies.

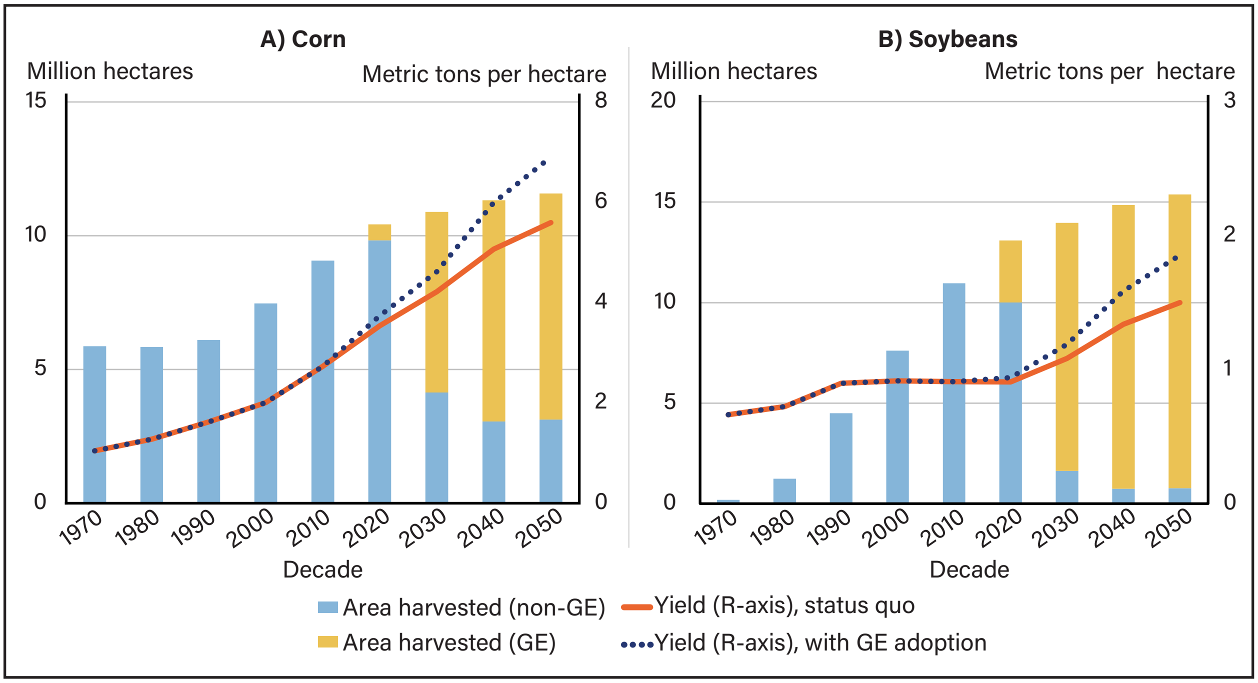
Note: The percent change (24 years) represents the difference from 1997–99 to 2021–23. The percent change (26 years) represents the difference from 2021–23 to 2050.

Source: USDA, Economic Research Service using data on current yields from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

Table A.4 also enables some important assumptions about how yields will be affected by the adoption of GE corn and soybeans. The table compares this with current or conventional technologies (Conv.), which are calculated by assuming yields will continue growing at a pace close to what they achieved over the past decade (as status quo). As noted earlier, yields under GE technologies for corn and soybeans are doubled by 2050, which is reasonable when compared to yields achieved in other countries adopting GE technologies (e.g., Brazil and South Africa) in figure A.8. The increase the authors impose on soybeans, however, is likely too high because yields do not typically increase as much with HT soybean adoption (i.e., not more than 50 percent during the 1990s and 2000s). However, the authors chose to maintain the 100-percent increase due to the current very low yields in India (0.9 metric tons per hectare).

Figure A.9 shows the final growth and allocation of area harvested under both conventional (non-GE) and GE technology scenarios and yields achieved under conventional technologies (status quo) and with GE adoption for corn and soybeans.

Figure A.8
**Assumed corn and soybean yields and area harvested under non-GE and GE varieties to 2050**




GE = genetically engineered.

Source: USDA, Economic Research Service model results and calculations with base data sourced from USDA, Foreign Agricultural Service, Production, Supply, and Distribution.

Table A.5 summarizes the final resulting yields by scenario and area harvested for all three commodities. The authors maintained the same assumed growth rates in areas harvested across the two yield scenarios (status quo and with GE), allowing the rate to only grow very marginally for corn and soybeans while remaining almost fixed for wheat (growing by only 4 percent between the 2020s and 2050). To ensure growth in the area harvested is reasonable, the authors limited the share to total arable land available across the three crops in the analysis, which rose slightly from 35.7 percent to 40.3 percent by 2050. They also assumed there might be some substitution taking place between crops as demand for corn and soybeans (in particular) outpace other crops because total arable land available is expected to decline over time.

Table A.5

**Average assumed yields and area harvested by decade, actual prior to 2024 and projected for 2024–50**

| Commodity/ Scenario | Average values by decade | | | | | | | | | Percent change |
|---|---|---|---|---|---|---|---|---|---|---|
| | Actual | | | | | Predicted | | | | |
| | 1970s | 1980s | 1990s | 2000s | 2010s | 2020s | 2030s | 2040s | 2050 | 2020s to 2050 |
| 1. Corn yield (mt/ha) | | | | | | | | | | |
| Status quo | 1 | 1.3 | 1.6 | 2 | 2.7 | 3.5 | 4.2 | 5.1 | 5.6 | 58.2 |
| with GE | | | | | | 3.4 | 3.3 | 3.3 | 3.2 | -4.6 |
| 2. Wheat yield (mt/ha) | | | | | | | | | | |
| Status quo | 1.4 | 1.9 | 2.4 | 2.7 | 3.1 | 3.6 | 4.3 | 5.1 | 5.6 | 54.2 |
| 3. Soybean yield (mt/ha) | | | | | | | | | | |
| Status quo | 0.7 | 0.7 | 0.9 | 0.9 | 0.9 | 0.9 | 1.1 | 1.3 | 1.5 | 65.1 |
| with GE | | | | | | 0.9 | 1.2 | 1.6 | 1.9 | 96.9 |
| 4. Area harvested (million ha) | | | | | | | | | | |
| All scenarios | | | | | | | | | | |
| Corn area | 5.9 | 5.8 | 6.1 | 7.5 | 9.1 | 10.5 | 11.1 | 11.8 | 12.2 | 16.6 |
| Wheat area | 20.2 | 23.2 | 25.1 | 26.8 | 29.9 | 31.4 | 31.9 | 32.4 | 32.7 | 4.1 |
| Soybean area | 0.2 | 1.2 | 4.5 | 7.6 | 11 | 13.1 | 14 | 14.9 | 15.4 | 17.5 |
| Total (all 3) | 26.3 | 30.3 | 35.7 | 41.9 | 50 | 54.9 | 57 | 59.1 | 60.3 | 9.7 |
| Arable land | 162.2 | 163.2 | 162.1 | 159.3 | 156.3 | 153.8 | 152.1 | 150.4 | 149.4 | -2.9 |
| Percent of arable | 16.2 | 18.5 | 22 | 26.3 | 32 | 35.7 | 37.5 | 39.3 | 40.3 | 4.6 |

GE = genetic engineering. mt/ha = metric tons per hectare.

Note: For wheat, the authors assumed a slight improvement from other technology or crop management interventions. GE only affects corn and soybeans.

Source: USDA, Economic Research Service calculations using data from USDA, Foreign Agricultural Service, Production, Supply, and Distribution for current yield (to 2023) and the authors' projections (2024–50) based on past trends and the yield performance of other countries that adopted GE technologies for corn and soybeans (e.g. South Africa and Brazil).