Nextgen technologies for a progressive food processing sector

May 2025

Foreword by ASSOCHAM

Manish Singhal
Secretary General
ASSOCHAM

India's journey towards becoming a developed and self-reliant economy – Viksit Bharat – is being closely shaped by the transformation of its food processing ecosystem. The vision of proactive and sustained effort is regarded to be highly relevant to the evolving landscape of India's food processing sector – an industry recognised both as a key economic driver and a vital link between agriculture and the nation's nutritional needs.

Functioning as a crucial conduit between the farm and the consumer, the sector is recognised for its significant potential in minimising post-harvest losses and strengthening food security, and also in driving value addition and enhancing export capabilities. Realising this potential, however, necessitates further innovation.

The era of Industry 4.0 is being recognised as a pivotal moment to reimagine food processing through the integration of advanced technologies. Technologies such as AI, blockchain, IoT and data analytics are no longer futuristic – they are increasingly being adopted as a standard practice. Through their implementation, food systems are being transformed into smarter, more efficient and sustainable models that are better aligned with market demands, and enhance traceability, uphold safety standards and reduce environmental impact.

The opportunities and barriers associated with the adoption of nextgen technologies across India's food processing value chain are highlighted in this knowledge paper. We've presented insights that are both practical and forward-looking, and based on a comprehensive review of policy frameworks and implementation models.

The urgency of enabling technology adoption is underscored in this paper, with emphasis placed on the need for a coordinated effort involving R&D institutions, industry leaders, startups and policymakers. The significance of digital infrastructure, streamlined regulations, capacity enhancement and incentive mechanisms is highlighted as essential for making innovation both accessible and scalable – particularly for MSMEs and rural enterprises.

We're glad to have partnered with PwC, with their technical expertise and analytical contributions having played a significant role in the identification of scalable solutions for a technology-driven transformation of the sector. A roadmap to guide future policy action and industry collaboration has been developed through their involvement.

As we consider the way forward, the need to adopt an inclusive and collaborative approach is increasingly emphasised. A global competitive food processing industry, capable of fulfilling domestic needs while positioning India as global leader in food innovation and sustainability, can be built through cross-sectoral and interdisciplinary cooperation.

Let us embrace this moment to turn challenges into opportunities for growth and ensure that the future of India's food processing sector is shaped by intelligence, innovation and meaningful impact.

Foreword by ASSOCHAM

Vivek Chandra
Chairman – Food Processing and Value Addition Council
ASSOCHAM
and CEO – Global Branded Business
LT Foods

With India on the verge of becoming a global economic force, the food processing sector is emerging as a strategic enabler of its growth agenda. This sector is instrumental in addressing food security challenges as well as driving the sustainable economic progress across regions.

India's food processing sector is undergoing a transformation, with technology as a catalyst for the change. In an era where innovation has become a mandate, the sector is leveraging cutting-edge tools like automation, digital solutions and data analytics. Doing so enhances the efficiency of food production processes while improving the quality of the product, reducing wastage and ensuring the sustainability of the entire value chain.

Being a leader in the global food processing landscape, it becomes vital to identify the interdependence of our agricultural systems, production practices and technological evolution. Opportunities are being unlocked through the inclusion of nextgen technologies like AI, IoT and blockchain into food processing operations, enabling enhanced traceability, improved food safety standards and empowerment of businesses in order to meet the growing demand for high-quality, nutritious and sustainable food products.

However, the growth of this sector is not without its challenges. To ensure operations can be scaled effectively, a supportive policy framework, access to modern infrastructure and a focus on capacity building are essential. Inclusive growth can be fostered by empowering small-scale producers and rural enterprises through digital tools and technology, thereby benefiting the entire supply chain.

In this context, the invaluable collaboration with PwC is gratefully acknowledged, with their expertise in market analysis and strategic insight having been instrumental in shaping a practical roadmap for a future-ready food processing sector. Actionable solutions and frameworks that can drive industry-wide transformation have also been identified.

As we move forward, the combination of innovation and sustainability is essential to ensure that the food processing industry remains agile, competitive and well-equipped to meet both domestic and global demands. The adoption of emerging technologies, along with the collaboration among all stakeholders, is vital to the development of a resilient, globally competitive and future-forward food processing sector.

Taking decisive steps now will pave the way for a prosperous and food-secure tomorrow.

Foreword by PwC India

Shashi Kant Singh
Partner – Agriculture and Food Sector
PwC India

India's food processing sector has been growing steadily and is poised to double its size by 2030. The sector has been playing a crucial role in maintaining a balance between diverse production and consumption trends and ensuring food and nutritional security.

As per the FAO, global food loss and wastage is estimated to be about USD 936 billion annually.[1] Further, a World Bank report estimates that foodborne illnesses cost USD 110 billion annually, in lost productivity and illness expenses.[2] Here, technological innovations across processing, storage and distribution are expected to largely overcome these barriers and pave the way for favourable outcomes for producers, processors and consumers alike.

The government has made substantial investments to tackle the issue of food security and safety by enhancing food processing capabilities in our country. Initiatives such as Pradhan Mantri Kisan Sampada Yojana (PMKSY) and the Pradhan Mantri Formalization of Micro Food Processing Enterprises (PMFME) aim to create a modern infrastructure for food processing, thus minimising wastage and formalising the food processing sector.

The advancements across ML, AI, IoT, blockchain, robotics and automation are reinventing the way food is handled and processed, presenting a huge opportunity in the market. Therefore, concerted efforts can be made towards generating awareness and enhancing access for stimulating the large-scale adoption of these Industry 4.0 technologies.

We're pleased to collaborate with ASSOCHAM for this report, wherein we've presented a comprehensive industry analysis, underscoring actionable insights for the entire spectrum of stakeholders. The synergies across industry, research institutions and academia, and startups driven by a supportive policy environment and infrastructural advancements, will greatly help actualise this transformation towards making this sector more vibrant and globally competitive.

1. https://openknowledge.fao.org/server/api/core/bitstreams/ba2a1df9-5adb-41c2-85db-c223fb391412/content
2. https://www.worldbank.org/en/news/press-release/2018/10/23/food-borne-illnesses-cost-us-110-billion-per-year-in-low-and-middle-income-countries

Executive summary

The global food system is a comprehensive network comprising production, processing, distribution and consumption. Such a system is essential to ensure food safety and security while carefully complementing natural resource conservation and mitigating critical environmental concerns. Since 2000, the worldwide food production has increased by 56%.[3] The global food system is greatly influenced by several factors – government policies, environmental and economic factors, and climate change which determines the availability, accessibility and nutritive value of sustenance. However, food production's growth is not the same everywhere and per capita food availability varies across the world. Food scarcity remains a challenge due to unmitigated post-harvest losses, insufficient processing infrastructure, inept distribution and storage systems.

Worldwide food wastage accounts for one-third of all food produced.[4] Additionally, farm productivity showcases an estimated 56% gap between 2010's crop calories and the requirement by 2050, which could be further impacted due to soil degradation, water scarcity and other factors due to climate change.[5] As the global population crosses 8.2 billion in 2025, food demand could impact resource management of production systems.[6] Food safety is one of the major challenge of food systems, with ~USD 110 billion annual foodborne diseases cost for low- and middle-income countries.[7] The processing sector, though highly promising, requires various government policies and initiatives to promote food security and reduce food wastage. Other stakeholders should complement these efforts through technological investments and innovation and adapt to the changing market landscape.

The national food processing market is expected to reach USD 700 billion by 2030.[8] The aim of this industry is to enhance raw produce through sorting, grading, processing and packaging which ultimately caters to the consumption needs for the general populace, indicating significant growth potential in terms of industry coverage. The dynamic market trends of every industry are evolving, and the food processing sector must also adapt to the focus on sustainable sourcing, decreasing environmental effect and ensuring food security. Industry 4.0 technologies like AI, ML, IoT, augmented reality (AR) and blockchain have led to a technological revolution in food processing sector. Standardisation of quality, measurements and processing

3. https://openknowledge.fao.org/server/api/core/bitstreams/fba4ef43-422c-4d73-886e-3016ff47df52/content
4. https://www.fda.gov/food/consumers/food-loss-and-waste
5. https://www.wri.org/insights/how-sustainably-feed-10-billion-people-2050-21-charts
6. https://news.un.org/en/story/2024/07/1151971
7. https://www.worldbank.org/en/news/press-release/2018/10/23/food-borne-illnesses-cost-us-110-billion-per-year-in-low-and-middle-income-countries
8. https://www.ibef.org/industry/food-processing

environment can be ensured by automated systems. Industry 4.0 tools can help enhance the safety and hygiene of food by minimising human intervention and enhancing the speed of production pipelines. AI can be used to monitor food processing variables for effective machine performance and default alerts for maximum efficiency and consistent processed output. Additionally, when combined with AI, ML can be used to optimise inventory management, route planning, demand forecasting and chalk machine maintenance requirements. IoT can also play a fundamental role in the sector for real-time monitoring and controlling food quality. Blockchain technology can help in enhancing the transparency of supply chain operations, reduce lags and minimise fraudulent transactions which can help in compliance management. Furthermore, adopting energy-optimising machinery can significantly reduce carbon footprints. While the potential for adopting Industry 4.0 technologies in the food processing sector holds great promise for enhancing effectiveness, efficiency and food quality, such transition is often dependent on various economic, policy and operational scenarios related to initial seed costs, payback duration and market acceptance. Further, the industry is facing a shortage of skilled workers, cybersecurity risks along with the problem of integrating legacy equipment with new technologies, which can further impact the digitisation of the food processing industry.

Policy enablers can act as a stimulant for the adoption of advanced technologies through standardised regulations and compliance, leading to enhanced market entry and expansion. Considering these scenarios, through sustainable investments and practices and technological solutions, is essential for developing a robust food processing sector for a more sustainable food landscape. Government initiatives could play a crucial role by offering a conducive ecosystem for innovation and growth through financial aid, infrastructure development, market access and various other policy support. Key government schemes, startups which leverage public-private partnerships (PPPs) and emerging trends in venture capital funding are driving the adoption of nextgen technologies in the food processing sector. These technologies can address waste reduction and pave the way for a more resilient and sustainable food system.

Table of contents

01 Introduction

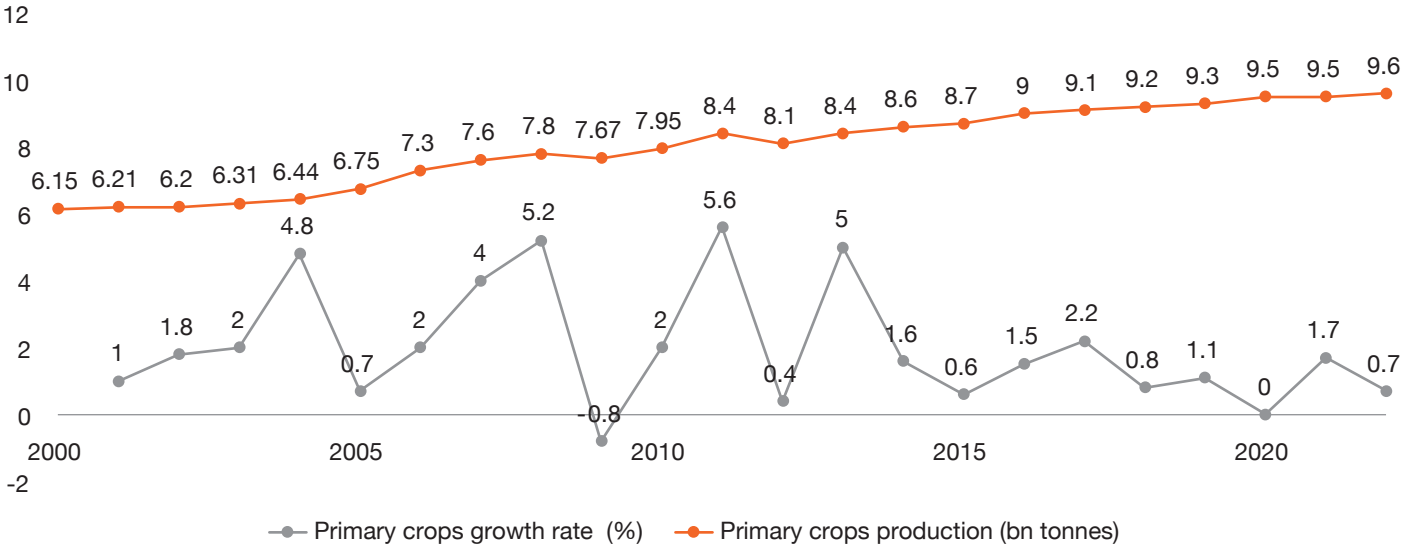
Global food systems

The global food system is a comprehensive network of production, processing, distribution and consumption systems. Factors like increasing population, technological development and socio-politico-economic dynamics are shaping this evolving system.

Harvesting progress: The importance of food processing

According to Food and Agriculture Organization (FAO), there has been a 56% increase in food production since 2000.[9] Food processing plays the crucial role of balancing the interdependence of post-production processing, storage and distribution to ensure the availability of quality food for consumption.

Figure 1: World crop production volumes and growth



Sources: https://ipad.fas.usda.gov/rssiws/al/global_cropprod.aspx; https://openknowledge.fao.org/server/api/core/bitstreams/58971ed8-c831-4ee6-ab0a-e47ea66a7e6a/content

9. https://openknowledge.fao.org/server/api/core/bitstreams/fba4ef43-422c-4d73-886e-3016ff47df52/content

According to a report, the current value of the global food processing market is around USD 10 trillion (2025).[10] This is driven by urbanisation, changing dietary preferences, technological advancements and an increase in global population. Despite this, food scarcity persists in many areas due to high post-harvest losses, limited processing infrastructure, poor distribution and storage issues. Further, efforts are needed to minimise nutrient loss and environmental impacts of processed food. This underscores the need for innovative approaches in post-harvest management, food processing and distribution to ensure sustainable management of the rising food demand in a resource-constrained environment.

Feeding the future generations: Population growth and per-capita food availability

As the global population increases due to longer life spans and decreasing mortality rates, the pressure on food systems also increases. According to the UN, the world population will reach 9.8 billion by 2050,[11] from 8 billion (2022).[12] These figures highlight the need for more effective and efficient food production, processing, storage and distribution systems.

10. https://www.pwc.com/gx/en/issues/business-model-reinvention/how-we-feed-ourselves/reconfiguring-global-food-system.html
11. https://www.un.org/en/development/desa/population/events/pdf/other/21/21June_FINAL%20PRESS%20RELEASE_WPP17.pdf
12. https://population.un.org/dataportal/home?df=c451a24f-99d0-4370-99c3-87f3a4b16ce0

Table 1: Daily per capita supply of calories vs GDP per capita 2022

Countries	Calorific supply (Kcal per day)	GDP per capita in 2022 (in USD)
Luxembourg	3,453	137,059
Ireland	3,844	124,991
Switzerland	3,432	83,007
US	3,875	72,842
India	2,574	8,545
Myanmar	2,829	5,350
Nepal	3,013	4,763
Syria	2,351	4,455
DR of Congo	2,079	1,385

Source: https://ourworldindata.org/grapher/daily-per-capita-caloric-supply

Countries with better economic prosperity enjoy higher daily caloric intake, ensuring better food security and nutrition. Conversely, developing nations often face food insecurity and malnutrition, highlighting the need for targeted interventions to bridge this disparity and create a more equitable and sustainable global food landscape.

Figure 2: Snapshot of the top five agricultural exporters

USD 176 bn

US

Largest exporter of food specialising in soybeans, corn, meat and dairy products

USD 103 bn

China

Leading exporter of chicken, eggs, fruits, vegetables, grains and cotton

USD 153 bn

Brazil

Major exporter of soybeans, sugar, coffee and beef

USD 139 bn

Netherlands

Major exporter of dairy, meat and vegetables

USD 48 bn

India

Major exporter of rice, wheat and pulses

Sources: https://www.fas.usda.gov/data/trade-spotlight-us-agricultural-exports-close-2024-on-strong-note;

https://www.cbs.nl/en-gb/news/2025/03/value-of-agricultural-exports-up-by-nearly-5-percent-in-2024

https://www.gov.br/agricultura/en/news/brazilian-agribusiness-exports-surpass-usd-153-billion-in-2024;

https://www.statista.com/statistics/1200541/chinas-export-value-of-agricultural-products/;

https://www.ibef.org/exports/agriculture-and-food-industry-india%20

Substantial export values of major countries highlight their role in food processing systems while the less prosperous regions emphasise the need for targeted interventions to improve food systems. Therefore, it is important to build a comprehensive food processing facility and invest in developing cutting-edge mechanisms to bridge the gap in supply across the globe.

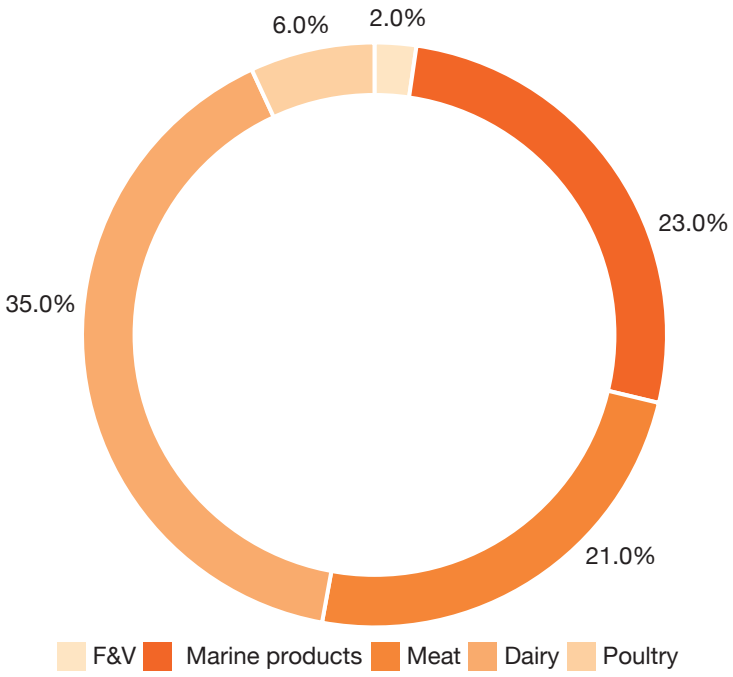
Current landscape of domestic food systems

India has emerged as one of the key players in the food landscape. Known for its diverse agri-climatic zones, India is the largest producer of milk, pulses and spices, and the second-largest producer of rice and wheat. The country's focus is on increasing productivity, minimising food loss and adapting to challenges arising from natural resource

constraints and global trade economics. Enhancing food processing capabilities by adopting innovative technologies to improve efficiency, extend shelf life, reduce waste, ensure food safety and address nutritional requirements are crucial for managing the demands of a growing population. The demand for food continues to rise, with the annual per capita availability of food grains increasing from 183.1 kg in 2019-20[13] to 207.6 kg in 2022-23.[14]

The national food processing market is growing at a CAGR of 7.3% (2015–22).[15] Various sub-sectors which encompass the food processing sector are fruits and vegetables, dairy, poultry and meat, fisheries and other marine species, grains, spices, nutraceuticals, ready-to-cook (RTC), ready-to-eat (RTE) and ready-to-serve (RTS) foods.

Figure 3: Food processing sub sectors in India, 2019



Source: https://www.mofpi.gov.in/sites/default/files/OpportunitiesinFoodProcessingSectorinIndia.pdf

India's diverse population and landscape contributes to the varied food consumption patterns of the country. The shift in preference of processed and convenient foods can be attributed to the rapid increase in urbanisation, enhanced disposable income and changing lifestyles of people. The food consumption pattern diversity across both rural and urban areas in India

13. https://sansad.in/getFile/annex/259/AU243.pdf?source=pqars
14. https://www.statista.com/statistics/1050931/india-annual-availability-of-food-grains-per-capita/
15. https://www.ibef.org/industry/food-processing

showcases numerous advantages for the food processing industry. However, processed food may lack nutritional value and micronutrients. Challenges like malnutrition persist among the vulnerable population of the country despite the government's intervention through planned initiatives. Therefore, advancements in the food processing sector should focus on improving food quality while ensuring that nutritional balance and accessibility are maintained for everyone, everywhere. The process of transforming raw agricultural produce into safe consumable goods is a tremendous task since the focus of such processes should be on increasing the shelf life, enhancing the safety of the processed food items and ensuring optimal nutritional value. At the national level, efficient post-harvest management, food processing, increasing the shelf life, enhancing the nutritional profile, storage, logistics and distribution, and waste reduction should be prioritised.

Challenges

The impact of rising population, decreasing agricultural productivity and food wastage

According to a report, the global worldwide population will grow beyond 8.2 billion people in 2025.[16] Due to this increase in the population, the demand for food, water and energy will increase, which could further impact the natural resource reserves. With an arable land per capita of approximately 0.11 hectares (1,100 square meters), India is just over half of the global average of arable land per capita of about 0.18 hectares (1,800 square meters).[17] This underscores the need to manage food production and processing in a sustainable manner, while minimising waste.

Table 2: Nationwide arable land per capita Ha, 2021

Regions/nations	Arable land per capita (Ha)
Oceania	1.22
North America	0.53
South America	0.24
Europe	0.22
Sub-Saharan Africa	0.19
India	0.11

Source: https://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC?locations=IN

16. https://news.un.org/en/story/2024/07/1151971
17. https://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC?locations=IN

Various factors like soil degradation, scarcity of water and drastic weather changes stemming from climate change impact agricultural productivity. Sustainable practices and new technologies can improve agricultural productivity and minimise post-production food waste. According to a WHO report, over 800 million people are affected by malnutrition.[18] Global food wastage has resulted in loss of USD 1 trillion annually, as per the World Food Programme.[19]

Regional disparities provide great insights on the food loss patterns where developed countries suffer from ill-managed consumption while developing countries suffer from post-harvest management, including logistics and storage. If such challenges could be mitigated with proper ideation, execution and management of other food waste causing actors, we can feed an additional 2 billion people by 2050.[20]

Food safety

Food safety is an important aspect of food security. A report from World Bank estimates that an approximate cost of USD 110 billion was borne by low- and middle income countries due to foodborne diseases.[21] Several products which mimic traditional foods but are made using non-traditional ingredients or analogue products hinder food safety. Mislabelling also remains a problem of analogue products. Such public health risks can only be mitigated through stringent compliance measures and increasing the awareness of the consumers.

As stated by the FDA, 0.15% of India's food export rejection (2019-2023) has been recorded to be higher compared to other major agriculture exporters like China (0.022%) and Mexico (0.025%).[22] Such instances of export rejections highlight the need for standardisation and implementation of compliance and regulatory norms along with safety assessments to ensure public health safety.

Government and industry responses

To support the food processing sector and address food security, public health and environmental stability, various policies and programmes have been implemented by governments across the globe. In the US, food safety through preventive controls is ensured through the Food Safety Modernization Act (FSMA). Grants and loans are provided for food processing infrastructure and innovation through such initiatives of United States Department of Agriculture (USDA). The Meat and Poultry Processing Expansion Programme is one of the notable success stories as it has helped in the expansion of processing capacity, which in turn has created jobs, and lowered food costs. In 2020, USDA's Food Recovery Challenge effectively reduced food waste, with participants mitigating 1.2 million tonnes of food waste from landfills.[23] The Federal

18. https://iris.who.int/bitstream/handle/10665/66505/WHO_NHD_00.7.pdf
19. https://www.wfp.org/stories/5-facts-about-food-waste-and-hunge
20. https://www.census.gov/popclock/world
21. https://www.worldbank.org/en/news/press-release/2018/10/23/food-borne-illnesses-cost-us-110-billion-per-year-in-low-and-middle-income-countries
22. https://indianexpress.com/article/business/economy/indias-us-food-exports-refusal-rate-7-times-higher-than-chinas-8994168/
23. https://www.epa.gov/sustainable-management-food/food-recovery-challenge-results-and-awardees

Ministry of Food and Agriculture (BMEL) Germany, has introduced a notable initiative' where sustainability and innovation in the food processing industry is encouraged for research and development projects. One of the main themes of this aid revolves around renewable energy use, which helps reduce the environmental footprint of food processing. Tax incentives attract investment, improving food security and reducing wastage. Several initiatives of food processing sector that target both large-scale enterprises and micro, small and medium enterprises (MSMEs), have also been implemented and propagated by the Government of India. Pradhan Mantri Kisan Sampada Yojana (PMKSY) with sub schemes like Mega Food Parks, Operation Greens, among others, and the Pradhan Mantri Formalization of Micro Food Processing Enterprises (PMFME) are few of the prominent initiatives which aim to create modern infrastructure for food processing, formalise the organised processing sector and encourage waste reduction.

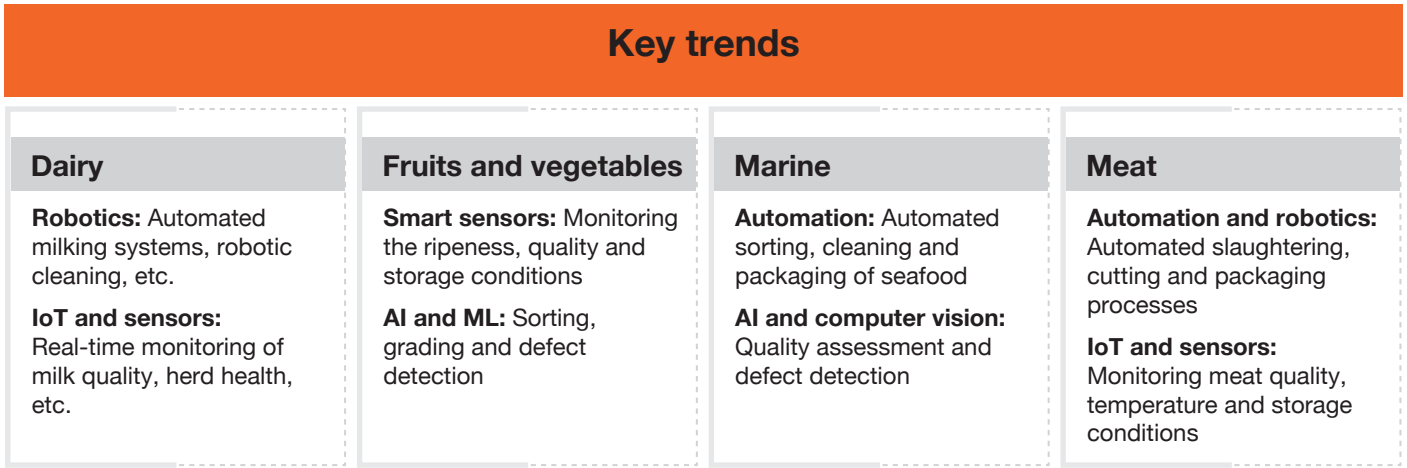
Innovation and ideation are fostered by comprehensive stakeholder collaborations between the government, private sector and research institutions. Different investments in modern edge technology for contamination detection, risk modeling and supply chain optimisation have been adopted by many organisations to enhance food safety and reduce waste. Environmental concerns are being managed through sustainable practices, such as using renewable energy and reducing carbon footprint. The scope and potential for growth in the food processing sector is immense, and it is important to address critical issues of food systems and processing sector while also highlighting remaining gaps and opportunities.

Key technological trends in food processing

Industry 4.0 technologies have been indispensable in accelerating the efficiency of food processing through waste reduction, quality enhancement and operational improvements. When it comes to optimising production processes and augmenting quality, AI and ML are indispensable for identifying data anomalies and deviations from standard parameters and helping in real-time adjustments. AI and ML are proficient in predicting failure in processing equipment which helps in maintenance cost and downtime reduction. Inventory management, demand forecasting and route optimisation are imperative in supply chain management, wherein AI and ML can stimulate efficient delivery of food products and lower wastage. Another technology which is important in the food packaging industry is robotics and automation. Additionally, repetitive tasks like slicing and dicing can also be managed by robots for consistent accuracy.

Real-time monitoring and food processing operations' control can be managed by IoT, considering physical parameters like temperature, pressure, humidity, smart sensors , in order to monitor optimal conditions for food safety and quality. In food processing facilities, Industry 4.0 technologies implementation can help improve productivity, maintain high standards of quality and ensure product safety. Blockchain can be used for enhancing traceability, providing consumers with better knowledge regarding the origin and pipeline of their food.

Figure 4: Sectorial key technological trends and application in the food processing industry



02

Challenges in the food processing industry

One of the cornerstones of India's economy is the rising food processing sector. The industry has been making substantial contributions at every stage of the production supply chain, from post-harvest handling to the finished products for consumer partaking. With a gross value added (GVA) contribution of 10.54% in manufacturing and 8.39 11.57% in agriculture (FY20-21), the food processing industry has been playing a crucial role in the national economy and its upliftment, as per an IBEF report.[24] Raw materials are processed for value enhancement and undergo grading, processing, packaging and branding processes to deliver a final product for the consumer.

Concerns related to advanced equipment, technology compatibility and supply chain related issues such as limited cold storage and processing facilities still persist. Financial constraints, regulatory and policy duplications, and skilled workforce shortage also add to the same.

According to a report, around 2% of fruits and vegetables (F&V), 35% of milk (dairy) and 6% of poultry are covered for processing.[25] This highlights the vast potential for food processing industry in India. New market trends and changing consumer preferences such as demand for plant-based foods and balanced food services also provide an opportunity for the industry to grow and diversify its operations.

Challenges related to processing and packaging

Acquiring and optimising raw materials is one of the key challenges in the food manufacturing industry. The process involves selecting quality raw materials in adequate amounts and utilising them optimally to minimise food waste and additional costs. The uniform application of processing, stabilisation and preservation treatments are essential to maintain product quality and safety after the raw materials are secured. According to a WHO report, nearly 4,20,000 deaths were recorded worldwide due to foodborne illnesses annually.[26]

24. https://www.ibef.org/industry/food-processing
25. https://www.mofpi.gov.in/sites/default/files/OpportunitiesinFoodProcessingSectorinIndia.pdf
26. https://www.who.int/news-room/fact-sheets/detail/food-safety

Table 3: Country/region wise annual cases and deaths due to foodborne illnesses

Country/region	Annual cases of foodborne illnesses (million)	Annual deaths
Southeast Asia (including India)	150	1,75,000
Africa	91	1,37,000
America	77	9,000
Europe	23	4,700

Sources: https://www.who.int/india/health-topics/food-safety;
https://time.com/4133193/foodborne-illness-children-food-safety/;
https://www.paho.org/en/news/7-6-2022-panaftosa-states-foodborne-diseases-can-be-avoided-preventive-actions-along-farm;
https://www.who.int/news/item/05-06-2019-23-million-people-falling-ill-from-unsafe-food-each-year-in-europe-is-just-the-tip-of-the-iceberg

Diverse food laws, labeling requirements and food safety standards should be standardised and monitored to ensure the safety of the consumers. According to WHO, unsafe food results in approximately USD 110 billion in annual productivity losses and medical expenses for low- and middle-income countries.[27]

Another significant challenge is the high energy and water usage during processing. Food processing often demands substantial amounts of energy and water, leading to high operational costs and environmental impact.

27. https://www.who.int/news-room/fact-sheets/detail/food-safety

Table 4: Freshwater withdrawals per kilogram of food product

Produce	Freshwater withdrawals (litre)
Cheese	5,605
Nuts	4,134
Fish (farmed)	3,691
Rice	2,248
Poultry meat	660
Apples	180

Source: https://ourworldindata.org/water-use-stress

Packaging wastage, especially non-biodegradable plastics, further complicates the situation. According to the US Environmental Protection Agency, the US generated 35.7 million tonnes of plastics in 2018, representing 12.2% of the total municipal solid waste.[28] The largest portion of this plastic waste came from the containers and packaging category, which accounted for over 14.5 million tonnes.[29] To address this, the sustainable packaging market, known for its environmentally friendly solutions, is expected to grow significantly, which can further contribute to the growth of the food processing industry.

Supply chain inefficiencies

According to the United Nations Environment Program, poor logistics planning and market inefficiencies account for considerable global food waste. Addressing inefficiencies in the supply chain is crucial for reducing food wastage and improving the timely distribution of food products across India.

India loses approximately INR 1.53 trillion worth of agricultural produce annually due to post-harvest losses. These losses occur throughout the food production and supply process, mainly due to inadequate storage infrastructure, inefficient supply chain management and poor transportation facilities.[30]

It is important to enhance the cold storage facilities for preserving the freshness and quality of perishable goods. The development of cold storage needs to extend beyond storage facilities and warehouses to include logistics and distribution services as well. Effective temperature control plays a key role in ensuring the freshness and quality of the product upon its arrival to the customer. However, this aspect of cold chain logistics presents unique challenges due to various factors such as inadequate infrastructure, unreliable electricity supply and the need for advanced refrigeration systems.

28. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
29. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
30. https://krishijagran.com/blog/post-harvest-losses-in-indian-agriculture-a-hidden-challenge-with-far-reaching-impacts-causes-impacts-and-solutions/

Optimising inventory levels is key to balancing demand and supply. Poor inventory management like over-ordering, improper storage or expired inputs leads to significant raw material wastage. Technologies such as IoT sensors and AI/ML forecasting models are being piloted by Indian companies to improve real-time visibility and decision-making.

Disruptions due to geopolitical tensions and climate events further complicate supply chain management. The United Nations Framework Convention on Climate Change (UNFCCC) reports that food loss and waste account for 8–10% of annual global greenhouse gas emissions, costing around USD 1 trillion annually.[31]

Changing market and consumer trends

In India, the ultra-processed foods (UPF) sector grew at a CAGR of 13.37% in retail sales from 2011 to 2021.[32] However, the consumption of UPFs is linked to various health issues. A study of over 10,000 food and beverage products revealed that about 68% contain excess salt, sugar or saturated fats.[33] This underscores the need for healthier alternatives, reducing the reliance on ultra-processing methods. The shift in preference is driven by increasing health concerns and the shift in the choice of the consumers who now prefer healthy alternatives.

There is also a significant rise in the demand for plant-based alternative proteins.

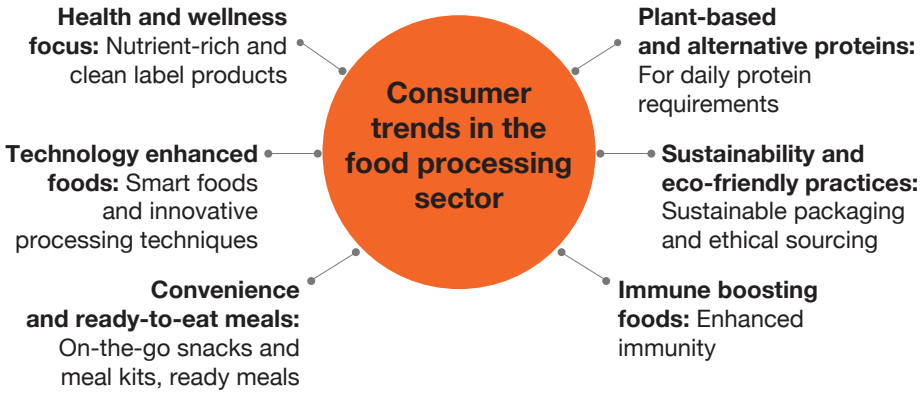
One of the most important factors which is driving the consumer preference is sustainable packaging solutions and ethical ingredient sourcing. The clean label food market has been estimated to grow at a rate of 7.5% (2020–25), driven by a preference for health-oriented and sustainable products.[34]

The consumption of immune boosting foods is also on the rise. These food products are being marketed to address various health concerns, reflecting a proactive approach to health and wellness beyond the dependency on pharmaceutical supplements.

Smart foods are revolutionising the food industry. These smart foods are developed using innovative processing techniques that not only enhance the shelf life of food but also increase their nutritional value.

31. https://unfccc.int/news/food-loss-and-waste-account-for-8-10-of-annual-global-greenhouse-gas-emissions-cost-usd-1-trillion
32. https://icrier.org/pdf/Ultra%20Processed%20Food%20-Policy-brief.pdf
33. https://health.economictimes.indiatimes.com/news/policy/68-of-indian-ultra-processed-food-products-have-excess-salt-sugar-study/88047674
34. https://agronfoodprocessing.com/riding-the-clean-label-wave/

Figure 5: Consumer trends in the food processing sector



03

Potential of nextgen technologies and opportunities

The food processing industry is rapidly adopting new technologies and innovative approaches. By addressing critical challenges and paving the way for a more efficient, sustainable and consumer-oriented industry, these advancements in technology are desirable to transform the food processing sector.

Technologies such as smart sensors, robots and IoT, which can significantly enhance precision and safety in food processing, improve operational efficiency, reducing waste, and ensure product quality. By adopting hybrid approaches that include automation, food processors are steadily progressing towards digital transformation which results in clear returns on investment.

Reduction in storage costs can be achieved by streamlining warehouse management systems, inventory control and timely order fulfillment. Increment in efficiency and reduction in downtime can be done with the help of production monitoring tools that provide real-time data to optimise manufacturing processes. Product quality improvisation and waste reduction can be done with the help of AI applications which enhance quality control, and enable predictive maintenance and demand forecasting.

Energy and water solutions are also being revolutionised with the help of Industry 4.0 technologies. IoT has been implemented to monitor water quality and detect leaks in real time, significantly reducing water wastage and ensuring safer water supply.

There is increased demand for sustainable and eco-friendly products due to the shift in consumer trends. Blockchain technology provides a reliable and tamper-proof log that keeps a record of every operation and distribution of products. This allows real-time tracking from farm to fork which enhances transparency and reduces the risk of contamination.

Advancements in food processing machinery

India's food processing industry has made notable progress in recent years. In dairy processing, the replacement of traditional processes like batch pasteurisation is done by more effective techniques like high-temperature short-time (HTST) pasteurisation and ultra-high temperature (UHT) processing. Furthermore, membrane filtration technologies are now used to purify and concentrate milk components which further enhances the shelf life and quality of the product. India has evolved from traditional methods like milling with millstones and machines for sieving to modern technologies such as roller mills, pneumatic conveyors and automated bagging machines for processing of cereals. The revolution of cereal-based products has been bought by extrusion cooking, while nutritional profile and reduced cooking time for cereals has been improved by enzyme technology and micronisation using infrared radiation. Conventional processing of fruits and vegetables involves manual washing, peeling and cutting, using bubble cleaners and brush peelers which has been replaced by ultrasonic processing and laser-guided cutting machines. To further enhance juice extraction, reduce surface decontamination and improve the shelf life of juices, technologies such as pulsed electric field (PEF) technology and cold plasma treatment have been introduced. The shelf life of fresh produce is extended by modified atmosphere packaging (MAP). Traditional processing of meat and poultry involved techniques which included labour-intensive processes and resulted in higher risks of contamination while being less efficient. By using advanced technologies, marination of meat and poultry is done with the help of vacuum tumbling, while modern deboning machines have significantly transformed the industry by improving efficiency and precision. However, the full potential of these technologies remains untapped as many processors still depend on traditional methods. Enhancement in productivity, waste reduction and improvement in quality and safety of food products along with meeting the growing demand for high-quality, sustainable food in India can be brought collectively by adoption of these technologies. Adoption challenges include the high initial investment costs associated with advanced technologies and the requirement of qualified professionals for managing these new systems. Addressing these challenges is crucial for the widespread implementation and success of modern processing technologies.

Automation and robotics

Automation and robotics have enabled the food processing sector to tackle several challenges, including maintaining consistency and quality, ensuring safety and hygiene, reducing wastage, improving efficiency, addressing the skills gap, and managing costs. For example, in bakeries, robots control ingredients measurements and processing conditions and minimise human contact which reduces chances of food contamination. Similar instances can also be observed in meat processing plants.

By automating tasks such as sorting, packing and palletising, the processes become much faster and efficient. Repetitive tasks are a challenge for many industries. By automating these tasks, food processing units can reduce repetitive tasks and allow the employees to focus on more complex roles. In spite of high initial investment, the long-term benefits of automation include reduction in labour costs and increase in productivity as automated assembly lines in food manufacturing can operate continuously with minimal downtime.

For instance, robotics in food processing include automated food assembly for products like sandwiches and pizzas, ingredient handling and dispensing, and food grading and sorting by using sensors and vision systems. Operations like cutting and slicing by robots in processing in poultry industry can improve productivity while automated guided vehicles (AGVs) can streamline internal logistics by transporting raw materials, packaging materials and finished products.

Robotics play a crucial role in the food manufacturing industry by enhancing efficiency and safety. The global food robotics market size reached USD 2.63 billion in 2023. Supported by the advancements in automation technology and increasing demand for efficiency in food production, the market is projected to further grow at a CAGR of 9.70% between 2024 and 2032, to reach a value of USD 6.08 billion by 2032.[35]

AI and ML

AI is being used to manage challenges related to processing, supply chains, products quality and industrial hygiene.

Applications of AI and ML in food processing

Quality control: AI systems use computer vision and ML to non-invasively inspect food products for defects, contamination and consistency.

Predictive maintenance: AI sensors monitor machinery performance and predict potential failures, preventing costly downtime.

35. https://www.globenewswire.com/news-release/2025/01/08/3006454/28124/en/Food-Robotics-Market-Size-Shares-Trends-and-Growth-Analysis-2024-2032-for-Articulated-Parallel-SCARA-Cylindrical-and-Other-Food-Robots.html

Process optimisation: AI enhances different parameters of food processing including fermentation, mixing and temperature monitoring for highest efficacy leading to constant product quality irrespective of input variations. For instance, AI is used in breweries to optimise fermentation processes, which ensures consistent product quality.

Supply chain management: AI optimises inventory management, route planning and demand forecasting.

Product development: AI assesses consumer preferences and ingredient suitability to develop formulations for new food.

Use of IoT in real-time monitoring of food safety, temperature and machine performance

The integration of IoT in food processing is driven by the need to enable quick decision-making and ensure real-time monitoring and control. The global agri tech market is projected to double from USD 20 billion to over USD 40 billion by 2030.[36]

IoT sensors enable real-time monitoring and control of environmental conditions such as temperature, humidity and contamination levels, ensuring consistent food safety and quality. In inventory management, IoT automates tracking, providing real-time data on stock levels and expiration dates which helps in the reduction of overstocking and stockouts. Inconsistent data collection and equipment monitoring across processing facilities is a significant challenge. To address this, a manufacturer uses IoT sensors to monitor its processing equipment to ensure continuous, real-time data collection. IoT is critical in managing various processes such as sterilisation, pasteurisation and cooking. IoT systems also enhance safety by alerting users to anomalies, resulting in the prevention of accidents and ensuring the maintenance of food quality.

Importance of blockchain for supply chain traceability and ensuring food authenticity

Transparency in the supply chain can be enhanced with the help of blockchain technology by creating a secure ledger. This shared ledger allows participants to view and verify transactions in real-time, ensuring data accuracy and tamper-proof records. Blockchain helps companies to track goods from origin to destination, providing detailed information about each step. Enhanced transparency can also help in detecting fraudulent activities and ensure regulatory compliance.

36. https://www.weforum.org/stories/2024/05/innovators-reimagine-the-future-of-food-systems/

For instance, implementation of blockchain technology in food processing reduces the time to trace products which are contaminated. Food fraud can also be prevented by providing a secure and transparent record of the entire supply chain, making it challenging for fraudulent activities to go unnoticed. In high-value supply chains like wine and olive oil, use of blockchain technology helps in preventing fraud and also ensures the authenticity of products.

Moreover, blockchain technology enhances tracking by providing a transparent and verifiable record of the journey of the product, fostering reliability among consumers, investors, and other relevant stakeholders. For instance, blockchain application allows customers to scan QR codes on various products to view their journey from farm to fork, and enables the organisation to enhance transparency and consumer trust.

Industry 4.0 growth prospect

In food processing, adopting energy-efficient machinery results in reducing carbon footprints by optimising energy use. Systems which involve real-time data monitoring help in predicting the shelf life and reducing food waste, while strategies like upcycling food waste and using eco-friendly packaging are essential. Industry 4.0 solutions such as smart sensors, IoT and big data analytics helps in monitoring, predictive maintenance and improving the manufacturing capabilities of the food industry. According to the Viksit Bharat@2047 report, India's food processing sector will grow significantly, reaching USD 1,100 billion by FY35.[37]

Stakeholder collaboration supported by research and development is expected to play a key role in stimulating adaptation and adoption of global nextgen technologies in domestic use.

37. https://www.ibef.org/industry/food-processing

04

Challenges in the adoption of nextgen technologies

As the potential of Industry 4.0 technologies in food processing is immense, their adoption paves the way for improving efficiency, productivity and overall quality of food products. However, challenges which are economic, policy-based or operational in nature, continue to remain. In such circumstances, the benefits of robotics, AI, automation and blockchain technology can only be leveraged by businesses and policymakers after overcoming their implementational hurdles, in order to move forward.

Presently, the adoption of these technologies is impeded due to the absence of adequate infrastructural support – particularly in remote areas with limited network connectivity and lack of robust energy supply. Additionally, information asymmetry and isolated approaches pose a challenge towards the common goal of stakeholder familiarity with technologies and overcoming restricted knowledge sharing and collaboration.

Some of these challenges have been highlighted below:

a. **Investment challenges:** Implementation of advanced technologies in the food processing sector, such as IoT, ML and AI, result in high initial investment costs. These costs include the expansion and upgradation of existing infrastructure, investing in new equipment and training personnel.

Market validation: Startups and new enterprises need to demonstrate the market need for the Industry 4.0 technologies in the food processing sector. Showcasing commercial viability and customer trust is how any product service can foster market validation. Although the interest in implementing upcoming technologies is significant, widespread adoption of the same will require more viable market validation.

b. **Long repayment periods and associated RoI:** Businesses face challenges in sustaining operations as the investments in new technologies are not only large but also come wrapped in long payback periods. Therefore, informed decisions regarding investments can only be taken with a comprehensive understanding of the RoI and payback period. Additionally, allocation of cost and benefit to a specific technology within the processing spectrum is a complex task.

c. **Operational challenges:** There are different operational challenges in adopting nextgen technologies in the food processing industry.

   A marked shortage of skilled human resources persists as a major gap between advanced technologies and operational competencies of the food processing sector. This gap can hinder the effective implementation and operation of Industry 4.0 technologies.

   Implementing new technologies is accompanied by increased susceptibility to cyber-attacks and data leakage, which can ultimately lead to food safety risks.

   Integration of new digital technologies in legacy equipment results in increased downtime, escalating maintenance costs and efficiency reduction in the initial stages.

d. **Regulatory challenges:** Significant hurdles stem from the adoption of Industry 4.0 technologies in the food processing industry due to non-standardised regulations. Food processors attempting to implement advanced technologies often face compliance inconsistencies and operational inefficiencies. An example of this is that worldwide food safety and standards are managed by the Codex Alimentarius Commission but the implementation varies globally, creating non-homogeneous national regulations and enforcement capabilities.

Challenges arising from these inconsistencies include differences in the acceptance and adoption of food safety and quality standards across regions. Compliance requirements often delay technological advancements, and varying data privacy and security regulations affect the usage and sharing of data from automated systems and augmented reality tools.

Energy consumption along with waste management can also be revolutionised through Industry 4.0 technologies. However, non-homogenous acceptance and regulation of environmental standards are also subject to rigorous overseeing. Such disparity affects the seamless adoption of advanced technologies. Complications also arise in the form of strict data privacy and protection requirements of new automation and augmented reality technologies that manage data collection and processing, further delaying their acceptance. Personal data compliance is ensured through General Data Protection Regulation (GDPR) standards so that its processing remains lawful and transparent. Automated systems tasked with data collection and analysis face the challenge of very conformed data handling through robust data protection measures, like explicit individual consent, and data minimisation and anonymisation. Compliance failure results in serious penalties and legal repercussions. In India, the Food Safety and Standards Authority of India (FSSAI) established under the Food Safety and Standards Act, 2006, is the apex regulator of the food processing standards of safety and quality. About 98% of the food processing sector (about 2.5 million food processing enterprises) is still unorganised and operates in an informal manner.[38] Any adoption or policy implementation becomes tricky when it comes to uniform regulatory compliance in an unorganised set of entities.

There are also amendments to ownership values of data. Digital transformation is making it imperative for new paradigms to be based on trust and transparency. Legal rights and obligations of data as a commodity and its understanding is evolving.

Compliance framework and legislation are crucial in this evolution. Nationally, introducing key concepts like data minimisation, usage consent and user rights to safeguard individual privacy are being streamlined by the Digital Personal Data Protection Act, 2023 (DPDP Act). Despite policy support and understanding enhancement, compliance with the DPDP Act is limited and significant efforts are still required to ensure that entities in the food processing sector can navigate the intricacies of data protection and privacy regulations.

38. https://indbiz.gov.in/micro-food-processing-units-get-new-policy-support/

05

Government and other stakeholder initiatives to stimulate adoption

The most comprehensive support any sector can avail is through the seamless synergy of different actors in any ecosystem. Here, the initiatives and schemes by governments play a pivotal role in the adoption and scaling of new technologies. Such initiatives – e.g. fiscal aids, infrastructural development or regulation support – create a conducive environment for innovation and growth. The validated technologies are taken to commercialisation, which bridges private investment and new accessible technologies so that the broader population can benefit from it. This chapter highlights key government schemes, successful examples of start-ups and public–private synergies and venture capital funding, and emerging trends that are stimulating the adoption of nextgen technologies in the food processing sector.

Table 5: Key stakeholder initiatives for the food processing sector

Government ministries			
Ministry of Food Processing Industries	Apex nodal for formulating and implementing policies for the food processing sector	**Pradhan Mantri Kisan Sampada Yojana**	
		Umbrella initiative fostering modern infrastructure with efficient supply chain management from farm-to-end consumer consumption	Sub-schemes: Agro Processing Cluster scheme, creation/ expansion of food processing and preservation capacities, food testing labs, mega food park, cold chain, value addition and preservation infrastructure
		Prime Minister Formalization of Micro Food Processing Enterprises	
		Organising micro enterprises of the food processing industry	
		Production Linked Incentive Scheme for Food Processing Industry	
		Investment in the food processing sector by providing incentives based on sales and venture	
Ministry of Consumer Affairs and Public Distribution	Fostering food security, consumer protection and regulating essential commodities	**Pradhan Mantri Garib Kalyan Ann Yojana**	
		Provision of nutrition to the underprivileged citizens of India through the public distribution system, where grains are provided to all the priority households	
		Procurement and storage	
		Fostering the trade of the entire chain of production, supply and distribution of different food grains	
		National Consumer Disputes Redressal Commission	
		Consumer rights protection through effective grievance redressal	
International and national banks			
National Bank for Agriculture and Rural Development (NABARD)	Aiding the establishment of food parks and processing units for rural economic prosperity	**Food Processing Fund (FPF)**	
		Enhancing infrastructural capacity by supporting food parks and individual units for reducing post-harvest losses	
		Warehouse Infrastructure Fund (WIF)	
		Food storage and waste mitigation through infrastructural capacity development across warehousing	

Small Industries Development Bank of India (SIDBI)	Supporting MSMEs in the food processing sector through financial assistance and capacity-building initiatives	**Mission Swavalamban**
		An umbrella initiative for MSMEs – financial and capacity building support
		PRAYAAS
		Credit facilitation to informal micro-entrepreneurs/micro-enterprises (IMEs) for their livelihood promotion
World Bank	Global projects and fund support to enhance food systems' resilience and sustainability	**Food Finance Architecture: Policy brief**
		Unlocking opportunities for sustainable food systems and addressing social, economic and environmental costs
		Food Systems 2030
		Helping countries establish resilient and sustainable food systems by 2030, through a multi-donor trust fund
Academic and research institutions		
Indian Council of Agricultural Research (ICAR)	Agriculture based research and development which includes food processing technologies	**Agro-processing centres (APCs)**
		Small-scale processing units at the village level to process local produce and generate employment
		Krishi vigyan kendras (KVKs)
		Training and demonstrations on food processing technologies to farmers and entrepreneurs for enhancing their skills and knowledge
		National Agricultural Innovation Project (NAIP)
		World Bank funded innovation development project aiming to develop agricultural research, including food processing technologies, for improving productivity and sustainability
National Institute of Food Technology Entrepreneurship and Management (NIFTEM)	Education, research and consultancy services in food technology and management	**High-tech processing incubation centre**
		Fostering start-ups and entrepreneurs in the food processing sector with state-of-the-art facilities and mentorship
		Food quality testing laboratory
		Provides National Accreditation Board for Testing and Calibration Laboratories (NABL)-accredited testing services to ensure the safety and quality of food products

Statutory and public policy bodies		
NITI Aayog	Facilitates policy formulation and strategic planning for myriads of sectors and works to improve food processing sector's efficiency and innovation	**NITI for States** A knowledge platform to access the latest national and regional information regarding various sectors including agriculture and allied sectors **Task Force on Agriculture Development** Coordination and development of synergy with central ministries and state government task forces to recommend strategies for reinvigorating agriculture in all its aspects and formulating strategies for reforms, innovation and technology diffusion
Agricultural and Processed Food Products Export Development Authority (APEDA)	Responsible for promotion and development of the export of agricultural and processed food products	**Financial Assistance Scheme (FAS)** Export promotion scheme run by APEDA which aims to facilitate the export of agri-products by providing assistance to exporters **Traceability systems** Ensuring the quality and safety of agricultural exports from India through traceability systems **Agri Exchange** Online trade portal under the Ministry of Commerce and Industry, Government of India, for buyers and sellers in the agricultural business to negotiate and transact deals
Food Safety and Standard Authority of India (FSSAI)	Regulating various laws for the availability of safe and wholesome food for human consumption	**Food Innovators Network (FINE)** Innovative solutions for food innovators and startups in food safety and nutrition **Food Safety on Wheels** Deployment of mobile food testing labs to ensure food safety and hygiene across various regions **Food Safety Compliance System** An online platform used for the dissemination and standardisation of regulations to enhance the food safety compliance process

Sources:

https://www.mofpi.gov.in/;
https://consumeraffairs.nic.in/;
https://www.nabard.org/Hindi/Default.aspx;
https://www.sidbi.in/en/;
https://www.worldbank.org/ext/en/home;
https://apeda.gov.in/hortinet-static
https://fssai.gov.in/;
https://www.niti.gov.in/

Startups and public–private partnerships (PPPs)

Startups and PPPs have been leveraging the new wave of innovation to enhance the efficiency, quality and sustainability of food processing. Startups bring fresh ideas and agility, while PPPs provide the necessary infrastructural assistance and resources to create a holistic environment for technological growth. Such collaboration is crucial for the adoption and dissemination of these technologies and will help tackle challenges like food waste, security and safety.

Nearly 3,319 recognised startups in the national food processing industry have been identified by Department for Promotion of Industry and Internal Trade (2023). Spread across 425 districts and providing livelihood to more 33,000 people, these startups can be prioritised for homogenous adoption and acceptance of 4.0 technologies.[39]

Figure 6: Startups in India

01 **58% of startups are from Tier 2 and 3 cities with Maharashtra at the top**

02 **Top performing startup industries: Food and beverages(36%)**

03 **Sub-sectors – grains, sugar, edible oils, beverages and dairy products**

Sources:

https://timesofindia.indiatimes.com/business/startups/trend-tracking/58-of-govt-recognised-start-ups-in-5-states-maharashtra-tops-list/articleshow/96320089.cms;

https://www.startupindia.gov.in/content/dam/invest-india/startup-milestone/FactbookJan25.pdf

39. https://www.startupindia.gov.in/content/sih/en/bloglist/blogs/food-processing-sector.html

Table 6: Startups technology focus

Focus areas	Technology leveraged	Outcomes
Automated supply chains	Adoption of automated supply chains from farm gate to end consumer with AI-driven distribution and logistics.	Reduction in food wastage and streamlined operations
Digital financing	Digital financing for smart warehousing solutions	Successful sourcing of financial resources
AI and IoT	Assessment of quality of food products through AI and IoT	Improved product quality testing and regulatory compliance

Role of venture capital

Capital exchange for equity or ownership stake is led by a venture capital business model. These units are becoming a steady support in the form of private equity financing for startups and small businesses with high growth potential. Considering investment challenges, there is an urgent need to foster the food processing sector through economic growth, innovation and development of new technologies. Venture capital can help these startups rapidly expand, setting new industry standards.

Considering the above information, it becomes clearer why stakeholder synergy between the Government and private players is pivotal in the adoption of emerging technologies in the food processing sector. A conducive environment for innovation and growth can only be created by balanced capital provision, regulatory and policy support as well as infrastructural development. While governmental policies are driving the tide, Industry 4.0 technologies are being leveraged by different PPPs for efficiency, quality and sustainability in food production. For supply chain transparency and food waste mitigation, these entities have to evolve from being the first movers to the collaborative forefront of the sector.

06

Use cases

Food processing companies are periodically seeking ways to enhance efficiency, ensure quality and meet the evolving demands of consumers. While there has been movement regarding integrating Industry 4.0 technologies into the food sector, the reimagining of the entire food production process and creating a more sustainable, efficient and transparent system will require considerable efforts. Illustrations of a world where food freshness checks can be done remotely through smart sensors, and an entirely traceable supply chain where blockchain oversees every ingredient from farm to fork, is not far. The reality that Industry 4.0 offers is already here, and many commercialisation and research pilots are underway, witnessing remarkable improvements in the operations of present food systems.

Some compelling use cases have been mentioned here to highlight the solutions of Industry 4.0 in the food processing sector.

Use case 1: Blockchain initiative for supply chain traceability

It is important to recognise the increasing consumer interest towards transparent supply chains and ethical sourcing. Blockchain technology is seen as a solution to establish a reliable supply chain traceability system. Food processing players handling complex supply chain processes are undertaking pioneering initiatives of integrating blockchain solutions.

Challenges

1. Data reliability: Unverified supply chain data

2. Consumer demands: Rising consumer demands about clean consumption, ethical sourcing, food safety and sustainability

3. Compatibility: Integrating new blockchain technology into legacy equipment and existing supply chains

Solution

Blockchain platforms offer innovative solutions, enabling transparency in supply chains to track food products back to the farm, providing detailed and immutable information about the product's journey for consumer awareness. Consumers can further access and verify the fidelity of data. This fosters transparency and trust for the companies among consumers.

Outcome

Implementation of blockchain technology and consequent signalling leads to an increase in consumer trust. Broader applications of allied technologies can bring transparency and ethical accountability in global supply chains.

Figure 7: Outcomes of implementing blockchain technology in supply chains

01 **Successful traceability:** The program successfully traces food product ingredients to their sources.

02 **Enhanced consumer trust:** The transparency provided by the blockchain system enhances consumer trust.

03 **Improved efficiency:** The technology enhanced supply chain efficiency considerably.

Use case 2: Optimising processing lines with advanced technologies

Food processors require real-time data for timely identification of anomalies and taking corrective actions. Companies have adopted advanced technologies like computer vision and ML to identify, analyse anomalies and ensure conformity with desired standards. Coupling these technology inputs with cloud computing helps with real-time data access and decision making.

Challenges

1. Manual inspection process: Creates bottlenecks in the production processes such as inventory counting and machine inspections, which are time-consuming and error-prone

2. Lack of real-time insights: Lack of real-time data from traditional methods, preventing timely decision-making and issue resolution

3. Operational inefficiencies: Operational inefficiencies stemming from inventory management issues and product carrier failures that further hamper production

Solution

- Companies are integrating computer vision and ML technologies into their processing lines.
- Computer vision solutions are implemented to automate manual inspection of processing lines. This facilitates capturing, processing, and analysing images and videos to extract meaningful information about each critical processing node.
- Integration of ML facilitates automation of time-consuming analysis to increase accuracy and efficiency.
- ML is utilised for object detection to improve inventory management and detect product carrier failure.

Outcome

These solutions have helped food processors to improve the quality of their products with efficient inventory management.

07

The way forward

Future trends for the food processing industry

The food processing industry is on the verge of significant transformation, driven by technological innovations, sustainability initiatives and changing consumer preferences. India's food processing sector's market size is estimated to more than double to USD 700 billion by 2030.[40] This increase demonstrates a growing demand for food processing, influenced by urbanisation, changing dietary preferences and technological advancements. This steady growth is expected to lead continued investment in the sector, which will likely stimulate the adoption of modern technologies.

A comprehensive study of the significant trends and advancement outlines the way forward for shaping the food processing industry.

Embracing Industry 4.0 technologies: The adoption of Industry 4.0 technologies such as AI, ML, IoT and big data will revolutionise the food processing industry. These technologies can enhance production efficiency, improve quality control and optimise supply chains.

AI technologies are reshaping quality control processes by using ML algorithms to spot defects and guarantee consistency of the product, causing less wastage.

Predictive analytics is characterised using historical data, statistical algorithms and ML techniques to identify the possibility of future outcomes. Predictive analytics in the food processing sector can significantly improve various aspects of operations like demand forecasting, quality control and inventory management.

Optimising supply chains in the food processing sector can be done with IoT-enabled cold storage monitoring, AI-driven predictive analytics and real-time tracking systems – maintaining the quality of the product and minimising waste. Furthermore, collaborative supply networks can enhance data integration, improving coordination among stakeholders and efficiency across the entire supply chain.

Automation and robotics: Robotic process automation (RPA) helps in automating repetitive tasks. Efficiency and accuracy in food processing operations can be achieved with the help of this technology.

Cobots (human collaborative robots) play a key role in improving productivity and safety in this sector. Cobots help in automating packaging tasks – such as carton assembly, product loading, sealing and labelling – which further improves output, reduces errors and ensures compliance with regulations. Enhancement in quality control and

40. https://www.ibef.org/industry/food-processing

inspection is done by using advanced vision systems whereas sensors help to detect defects, contaminants and irregularities with high accuracy. In addition to this, cobots are efficient in handling and sorting food products – including fresh items and irregular shapes – by performing tasks like palletising, de-palletising, sorting, and bin picking with accuracy and dexterity.

Automation in the food processing sector is poised for further growth, boosting efficiency, sustainability and safety in the sector.

Smart factories: An interconnected and automated production environment can be created by the integration of AI, robotics and IoT. These technologies enable real-time monitoring, predictive maintenance and data-driven decision-making, leading to remarkable improvements in efficiency and quality of the product.

In summary, the adoption of Industry 4.0 technologies is driven by the increasing market size and sustained growth rate of the food processing industry. These technological advancements result in enhancing efficiency, sustainability and consumer satisfaction, ensuring that the sector remains innovative and competitive.

Key findings and the importance of adopting nextgen technologies

The various key insights that underline the importance of adopting nextgen technologies in the food processing sector are highlighted below:

1. Operational efficiency and productivity can be enhanced with the help of automation, robotics and AI.
2. Reduction in energy consumption and waste, and improvement in resource efficiency can be achieved with these emerging technologies.
3. Food safety can be improved by establishing real-time monitoring and control of processing conditions.
4. Transparency in supply chains can be enhanced by using blockchain technology, allowing the origin and journey of food products to be traced.

About ASSOCHAM

Contact us

Harsh Vardhan Sharma
harsh.sharma@assocham.com

Nayonika Das
nayonika.das@assocham.com

ASSOCHAM corporate office
4th Floor, YMCA Cultural Centre
and Library Building
01, Jai Singh Road, New Delhi – 110001
Tel: 011 46550555
www.assocham.org

The Knowledge Architect of India

Evolution of value creator

ASSOCHAM initiated its endeavor of value creation for Indian industry in 1920. Having in its fold more than 400 chambers and trade associations and serving more than 4,50,000 members from all over India. It has witnessed upswings as well as upheavals of Indian Economy and contributed significantly by playing a catalytic role in shaping up the trade, commerce and industrial environment of the country.

Today, ASSOCHAM has emerged as the fountainhead of knowledge for Indian industry, which is all set to redefine the dynamics of growth and development in the technology driven cyber age of 'Knowledge Based Economy'.

ASSOCHAM is seen as a forceful, proactive, forward-looking institution equipping itself to meet the aspirations of corporate India in the new world of business. ASSOCHAM is working towards creating a conducive environment of India business to compete globally.

ASSOCHAM derives its strength from its promoter chambers and other industry/ regional chambers/associations spread all over the country.

Vision

Empower Indian enterprise by inculcating knowledge that will be the catalyst of growth in the barrier-less technology-driven global market and help them upscale, align and emerge as a formidable player in respective business segments.

Mission

As a representative organ of corporate India, ASSOCHAM articulates the genuine, legitimate needs and interests of its members. Its mission is to impact the policy and legislative environment to foster balanced economic, industrial and social development. We believe education, IT, BT, health, corporate social responsibility and environment to be critical success factors.

Members: Our Strength

ASSOCHAM represents the interests of more than 4,50,000 direct and indirect members across the country. Through its heterogeneous membership, ASSOCHAM combines the entrepreneurial spirit and business acumen of owners with management skills and expertise of professionals to set itself apart as a chamber with a difference.

Currently, ASSOCHAM has more than 100 national councils covering the entire gamut of economic activities in India. It has been especially acknowledged as a significant voice of Indian industry in the field of corporate social responsibility, environment and safety, HR and labor affairs, corporate governance, information technology, biotechnology, telecom, banking and finance, company law, corporate finance, economic and international affairs, mergers and acquisitions, tourism, civil aviation, infrastructure, energy and power, education, legal reforms, real estate, food processing and rural development, competency building and skill development to mention a few.

Insight Into 'New Business Models'

ASSOCHAM has been a significant contributory factor in the emergence of new-age Indian corporates, characterized by a new mindset and global ambition for dominating the international business. The chamber has addressed itself to key areas like India as an investment destination, achieving international competitiveness, promoting international trade, corporate strategies for enhancing stakeholders value, government policies in sustaining India's development, infrastructure development for enhancing India's competitiveness, building Indian MNCs, role of the financial sector as the catalyst for India's transformation. ASSOCHAM derives its strengths from the following promoter chambers: Bombay Chamber of Commerce and Industry, Mumbai; Cochin Chambers of Commerce and Industry, Cochin: Indian Merchant's Chamber, Mumbai; The Madras Chamber of Commerce and Industry, Chennai; PHD Chamber of Commerce and Industry, New Delhi. Together, we can make a significant difference to the burden that our nation carries and bring in a bright, new tomorrow for our nation.

As a representative organ of corporate India, ASSOCHAM articulates the genuine, legitimate needs and interests of its members. Its mission is to impact the policy and legislative environment to foster a balanced economic, industrial and social development. We believe education, IT, BT, health, corporate social responsibility and environment to be the critical success factors.

About PwC

At PwC, our purpose is to build trust in society and solve important problems. We're a network of firms in 149 countries with over 370,000 people who are committed to delivering quality in assurance, advisory and tax services. Find out more and tell us what matters to you by visiting us at www.pwc.com.

PwC refers to the PwC network and/or one or more of its member firms, each of which is a separate legal entity. Please see www.pwc.com/structure for further details.

Contact us

Amulya Patnaik
Partner, Agriculture and Food Sector
PwC India
amulya.patnaik@pwc.com

Shashi Kant Singh
Partner, Agriculture and Food Sector
PwC India
shashi.k.singh@pwc.com

Mandeep Ahuja
Director, Management Consulting
PwC India
mandeep.ahuja@pwc.com

Contributors

Ritraj Singh

Simone Roy Gupta

Parvani Sharma

Editorial support

Rashi Gupta

Design

Kirtika Saxena

pwc.in

Data Classification: DC0 (Public)

KS/May2025 - M&C 45644