Kanika S. Tomar[1*]
Dr. Mahua Bhattacharjee[2]
Dr. Anjali Tandon[3]

Advancements, Challenges, and Policy Interventions in Agriculture-Related Manufacturing in India: A Critical Analysis

JES Journal of Electrical Systems

Abstract
The present study focuses on the role and evolution of agriculture-related manufacturing in India, crucial for economic growth, employment, and the generation of rural incomes. The study looks into a holistic analysis of historical development, policy frameworks, technological adoption, and current challenges in the integration process of agriculture-manufacturing. Methodologically, it probes the transformation of agriculture from traditional to modern practices. It underlines key developments in agricultural transformation: the Green Revolution, mechanization, and adoption of Industry 4.0 technologies, like AI, IoT, and precision agriculture. The study examined interventions by the government in subsidizing, tax incentives, and schemes like PM-KISAN and Make in India for an understanding of the impact on the manufacturing panorama and larger agriculture-manufacturing nexus. Results have shown that these interventions have contributed a great deal to increasing agricultural productivity and improving rural incomes. Especially, technological advances in smart manufacturing and precision farming have also assisted the sector in enhancing efficiency, reducing reliance on labor, and improving export potential. Fragmented supply chains, lack of appropriate infrastructure especially cold chains, inconsistency in regulation, and labor shortages are some of the issues that still need to be overcome for better growth. This means that for the getting of strength in manufacturing based on agriculture, continuous support by the government, infrastructure development, and adoption of sustainable practices are required. Promotion of digital technologies and formation of cooperatives among small farmers will lead to better market access and competitiveness. India's agriculture manufacturing would be based now on leveraging emerging technologies as implementation of policies pursued for sustainable growth, global competitiveness, and resilience of domestic and international markets.

Keywords: Agriculture-Related Manufacturing, Technological Advancements, Government Interventions, Precision Farming, Sustainable Growth

1. INTRODUCTION

India has a rich agricultural tradition, with agriculture playing a critical role in the nation's economic structure. Approximately 52% of the workforce is involved in agriculture, contributing around 18% to India's GDP (B. Arun, 2017). Agriculture in India is the backbone of the economy and has vast linkages with other sectors, particularly manufacturing. This connection is strengthened by agriculture's vital role in supplying raw materials to various manufacturing industries like food processing, textiles, and agro-machinery production. The manufacturing sector, including agro-based industries, further helps enhance value addition in agricultural products, boosting both the agricultural and industrial sectors. Without the development of both, a balanced economic growth becomes unattainable, making their coexistence essential (Sahoo & Sethi, 2012). The economic significance of agriculture-related manufacturing in India is profound. Agricultural manufacturing is closely tied to the country's industrial sector, with agriculture contributing nearly 60% of employment and around 20% of the GDP (Doria, 2023). Moreover, industries related to agriculture, such as food processing, textile manufacturing, and agro-machinery production, are substantial contributors to export earnings and employment generation in rural areas. For instance, India is a leading exporter of agricultural products, with significant contributions from cashews, spices, and textiles made from agricultural inputs. The food processing industry alone contributes to a significant portion of India's GDP and employs millions of workers (Tyagi, 2012).

The agriculture sector has historically been a cornerstone of the Indian economy. It contributes significantly to both employment and the country's Gross Domestic Product (GDP). Approximately 54.6% of the workforce is employed in agriculture, and the sector contributes around 13.9% to India's GDP (Wagh & Dongre, 2016). The development of agricultural machinery and modern farming techniques have gradually transformed traditional agriculture into a more mechanized industry. Indian agriculture has shifted from traditional practices towards the use of improved technologies, including high-yield seed varieties, chemical fertilizers, and agro-processing equipment. This transformation has catalysed growth in the manufacture of agricultural machinery industries that are vital for increasing productivity and exporting farm outputs (De, 2003). Food processing, which value-adds to agricultural output besides giving rural employment, is one of the most important components of the agro-based manufacturing industries. Along with a regular supply to urban markets, it supplies processed food at reasonable prices. This is expected because the sector is highly fragmented, with a plethora of SMEs dominating the manufacturing landscape of the country, though recently there has been a push towards modernization of agro-processing units and improving infrastructure related to storage and transportation (Jangaiah, 2017). The agricultural machinery industry, much in keeping with the needs of transitioning Indian agriculture from traditional practices to more mechanized processes

[1*]Scholar, Phd in Economics, Amity School of Economics, Amity University (Amity Rd, Sector 125, Noida, Uttar Pradesh 201301) Email Address: kanika.ks.singh@gmail.com
2Professor, Amity School of Economics, Amity University (Amity Rd, Sector 125, Noida, Uttar Pradesh 201301 Email Address: mbhattacharjee@amity.edu
[3]Associate Professor, Institute for Studies in Industrial Development (ISID) (4, Vasant Kunj Institutional Area, Vasant Kunj II, Vasant Kunj, New Delhi, Delhi 110070) Email Address: anjali.tandon.anjali@gmail.com

that increase yields and reduce labor dependency, has blossomed since the turn of the millennium (De, 2003). Hand in hand with this structural change has been that of the supporting agro-processing industries, which add value to the raw agricultural product and market it, thus enhancing its export potential. This type of intersectoral symbiosis promotes balance in economic growth. In fact, several empirical studies on the interrelationship of agriculture and industry in the economic development of India point out clearly that both sectors contribute to economic development positively, although agriculture contributes more to overall development and industry towards economic growth (Sahoo & Sethi, 2012). These are complimentary sectors, and joined development is a must if sustainable growth has to be achieved.

Economic Impact and Contribution to GDP

The agriculture sector contributes significantly to India's exports, particularly in the agro-processing and food manufacturing industries. Agricultural exports are responsible for around 13% of India's total export earnings, making it a critical source of foreign exchange and economic stability (Kaundal & Sharma, 2006). Agriculture's role extends beyond raw material production. It influences other sectors, such as transportation and storage, which directly benefit from agricultural output. In regions like Uttar Pradesh, agriculture drives not only the unregistered manufacturing sector but also the transport and communication industries, highlighting its centrality to India's overall economy (Khan & Ansari, 2018).

The Indian government has implemented various schemes and policies to strengthen the agriculture-manufacturing linkages. Initiatives like the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) aim to boost farmers' income, while the National Agricultural Market (e-NAM) facilitates easier trade for agricultural goods, enhancing the sector's competitiveness (Tripathi et al., 2023). Programs promoting modern agricultural practices and technological advancements are also helping to increase agricultural productivity and support the manufacturing sector by providing a consistent supply of high-quality raw materials.

The future of agriculture-related manufacturing in India hinges on improved investment in infrastructure, technological advancements, and policies that encourage sustainable agricultural practices. Strengthening the agro-based manufacturing sector will not only help stabilize the agricultural economy but will also contribute to national economic growth by creating jobs, enhancing productivity, and increasing export potential (Verma, 2015).

Objectives

1. Analyze the historical and present-day relationship between agriculture and manufacturing in India.
2. Explore the economic impact of agro-based manufacturing industries on rural employment, income generation, and the national economy.
3. Discuss policy interventions, challenges, and opportunities in the development of agricultural manufacturing.
4. Highlight the technological and infrastructural advancements required to improve the efficiency and productivity of agro-based manufacturing in India.
5. Suggest strategies for promoting sustainable agricultural manufacturing and its future potential in driving India's economic growth.

2. HISTORICAL DEVELOPMENT OF AGRICULTURE-RELATED MANUFACTURING IN INDIA

The agricultural system in India can be traced back to 9000 BC, with early practices involving the domestication of plants and animals. The Neolithic period, around 4000 BC, marked the beginning of sedentary agricultural activities, with early farmers cultivating crops and domesticating animals. These early farming practices formed the small-scale industrial basis for food storage, grain processing, and light tools production. For a long period of time, agriculture represented the backbone of the Indian economy and thus supplied essential raw materials for the rudimentary manufacturing industries. According to (Mulage 2017), by 500 BC, iron tools became popularly used, and therefore farming became more effective. This was also the age through which the Plow and irrigation systems were introduced and improved, which increased agricultural production. Such inventions were important in feeding the growth of the early industries such as metallurgy and textile manufacturing.

Commercialization of agriculture, especially in the 19th century in colonial India, has been one of the major turning points in the manufacturing of agriculture. The British colonial administration played a very decisive role in shaping the agricultural manufacturing sector of India. They introduced such crops in India as cotton, indigo, and tea, which became crucial for the international market. Along with modern agricultural tools and an irrigation system, this considerably raised the level of output in India's agriculture. Meanwhile, other traditional industries became precarious: for instance, the handloom weaving and metalwork sectors, due to the coming of cheap British manufactured goods.

2.1 Transition from Traditional to Modern Techniques

The Green Revolution truly marked the transition of agricultural manufacturing techniques from traditional to modern. This movement, beginning in the 1960s, introduced high-yielding varieties of seeds, chemical fertilizers, and improved irrigation techniques that greatly increased agriculture productivity. The Green Revolution initiated large-scale mechanization in Indian agriculture. Development in technology and relevant education in agriculture also played an important role in this transition. Scientific handling of farming was developed by ICAR and state agricultural universities. Their research also included crop yield improvement, most efficient techniques of farming, and assimilation of modern technologies into the agricultural sector. Mechanization in agriculture gave way to a series of industries engaged in the manufacturing of machinery, tools, and fertilizers related to agriculture (Singh, 2012).

2.2 Ecological and Traditional Knowledge

India's traditional farming systems are rooted in ecologically based practices developed through generations of observation and interaction with natural resources. These methods, passed down over centuries, were highly sustainable, ensuring long-term soil fertility, water conservation, and biodiversity maintenance. Among these key practices were intercropping, crop rotation, and agroforestry, which involved biological pest control. For example, double cropping and agroforestry improve soil quality but also offer materials to make tools for manufacturing food, timber, among other implements used in agriculture (Patel et al., 2020). Biological pest and disease control was yet another important practice of traditional farming. These included natural ways of crop protection using plant extracts and biological controls. Large parts of the country had an effective and viable traditional means of managing the pest situation; hence, there was little necessity of chemical pesticides that would become common with modern agriculture (Chhetry & Belbahri, 2009).

2.3 Traditional Tools and Agricultural Implements

Central in this farming system of India were the implements used in farming, which were traditional means such as in the nature of a wooden Plow, sickle, and ox-driven carts. Due to their ease and efficiency, these tools are primarily manufactured using local materials like iron and wood. Their adoption among the small-scale farmers is due to their feasibility, affordability, and adaptability. Most of these tools are still in use today, mainly in the remote areas where modern farm equipment has not yet fully reached (Karthikeyan et al., 2009).

For example, in a state like Tamil Nadu, traditional farming tools were developed over time with adaptation to the natural environment. These traditional farming tools were specially made to accomplish very specific farming tasks, such as tilling of fields for preparing soil for planting, weeding, and harvesting. This was further supported by the fact that these tools were generally manufactured by regional artisans, thereby giving rise to a petty production sector which gained strength from the demand for the agricultural tool kit. According to Karthikeyan et al. (2009), one of the earliest traditional methods of agriculture which influenced manufacturing in early agricultural India was slash-and-burn agriculture, especially within the tribal belt of Arunachal Pradesh known locally as "jhum kheti," this method involved clearing land by cutting and burning vegetation.

The ash produced from the burning enriched the soil with nutrients, allowing crops to be grown for a few years before the land was left fallow to recover. This method was sustainable in the context of low population density and long fallow periods. The system also enabled the production of tool and storage facilities since farming in such conditions led to the need for specialized tools for clearing, planting, and harvesting crops. For example, the early Indian farmers developed effective methods of putting away seeds as well as controlling pests. The conventional techniques of seed storing involved the use of natural materials like clay pots, bamboo baskets, and cow dung in protecting the seeds from pests and environmental deterioration (Tangjang, 2009). This helped assure that the seeds were available in time for the next planting season and did not affect the genetic diversity of that particular crop variety. Such storage systems are efficient and non-deleterious to the environment: seed quality was preserved without the use of chemicals (Shaila & Begum, 2021).

Traditional versus modern agricultural techniques in India show significant trade-offs, where traditional methods focus on sustainability and the use of local resources, while modern techniques aim at efficiency and productivity but come with environmental costs as shown in table 1.

Table 1: Comparison of Traditional vs. Modern Agricultural Techniques in India

Criteria	Traditional Methods	Modern Techniques	Citation
Efficiency	Moderate efficiency, relied on simple, manual tools like wooden Plows and sickles.	High efficiency due to mechanization, use of tractors, and advanced irrigation.	(Mulage, 2017), (Singh, 2012)
Environmental Impact	Low impact; practices such as crop rotation, mixed cropping, and natural pest management ensured sustainability.	Increased environmental impact due to use of chemical fertilizers, pesticides, and intensive irrigation.	(Patel et al., 2020), (Singh, 2012)
Tools and Implementation	Simple tools made from wood and iron, easy to produce and maintain locally.	Complex machinery, such as tractors and harvesters, often manufactured on an industrial scale and costly.	(Karthikeyan et al., 2009), (Singh, 2012)
Soil Fertility Management	Practices like jhum kheti (slash-and-burn), fallow periods, and organic inputs maintained long-term soil fertility.	Fertility is maintained through chemical fertilizers, which can degrade soil health over time.	(Tangjang, 2009), (Singh, 2012)
Economic Considerations	Low-cost techniques accessible to smallholder farmers; tools produced by local artisans.	High initial cost due to the need for machinery, seeds, and chemical inputs; requires financial investment.	(Karthikeyan et al., 2009), (Singh, 2012)
Manufacturing Dependence	Tools were locally produced, supporting small-scale artisans and ensuring self-sufficiency.	Heavy dependence on industrial manufacturing for machinery, fertilizers, and seeds, reducing self-sufficiency.	(Karthikeyan et al., 2009), (Singh, 2012)

3. CURRENT LANDSCAPE OF AGRICULTURE-RELATED MANUFACTURING IN INDIA

Agro-based manufacturing in India is a very important sector as it acts as a link between agriculture and industry. Starting from machinery to fertilizers and seeds, food processing, and a host of other industries contribute to adding value to the agricultural produce. The Indian government thrust on enhancing agricultural productivity and rural income spurred more investments and innovations in this sector.

3.1 Major Players in Agriculture-Related Manufacturing

India has a diverse range of players in the agriculture-related manufacturing sector, spanning from large multinational corporations to smaller, regionally focused companies. A leader in agricultural machinery, particularly in tractor manufacturing, Mahindra is one of the largest tractor manufacturers in the world. Another venturing manufacturing business of the firm is a harvester and other farm equipment (Gulati & Juneja, 2020). Other than that, the firm has a leading share in the Indian fertilizer industry because it adds value to farmers by providing growers with crucial nutrient requirements across India (Singh et al., 2020). Godrej Agrovet has a leading position in the active manufacturing landscape in the areas of animal feed, crop protection, dairy, and food processing. The company innovates in solutions related to animal nutrition and crop care (Ponniah & Sri, 2022). Most of the manufacturing units in this region are integrated with various government subsidy schemes, thereby encouraging modern agricultural tool usage (Kumar, 2021).

3.2 Latest Production Technologies and Processes

India's agriculture-related manufacturing sector has seen a rapid shift toward modernization and technology adoption. Innovations in digital agriculture, mechanization, and precision farming are transforming the way agricultural goods are produced and processed. Digital technologies, such as the Internet of Things (IoT), data analytics, and artificial intelligence (AI), are being increasingly used to optimize agricultural practices. It basically enables farmers to monitor health in crops, moisture in the soil, and patterns in weather that help them raise their productivity and reduce wastage (Goswami et al., 2023). Agri-tech startups mushroomed across India. Companies like DeHaat and AgroStar facilitate advisory services, quality inputs, and market linkages on digital platforms for farmers. This has considerably improved efficiency in the manufacturing supply chain associated with agriculture (Krishnaswamy, 2020).

Mechanization in Indian agriculture has been one of the strong drivers. Drastically, it has reduced labor costs by using tractors, harvesters, and irrigation systems, enhancing the efficiency of farms. India is becoming the largest producer of tractors in the world and exports to the USA and China are on the rise (Gulati & Juneja, 2020) . Industry 4.0 technologies in the manufacturing of agriculture-related products are at their infant stage but are very promising. Such technologies using drones, spatial imagery, big data analytics, and blockchain are being researched by (Arora, 2021) for precision farming, crop condition monitoring, and supply chain transparency.

India's manufacturing sector for agriculture-related industries makes for a critical strategy of this country for agriculture and economic growth. The agri-manufacturing segment of India has received a great boost with greater government support, presence of key players such as Mahindra and Tata, besides emerging technologies in digital and Industry 4.0 something reflected in Table 2. Indeed, regional hubs and agri-tech startups are also pushing modernization, improving efficiency and productivity.

Table 2: The Current Landscape of Agriculture-Related Manufacturing in India

Criteria	Description	Citation
Government Support	Increased government investment and focus on agricultural productivity and rural income.	(Singh et al.,
Major Players in Manufacturing	Mahindra: Global leader in tractor manufacturing; also produces harvesters and farm equipment.	(Gulati & Juneja, 2020)
	Tata Chemicals: Key player in agrochemicals, producing fertilizers and crop protection products.	(Singh et al., 2020)
	Godrej Agrovet: Focuses on animal feed, crop protection, dairy, and food processing; known for innovations in animal nutrition and crop care.	(Ponniah & Sri, 2022)
Regional Hubs	Madhya Pradesh is a key hub for farm machinery production, including rotavators and harvesters; manufacturers are integrated with subsidy schemes.	(Kumar, 2021)
Agri-Tech Startups	Startups like DeHaat and AgroStar provide digital platforms for farmer advisory, quality inputs, and market linkages.	(Krishnaswamy, 2020)
Industry 4.0 Technologies	Emerging use of drones, spatial imaging, big data, and blockchain for precision farming and supply chain management.	(Arora, 2021)
Future Potential	Continued adoption of advanced technologies promises to improve sector efficiency and sustainability.	(Arora, 2021)

4. TECHNOLOGICAL ADVANCEMENTS IN AGRICULTURE-RELATED MANUFACTURING

Greatest change has come about in the manufacturing-for-agriculture sector in India, because of automation, AI, robotics, precision agriculture, IoT integration, and smart techniques of manufacturing into it. These technologies are the future and change in agriculture since they enhance productivity, reduce waste, and make farming more sustainable. Automation in the farm sector has caused revolutionary changes in farming practices. Being that the population is increasingly growing, so does food demand as well. Most farming activities nowadays incorporate automation technologies, such as robotics and AI, to improve efficiency and eliminate reliance on human labor. Automated systems for planting, irrigation, harvesting, and pest control have improved productivity and reduced labor costs. Autonomous tractors and harvesters, leading manufacturers, such as Mahindra & Mahindra and John Deere, have developed autonomous farm machinery that can operate without human intervention, optimizing field operations and reducing downtime. For example, automated irrigation enables the realization of irrigation with high accuracy, such that crops would precisely get those amounts of water suitable for their needs, therefore allowing waste reduction of water and better yields. Soil moisture is detected by IoT-enabled sensors that automatically trigger irrigation systems (Krishnan, Swarna, & Balasubramanya, 2020). Then, there is robotic weeding; since this would involve automated machinery, it would need to make use of machine learning algorithms so that it would be able to recognize and remove weeds successfully, reducing the need for chemical herbicides, hence making farming more sustainable (Oliveira et al., 2021).

4.1 Artificial Intelligence and Machine Learning

In modern times, AI and machine learning find their places even in agriculture. It helps farmers arrive at informed choices for betterment in farm management. Applications range from crop monitoring and yield prediction to estimation of soil health. This is a platform which enables the usage of machine learning algorithms for farmers to predict weather patterns, detect diseases, and make prudent resource allocation decisions without wasting even a single minute. It enables precision farming whereby vast volumes of data emanating from sensors, drones, and satellite imagery are analysed. The AI systems can assess the condition of the soil, predict weather events, and recommend the optimal time for planting and harvesting. Machine learning models can predict high-accuracy crop yields out of historic data and currently prevailing growth conditions to thereby allow farmers to plan their harvests in a manner that optimizes the same (Sharma et al., 2021).

4.2 Robotics in Agriculture

Robotic systems are being increasingly adopted in agriculture to perform tasks that are labor-intensive, repetitive, and time-consuming. Robotics has applications across various stages of agricultural production, from soil preparation to harvesting. On the one hand, integration of robotics develops productivity, while on the other hand, it reduces the heavy amount of physical work a farmer has to go through. Drones for monitoring crop health, spraying pesticides, and taking high-resolution images of the fields for condition analysis proliferate, driven by AI in the detection of water stress, pest attack, and nutrient deficiencies among many others (Emmi et al., 2023). With sensors and AI algorithms integrated, such robotic systems will be able to harvest autonomously. Most of the work of laborers will be reduced, therefore. Such applications find their pace in those crops which have more labor involvement, like fruits and vegetables (Oliveira et al., 2021). Weeding and seeding robots, which have gained momentum, can place seeds correctly at their specific places and uproot weeds without affecting the crops (Fountas et al., 2020).

4.3 Smart Manufacturing Techniques in Agriculture

Smart manufacturing in agriculture integrates automation, robotics, and AI into the production process, making farming operations more efficient and sustainable. Smart farms use connected devices and systems to monitor, control, and optimize every stage of production, from planting to harvesting. With the coming of emerging smart manufacturing technologies, the agrarian practice is constantly being transformed through a series of smart farm machineries and systems-efficient means for resource usage, raising productivity, and ensuring efficiency in farming. The Internet of Things has realized significance in smart farming through devices interconnected to monitor, manage, and perform various agricultural activities.

IoT systems are acquiring data from the field in real time, using sensors that track variable factors in soil moisture, temperature, health of crops, and other environmental conditions. Data received is sent to a centralized system for analysis and therefore provides insights to farmers in decision-making for better productivity and resource utilization. IoT devices include a soil moisture sensor, a weather station, and crop health monitors that provide accurate data of field conditions. It assists in irrigation scheduling optimization, saves water from being wasted, and improves the general plant health. According to (Gagliardi et al., 2021) for the project ENOTRIA TELLUS, an IoT architecture for precision farming was implemented in order to manage vine health by means of remote data analysis, with the processing of video input and sensors. IoT devices play a significant role in implementing precision farming owing to the fact that they provide detailed information about the condition of the crops.

Robotics in Smart Farms

Robotic systems are being used increasingly in agriculture for traditional field operations, such as planting, weeding, and harvesting. Equipped also with AI and vision systems, the robots are able to navigate the fields autonomously, identify weeds, and remove them without crop damage-a reduction in the use of chemical herbicides and a minimal environmental impact.

For instance, robots, such as those discussed by Fountas et al. (2020), can carry out planting and weeding at very high levels of precision, thus improving yields per acre while reducing costs related to inputs (Fountas et al., 2020). In this respect, robotic reapers follow the principle with complex machine learning algorithms that detect the ripe crop and harvest it with efficiency. These robots work continuously and independently, without any manual labor, and the harvesting of crops can be precisely at the right time, improving crop quality and saving labor costs (Oliveira et al., 2021).

Artificial Intelligence and Machine Learning Applications

AI and machine learning are critical components of smart agriculture, allowing for the analysis of vast amounts of data to predict crop performance, optimize inputs, and manage risks. AI models analyze historical data and current growing conditions to forecast crop yields with high accuracy. This allows the farmers to improve their practices regarding dates of planting, nutrient application, and irrigation schedules. A study by Sharma et al. in 2021 showed that the algorithms in machine learning can predict soil moisture, levels of organic carbon, among other things, which are very essential for yields (Sharma et al., 2021). Blockchain is increasingly being used along agricultural supply chains to reduce opacity, improve traceability, and increase trust among producers, processors, and consumers. From seed to table, blockchain can ensure that everything is traded with records and verifiability after the audit. This is particularly important for crops classified as organic or of high value since their origin and authenticity are needed to make them successful in the market (Emmi et al., 2023). It aids in tracking shipments, most especially stages involved in the real-time processing of shipment stages that help minimize delays and supply chain inefficiencies. These can lead to a reduction in transportation costs, higher speeds of delivery, and even lower spoilage or wastage (Quy et al., 2022).

4.4 Smart Irrigation Systems

Perhaps the most vital challenge to agriculture is in the domain of water management, wherein smart irrigation systems employ real-time data for superior optimization of water application. Using the weather forecast over a period of time, soil moisture, and plant water requirements, the system automatically adjusts the irrigation schedules to get the right amount of water to the crops at the right time (Gagliardi et al., 2021). Drip irrigation using automation calculates the moisture of the soil with the help of IoT sensors and automatically waters the plants using a minimum amount of water to prevent wastage. This, in addition to saving water, also prevents overwatering, which causes leaching of nutrients, leading to crop loss. Smart greenhouses are those that have sensors, automation systems coupled with AI; these work together to develop a controlled environment for the plants. These systems will maintain the temperature, humidity, light, and CO2 at the highest point of productivity (Prabha & Pathak, 2023). Sensors track every condition in real time inside of a greenhouse and adjust to the best environmental factor that can sustain plant growth. For example, it could be the automation that automatically closes its windows if it is cold outside, simply to preserve the heating inside and lower/raise illumination depending on the amount of sunlight outside. Automation, AI, robotics, IoT, and blockchain are some of the technological advances in manufacturing concerned with agriculture, as depicted in Table 3. In this case, these technologies enhance productivity further and optimize resources used aside from reducing dependence on labor, and can thus be used to transform old farming methods into more productive and sustainable ones.

Table 3: Technological Advancements in Agriculture-Related Manufacturing

Technological Area	Specific Technology	Key Features/Applications	Examples/Companies	References
Automation in Agriculture	Autonomous Tractors & Harvesters	Operate without human intervention, optimize field operations, reduce labor costs	Mahindra & Mahindra, John Deere	Krishnan et al. (2020)
	Robotic Weed Control	Machine learning to detect/remove weeds, reducing herbicide use, enhancing sustainability	-	Oliveira et al. (2021
Robotics in Agriculture	Drones for Monitoring & Pesticide Spraying	Monitor crop health, water stress, pest infestations; high-resolution field imagery	-	Emmi et al. (2023)
Smart Manufacturing Techniques	IoT Integration in Smart Farms	Connected devices monitor soil moisture, temperature, and crop health; enables precision farming	ENOTRIA TELLUS project	Gagliardi et al. (2021)
Smart Greenhouses	AI and Automation Systems	Regulate temperature, humidity, light, CO2; optimize conditions for maximum productivity	-	Prabha & Pathak (2

5. MARKET TRENDS IN AGRICULTURE-RELATED MANUFACTURING

The manufacturing sector related to agriculture changes due to changing consumer preferences, advances in technology, and the way the world is changing in terms of trade policies. The various factors shaping the agriculture-related manufacturing in India and the rest of the world are domestic demand, export opportunity, altered consumer behaviour, and competition.

5.1 Domestic and Global Demand

Domestic demand for agriculture-related products in India constantly rises, given its ever-growing population and a general shift towards mechanization in farming. In fact, industry reports also note that domestic demand is supported by government initiatives like PM-KISAN, which equips farmers with better financial resources to invest in improved and advanced agricultural machineries/technologies (Gulati & Juneja, 2020). Simplification In India, too, the demand for value-added agricultural commodities is on the rise. An increasing awareness of health among consumers is leading to a greater demand for high quality and nutritious agriculture produce also stated (Krishnaswamy, 2020). Due to the adoption of advanced technology, North America and Europe, especially the United States and Germany, hold the largest share in the agricultural machinery market globally. This demand trend is also coming out in India and China, where farm mechanization is encouraged through the adoption of subsidies and financing policies to support agricultural machinery purchases. In India, most small-scale farmers do not have access to expensive machinery, hence the heightened usage of rental models like the Custom Hiring Centre - CHC model (Krishnan et al., 2020). Food Processing and Packaged Foods: Increasing Requirements. Processing of food items is one of the most rapid-growth industries across the world, as consumers are increasingly demanding processed and packaged foods. In fact, this trend is more pronounced in urban areas since hectic lifestyles, coupled with higher disposable incomes, spur demand for ready-to-consume foods.

Growth in Europe and North America: because of the increased interest of consumers in organic, natural, and health-oriented cuisine, interest in organic agriculture products has increased. Increase in the middle-class incomes of several countries belonging to this region, such as China, India, and Indonesia, has increased the consumption of processed foods, thus giving a growth impetus to the Asia-Pacific region as well. Companies take advantage of the trend by investing in food processing technologies that improve the safety of food and enhance its shelf life, which is an important aspect in meeting export standards, especially in the international markets (Mitrofanova et al., 2021). In many countries, the global focus on sustainability and climate resilience influences demand for agricultural products and their associated manufacturing. The market for seeds is predicted to increase due to the investment in the production of genetically engineered seeds by agricultural manufacturers to put up with adverse conditions, especially in regions that experience climate change (Tian et al., 2021).

5.2 Geopolitical Factors Impacting Global Demand

Global demand for agriculture-related manufacturing is also influenced by geopolitical factors, including trade wars, export restrictions, and conflicts. COVID-19 Pandemic, the pandemic severely disrupted global agricultural supply chains, leading to temporary declines in the demand for agricultural equipment and food products. However, the global market demonstrated resilience, and agricultural trade recovered to the end of 2020. From that perspective, one research study estimated that COVID-19 caused a shrinkage in global agricultural trade of around 5-10%, especially in non-food commodities and highly valued agri-food products (Arita et al., 2021). The Ukraine war disrupted global supplies of grain, as both were among the world's biggest exporters of wheat and other staple crops. Global grain prices surged in a disruption, which made countries scurry for alternative import sources.

5.3 Trade Agreements and Export Opportunities

Global trade agreements and partnerships play a vital role in shaping the demand for agricultural products and machinery. The United States-Mexico-Canada Agreement (USMCA) and European Union (EU) trade policies have enabled agricultural exporters to access new markets and increase export volumes. It has gained more from the expansion of its export base, as it is one of the major exporters of rice, spices, and organic products. Its organic agricultural exports have surged in both Europe and North America as consumer demand increases for healthy and ecologically viable produce (Bhatia, 2021). With modernization in agriculture, especially in Africa and Southeast Asia, there is increased importation of farm machinery and technologies from countries like India, China, and Germany. This creates new opportunities for manufacturers to expand into emerging markets. According to Mitrofanova et al. (2021), consumer behaviour in agricultural markets is increasingly geared toward sustainable, healthy, and organic food products (Mitrofanova et al., 2021). The demand for transparency in the food supply chain has prohibitively gained grounds among consumers in many countries of the world, especially in North America and Europe, where there is a growing demand for organic, non-GMO, and fair-trade products. It finds expression in farm-to-table movements, and in the increased market share of organic agricultural products. The change in consumer behaviour is more pronounced in urban areas of India, and in these areas, demand for organic and natural food products is briskly rising (Bhatia, 2021).

India has considerable export potential in the agriculture-based manufacturing sector, especially in machinery, processed foods, and organic products. It features amongst the top ten exporters of agricultural commodities, including rice, spices, beef, sugar, and shrimp. Besides, India is the major exporter of farm equipment to developing countries in Africa, Southeast Asia, and Latin America, where demand for low-cost, efficient machinery is rising buoyantly. Increasing demand for processed foods within Asia and Africa has given exporters the opportunity to spread their market base (Shaik et al., 2020). Ukraine and Kazakhstan are new entrants into the global agricultural market, especially for cereals and pork products. The countries are modernizing the agricultural infrastructure and raising the quality of their products, especially to meet demand from abroad (Dambaulova et al., 2022).

5.4 Competition in Agriculture-Related Manufacturing

The global manufacturing market in regards to agriculture is very competitive, with key players from North America, Europe, Asia, and Latin America competing for shares. India faces tough competition from countries like China, Brazil, and Germany

in the manufacture of agricultural machinery and processed foods. Major competitors within the market of agricultural machinery include John Deere, Kubota, Mahindra, and AGCO, to name a few of the big ones, each with a host of products for the satisfaction of various market segments. Mahindra & Mahindra is the largest tractor manufacturer of India, and it has since set wider footprints across more than 40 countries around the world, including the United States and Brazil. According to Mitrofanova et al. (2021), in the processed food and organic product segments, Indian companies face competition from Brazil, Argentina, and Mexico, especially while exporting cereals, oilseeds, and other staple items.

The demand for organic products, which has been on the rise in Europe and North America, has thus presented a competitive environment where producers in countries like Spain, France, and Italy are leading in the exportation of organic fruits, vegetables, and grains. Volkava & Mickiewicz, 2022 reiterates that current trends within the agricultural manufacturing market present both great opportunities and challenges for both domestic and global players. With increasing domestic and international demand, changing consumer behavior for healthier and more organic produce, and with better export opportunities, India has all the wherewithal to increase its influence in agricultural manufacturing. Yet, the country is also to provide stiff competition when it comes to overall global players, particularly concerning agricultural machinery and the processed foods themselves. Table 4 summarizes trade agreements and partnerships, participating countries, the impact of the same on agricultural exports, and key opportunities and regional contributions to global agriculture markets.

Table 4: Trade Agreements and Their Impact on Agricultural Exports

Trade Agreement or Partnership	Countries Involved	Impact on Agricultural Exports	Citation
United States-Mexico-Canada Agreement (USMCA)	USA, Mexico, Canada	Enabled agricultural exporters to access new markets and increased export volumes, particularly for processed foods.	(Bhatia, 2021)
India's Export Partnerships	India, Europe, North America	Significant growth in exports of organic agricultural products to Europe and North America due to rising demand for health-conscious products.	(Bhatia, 2021)
Africa and Southeast Asia Modernization	India, China, Germany, African and Southeast Asian Countries	Increased imports of agricultural machinery and technology from India, China, and Germany as these regions modernize their agriculture sectors.	(Mitrofanova et al., 2021)
Export Opportunities in Processed Foods	India, Brazil, Argentina, USA	Expansion in the export of processed agricultural products to growing markets in Asia and Africa, driven by increased demand for processed foods.	(Shaik et al., 2020)
Eastern Europe Grain Exports	Ukraine, Kazakhstan	Investment in agricultural infrastructure allowed these countries to become key players in cereals and pork products, expanding their market reach globally.	(Dambaulova et al., 2022)

The trade agreements and partnerships that have significantly influenced agricultural exports globally as shown in table 4. Agreements like USMCA and EU trade policies have facilitated access to new markets, particularly for health-focused and organic products. India benefits from increased export opportunities in organic produce, while countries like Ukraine are expanding their agricultural exports through infrastructure modernization.

6. GOVERNMENT POLICIES AND INCENTIVES

The agriculture-related manufacturing sector in India is crucial for enhancing agricultural productivity and ensuring food security. The government has implemented a range of policies and incentives to promote this sector, addressing both domestic needs and export potential. The flagship initiatives are Make in India, subsidy for farm machinery and inputs, tax incentive, and DBTs for promoting agricultural manufacturing industries and general economic growth. The 'Make in India' programme initiated in 2014 was one of the flagship schemes aimed at transforming the country into a global manufacturing hub. The initiative covers several sectors, which include agricultural manufacturing, enhancing investment and innovation, and developing world-class infrastructure.

Even in the agricultural machinery sector, make in India has been a great beneficiary; Mahindra & Mahindra and Escorts are expanding their manufacturing capacity to not only cater to the domestic market but display leading exporters of tractors and farm equipment. The government support through the Make in India initiative has contributed to setting up new manufacturing units and also modernizing the existing units to enhance efficiency and productivity (Gulati & Juneja, 2020). Hence, allowing foreign direct investment in the agricultural machinery sector. Quite a few international companies have set up their bases in

India with joint ventures and other collaborations that result in the technology transfer and expertise development concerning precision farming and farm mechanization.

6.1 Subsidies in Agricultural Manufacturing

The Government of India provides a broad set of subsidies covering the promotion of modern farming technologies, subsidies on the manufacture of various farm inputs such as fertilizers, seeds, and machinery. Farm Mechanization Subsidies, to enhance farm mechanization, the government has implemented several schemes offering subsidies for purchasing tractors, harvesters, and other agricultural equipment. These subsidies are disbursed through programs like the National Mission on Agricultural Extension and Technology (NMAET). Further, the DBT mechanism for agricultural inputs has straightened the subsidy distribution mechanism so that funds reach the intended beneficiaries more effectively. That is achieved through an initiative known as the Direct Benefit Transfer Mechanism for Agricultural Inputs, which has helped in the efficiency at which the funds are provided to the farmers (Saini, Kishore & Alvi, 2020). Fertilizer subsidies help in improving crop yields and maintaining soil fertility. The Indian government provides subsidies for fertilizers dealing with urea and micronutrients like zinc and boron. Therefore, they ensure that the needed inputs are available at cheap prices to the farmers.

However, mismanagement and inefficiency concerns in the distribution of the subsidy have resulted in reforms, which include using Aadhaar-linked DBT in the purchase of fertilizers, a system that ensures transparency and reduces fraud (Anand & Sah, 2020). There are specific state-level initiatives aimed at addressing micronutrient deficiencies of soils; for example, the Zinc Subsidy Program exists in Andhra Pradesh. These subsidies are supposed to compensate for poor soils and enable farmers to use more productive farming practices, experts explain, arguing that direct cash could be an even better way of delivering such subsidies (Gupta et al., 2020).

6.2 Tax Benefits and Incentives

The Indian government provides various tax incentives to encourage investments in the agricultural sector. These tax benefits aim to reduce the financial burden on companies involved in the manufacturing of agricultural products and equipment, thereby promoting growth and innovation. Agricultural income is fully exempt from taxation under the Income Tax Act for all of India. It extends direct benefit to the farmers by way of decrease in price of raw materials and inputs as well as indirect benefit to the industries falling under the category of manufacturing agricultural outputs. Companies associated with agricultural machinery manufacturing industry are granted exemption and concession of excise duty. These exemptions reduce the cost of manufacture and purchase of agricultural machinery, thereby promoting mechanization in the country. A study on the implication of tax exemption for Indian manufacturing identifies that excise tax rules have incentivized manufacturers to stay in a miniature and agile entity to gain maximum fiscal incentives (Ramaswamy, 2021).
To boost innovation in agriculture, the government has given tax holidays for startups dealing in agri-technologies. It saves the financial burden of companies during their initial years through these tax holidays, further encouraging investment in research and development pertaining to smart agriculture solutions, which shall include IoT-based systems and precision farming technologies (Ponniah & Sri, 2022).

6.3 Direct Benefit Transfers (DBT) and the Use of Technology

The DBT system has reshaped subsidy disbursement and financial support that happen in the agriculture of India. In the case of DBT, the policy ensures that government subsidies related to fertilizers, seeds, and farm machinery are directly transferred into the bank accounts of beneficiaries. The blockchain-based solutions ensure that the subsidy is disbursed directly to the beneficiaries, cutting out all middlemen and reducing delays. A blockchain-based prototype developed for the disbursement of agriculture subsidies demonstrated transparency and efficiency in subsidy delivery (Bakare et al., 2021). Identification through Aadhaar-a unique identification system in India-has made subsidy disbursement more appropriate and smoother. Linking subsidy to Aadhaar by the government ensures that the benefit definitely reaches the beneficiary, reducing fraudulent claims.

Impact of Government Policies on Agriculture-Related Manufacturing

Proactive policies and incentives by the government have struck a chord with this sector's growth in India. The Indian government has been trying, through well-planned subsidies and tax benefits, to promote farm mechanization over time. This transformation in farming techniques has taken place across the nation. Such a policy will encourage farmers to adopt modern machinery such as tractors, harvesters, seeders, and irrigation systems that facilitate their shift from labour-intensive farming techniques to technology-based farming techniques. Productivity increased so much through mechanization that farmers can cultivate larger plots of land with less employment of labour resources. The use of tractors, for example, cuts down on the hours it takes to Plow, while modern irrigation methods reduce loss of water due to inefficiency. The yield of crops has therefore been improved even in those areas where drought is a common occurrence. Major initiatives, such as the National Mission on Agricultural Extension and Technology, have subsidized most agricultural equipment, hence making it more adoptable by poor and marginal farmers. From another perspective, mechanization has increasingly contributed to reducing labour costs due to rural-urban migration and aging in the agricultural workforce. With DBT for agricultural machinery, the process of receiving subsidies became smoother and reduced the involvement of middlemen in the distribution of policymakers. Assuredly, farmers directly benefited from the government scheme (Saini, Kishore & Alvi, 2020). According to Saini, Kishore & Alvi, 2020, Mechanization has also made farming more sustainable by encouraging precision agriculture.

Technologies such as automated seeding and GPS-guided tractors allow for more efficient use of inputs like seeds, fertilizers, and water, reducing environmental impact. In summary, the government's push for increased mechanization has made Indian agriculture more productive, sustainable, and competitive on a global scale, benefiting farmers and consumers alike.

6.4 Enhanced Export Potential

India's agricultural machinery and processed product exports have surged in recent years, thanks in part to government initiatives like Make in India. The Make in India campaign, which emphasizes domestic manufacturing and encourages global investment, has significantly enhanced India's capacity to produce agricultural equipment and food products for export. Indian companies like Mahindra & Mahindra and Escorts also expanded their global presence and gained positions among the world leaders in export of tractors and other farm machinery. The country attained an essential position as a supplier of farm machinery to emerging markets in Africa, South East Asia, and Latin America, where demand is continuously growing for low-cost machinery with pretension to efficiency. The export-friendly policies have also helped India's processed food industry, with spices, rice and ready-to-eat meals reaching the markets in Europe, North America, and the Middle East. The introduction of export incentives by the government apart from tax rebates for the agri-based industries has further reinforced the idea in the minds of the manufacturers. Schemes put forward, like RoDTEP, have helped bring down the cost of export, thereby making Indian products more competitive at the global level. Adoption of advanced manufacturing technologies in food processing-such as automation and AI-has usefully assisted Indian companies in meeting international standards (Bhatia, 2021). These, in turn, have been accentuated by certain improved logistics and supply chain infrastructure that eventually positioned India as a globe player in agricultural exports. With the increasing demand for Indian made machinery and processed food items, its export potential is very likely to go up further thereby giving a bullish run to economic growth.

Small and marginal farmers constitute the backbone of Indian agriculture, mainly representing over 85% of the country's farming population. These are farmers with less than two hectares of operational landholding, accompanied by limited financial capability to afford modern agricultural technologies and inputs. The government has framed a number of policies for improving livelihoods among small and marginal farmers through targeted subsidies, credit schemes, and DBT for critical inputs like seeds, fertilizers, and machinery. These schemes of the government, such as PM-KISAN, provide monetary support to the small farmers and enable them to invest in better agricultural tools and technologies. The mechanism of DBT has been implemented where the money regarding subsidy and financial assistance is deposited directly into the bank accounts of farmers to reduce intermediaries' influence and bring more transparency and efficiency in the system. These initiatives have given small farmers the power to use mechanization, improve farm output, and increase their income.

The formation of Farmer Producer Organizations was promoted; hence, it allowed the pooling of resources by small farmers, giving them access to better marketing opportunities. FPOs enable farmers to negotiate better prices for inputs, access modern machinery through group purchases, and get better returns for their produce by directly linking up with buyers, bypassing middlemen. These organizations facilitate access to government schemes so that even the smallest of farmers can gain from a whole array of subsidies/incentives available (Ponniah & Sri, 2022). Government policy and incentives have played an important role in fostering the growth of agriculture-related manufacturing in India. Initiatives such as Make in India, mechanization and input subsidies, tax incentives, and implementation of DBT have a collective effect on increasing productivity and competitiveness in the sector. Table 5 provides a detailed summary of different producer subsidies and tax incentives in place for the agricultural manufacturing industry in India, alongside its eligibility, effects, and relevant citations for each measure.

Table 5: Subsidies and Tax Benefits in India's Agricultural Manufacturing Sector

Type	Subsidy/Tax Benefit	Eligibility Criteria/Targeted Sub-Sector	Impact on the Sector	Citation
Subsidy	Direct Benefit Transfer (DBT)	Farmers registered with Aadhaar, linked to a bank account	Streamlines subsidy distribution, ensuring funds reach intended beneficiaries directly and reduces corruption.	(Saini, Kishore & Alvi, 2020)
Subsidy	Fertilizer Subsidies	Farmers purchasing fertilizers like urea and micronutrients	Reduces the cost of essential fertilizers, improving crop yields and maintaining soil health.	(Anand & Sah, 2020)
Subsidy	Zinc Subsidy Program	Farmers in regions with micronutrient-deficient soils (e.g., Andhra Pradesh)	Boosts crop productivity by addressing soil deficiencies with specific nutrient supplements.	(Gupta et al., 2020)
Tax Benefit	Income Tax Exemption	Agricultural income from farming	Reduces financial burden, makes farming more profitable, indirectly benefits agricultural manufacturers.	(Ramaswamy, 2021)

Tax Benefit	Excise Duty Exemptions	Agricultural machinery manufacturing	Lowers cost of manufacturing agricultural equipment, boosting mechanization adoption across India.	(Ramaswamy, 2021)
Tax Benefit	Tax Holidays for Agri-Tech Startups	Startups in agricultural technology, precision farming	Encourages innovation and investment in research and development of smart agriculture solutions like IoT systems.	(Ponniah & Sri, 2022)

These incentives, including subsidies for farm mechanization and tax exemptions for agri-tech startups, aim to boost productivity, foster innovation, and ensure affordable access to modern farming technologies as in table 5. The initiatives collectively promote growth, efficiency, and the adoption of advanced agricultural practices.

7. CHALLENGES AND BARRIERS IN AGRICULTURE-RELATED MANUFACTURING

Agriculture-related manufacturing faces significant challenges that affect its ability to meet growing global demands. These are multidimensional problems of supply chains, infrastructures, lack of labor supplies, and barriers in regulation. Supply chains in agriculture-related product manufacturing are very intricate and sensitive to internal and external influences. These issues range from deficiencies and inefficiencies in infrastructure, technological gaps, and coordination issues. Cold chain facilities are usually short among the biggest problems in any agri-supply chain, as is often the case even in developed countries. In preserving perishable agricultural products, cold chains are indispensable, including fruits, vegetables, and dairy products. High post-harvest losses are because of inadequate cold storage facilities. Studies have demonstrated a high percentage of lost fresh produce due to the lack of proper storage and transport in temperature-controlled systems. For example, one of the major losses in the fresh produce supply chain in India is attributed to the lack of cold chain infrastructure for mainly fruits and vegetables. It subsequently means reduced returns for the farmers, while for the consumer, it is inflationary prices (Singh et al., 2022). The quality of perishable goods declines rapidly without proper cold storage. This affects the marketability of products, leading to reduced profits for producers and distributors.

7.1 Logistical and Transportation Barriers

The major issues can be summarized as follows: agricultural logistics are riddled with issues that supply chains cannot work at an optimal level. First, there is a problem of general lack of transportation infrastructure, especially relating to those areas that are rural and produce agricultural goods. Problem of transport infrastructure: A good number of rural agricultural areas have poorly maintained roads and dependable means of transport to make the movement of items by farmers to markets or other centres for processing easy. Delays in transport further lead to higher spoilages of perishable products, with increased costs due to longer travel times and higher fuel consumption. Poor infrastructure amplifies time and effort in transportation of goods, hence increasing the risk of spoilage, thereby enhancing cost overruns (Singh et al., 2022). The cost of agricultural product transportation can be very high due to factors ranging from fuel prices, routing inefficiency, and the need for specialized vehicles-such as refrigerated trucks. Typically, these costs are passed down the value chain, physically increasing the cost of agricultural products for consumers.

Fragmentation and Lack of Coordination

The supply value chain in agriculture is broad, from small farmers and distributors to processors and into retail. Lack of coordination along the value chain leads to inefficiencies that contribute to breakdowns: Fragmented Supply Chains, small-scale farmers often operate in isolation from each other and from the larger supply chain, which makes it difficult to achieve economies of scale. This leads to fragmented production, distribution, and processing, and hinders farmers' price bargaining or assured quality products (Long et al., 2016). Efficiency in the supply chain is directly dependent on timely information sharing across the chain; however, in agricultural supply chains, this level of coordination is still at a minimum. For instance, farmers may not get current market information in time and hence fail to adjust production to effective demand.

Regulatory Challenges in the Supply Chain

Inconsistent regulations across regions: When there are different regulatory frameworks, it simply raises the barrier to supply chain integration. For instance, different levels of food safety, quality control, and environmental standards may set in at the local, regional, and national levels. Supply chain operators face a difficult time complying with all sets of such variable regulations (Zivkovic et al., 2022).

Delays Due to Bureaucracy: In many countries, delays in things such as regulatory approvals for the exportation of products, accessing of subsidies, or adoption of new technologies serve to slow down supply chain operations. Other than that, these bureaucratic inefficiencies further complicate the process of moving products through the supply chain and, therefore, create bottlenecks that reduce overall productivity (Smyth, 2020).

Sustainability is increasingly grossing a critical consideration in agriculture supply chains. The agricultural sector, being a major contributor, exerts particularly just a few of the environmental impacts in the form of deforestation, land degradation, and water usage. Thus, the introduction of sustainable practices within supply chains is quite important; nevertheless, many supply chains are challenged in implementing practices like waste reduction, carbon footprint minimization, and water

conservation (Mohseni et al., 2022). There is a growing pressure exerted both by consumers and regulators in terms of making sure that agricultural commodities are sourced in a responsible way. Yet, this move towards green supply chains has at times necessitated huge investment in new technologies and practices, which for the first time took an unprecedented toll on the finances of small and medium producers.

Farmers in rural settings, those from the most scattered areas, make infrequent and only limited use of maintenance services due to general lack of access; thus, they experience long downtimes with increased repair costs. These delays further reduce operational efficiency and generally keep farmers away from meeting market demands (Abirami et al., 2023). The expensive nature of advanced machinery puts them out of reach to many small-scale farmers, and high investment in buying and maintenance of such machines is a limiting factor to this date. The lack of financial incentives and subsidies from governments further exacerbates this issue, making it difficult for farmers to upgrade their technology and improve productivity. The agricultural manufacturing sector relies heavily on transportation to move raw materials, processed goods, and perishable products from farms to markets and processing facilities.

All these factors raise fuel costs, cause delays, and incur added costs of rerouting the goods with assistance from other means of transportation. The unavailability of efficient means of transportation restricts small-scale farmers with low bargaining positions against buyers and middlemen regarding the prices that should prevail in the market.

Cold chains play a very important role in maintaining the quality and ensuring the safety of perishable agricultural products. However, in the absence of refrigerated trucks and storage facilities at different touch points in the supply chain, food items get spoiled and wasted, a pattern commonly seen in India. If cold chain logistics is grossly inadequate, agricultural products decay before they reach customers, causing losses to farmers and manufacturers alike. In fact, (Singh et al., 2022) have made the following observation.

With the advancement of modern technologies in irrigation, such as drip irrigation and sprinkler systems, these methods have proved to be more viable and efficient. Yet, such technologies again require huge investments, which many small-scale farmers cannot afford (Neupane et al., 2023). Indeed, there is still limited access to irrigation due to general poor infrastructure or the high costs of water delivery systems in much of the world. This affects crop yields, especially in countries with erratic or low rainfall that is not sufficient for crop use. Inadequate irrigation infrastructure further lowers the farmers' capacities to produce high-value crops due to the need for a regular water supply.

It is also noted that power supplies, particularly in most developing countries and especially in rural areas, are unreliable and frequently disrupted. This inconsistency makes it very difficult for agricultural manufacturers to operate machinery efficiently, which may delay the orderly production cycle and increase operational costs. Farmers or manufacturers may need to rely on expensive generators to maintain productivity during power outages, thereby increasing the cost of production (Adriant et al., 2021).

7.2 Digital Divide and Technological Gaps

The increasing role of digital technologies in agriculture has underlined the digital divide between rural and urban areas and also between developed and developing nations. Most rural agricultural areas lack high-speed internet, which is important for accessing digital technologies related to precision farming, real-time data analytics, and blockchain for supply chain transparency. Without reliable access to the internet, no farmer or manufacturer can maximize the fullness of these innovations; therefore, they are very limited in their ability to fully optimize production processes and improve supply chain efficiency (Kraft & Kellner, 2022). A skills gap prevents the successful adoption and implementation necessary to improve productivity, reduce waste, and increase supply chain transparency (Long et al., 2016). Digital tools and technologies such as IoT sensors, drones, and satellite imagery are well beyond the budgets of most small-scale farmers. These technologies offer significant benefits for monitoring crop health, optimizing water usage, and improving yield forecasts, but their adoption remains limited due to the high cost of equipment and the lack of financial support for small and medium-sized farms.

7.3 Labor Shortages

Labor shortages pose a significant challenge in agriculture-related manufacturing, affecting productivity, operational efficiency, and the ability to meet growing market demands. These shortages are influenced by a complex array of factors including demographic changes, migration patterns, lack of skilled labor, poor working conditions, and the slow adoption of mechanization. Labor shortage has a trickling effect on the agricultural supply chain, starting from primary production to processing and distribution, ultimately affecting the growth and sustainability of the sector. One of the leading causes of shortages in labor within agriculture is continuous migration among laborers from rural agricultural places to urban centres for better prospects of employment. This has been a trend of rural-to-urban migration around the world, but the felt effects are more pronounced in developing countries where agriculture is the leading industry. Youth migrate from the countryside to cities, where perceived economic opportunities for themselves are better and wages higher with a perceived higher standard of living.

Agriculture, at least a traditional understanding of the profession, is rated as one of the less desirable career paths due to its hard physical work and relatively low financial rewards. As a result, farms as well as agricultural manufacturing facilities face a growing scarcity of workers, especially during peak farming seasons or when crops are ready for harvest, as identified by Abirami et al. (2023). For example, in Japan, the U.S., and most parts of Europe, the average age of farmers is growing older by the day, while there is less enthusiasm among the younger generation to take up farming. This aging manpower is apt to refuse new technologies, innovations, or expansion in the production capacity, thereby worsening the gap of labor in agriculture.

Younger people in their early adult years tend to be disinclined towards agricultural work due to the nature of the physical tasks involved, its perceived unprofitability, and the societal pressure to pursue urban-based jobs. This reluctance has offset the labor void which agricultural manufacturing is barely able to fill (Sivertsson & Tell, 2015). With fewer young entrants into the industry, that naturally would mean a possible loss of basic knowledge and experience that has been passed down through generations thus far.

Technological Skills Gap: Agricultural manufacturing, slowly but surely, is opening its doors to automation or precision based on digital tools such as the Internet of Things and blockchain. This raises certain concerns regarding the supply chain and calls for workers in the future who will be proficient enough to understand such prospective systems in application and maintenance. However, the usual rural worker lacks technical know-how while dealing with such systems; hence, there exists a gap between technology that is available and employable labor (Long et al., 2016). Many rural areas lack access to education and training programs that focus on the skills needed in modern agriculture. This shortage of education and training infrastructure limits the ability of rural populations to upskill and meet the demands of modern agricultural manufacturing. For example, the lack of vocational training programs targeted at the sector of agricultural technology diminishes the number of potential workers who can undertake management of mechanized equipment or digital supply chain systems (Abirami et al., 2023). Moreover, when these are available, there may be resistance among the older members of the workforce against the development of new practices and technologies, and thus the skills gap that pervades agriculture-related manufacturing further spreads. This reluctance or resistance to shift to newer methods violates the modernization process of agricultural manufacturers, especially in areas where manual labor is predominant (Adriant et al., 2021). Agriculture is one of the most seasonal occupations, with a peak labor demand during the seasons of planting and harvesting crops. Most farms, in intensive agricultural-producing areas, depend on temporary and migrant workers during peak periods. Yet, seasonal employees usually have poor conditions, insufficient housing, and lack of efficient protection provided by the law. Such conditions automatically increase labor mobility and hamper labor supplementation in the peak season of demand (Long et al., 2016). Basically, the seasonal worker does not always come back year after year; hence agricultural manufacturers are faced with unpredictability of supply by labor. Furthermore, political fluctuations-for example, changes in immigration policy or limitations on labor migrants-can make or break the availability of seasonal labor. Generally speaking, poor working conditions are also often associated with shortages of labor in agriculture, as many are not willing to take up such burdensome tasks. Above all, agricultural work is carried on in several developing economy regions, and it involves hard physical work, extreme temperatures, long working hours, and the application of chemicals like pesticides and fertilizers (Sivertsson & Tell, 2015). Better and less time-consuming employment opportunities with higher wages can be a discouraging factor for a probable worker to search for job opportunities in the sector. Poor housing, lack of healthcare, and low or no safety regulations often confront workers in many agricultural sectors-most depending on seasonal or migrant labor. The lack of worker protections reduces job satisfaction and increases turnover, hence making it difficult to maintain consistent work for agricultural manufacturers (Long et al., 2016). Agriculture is an area where serious risks to health are considered: chemicals used, long-term musculoskeletal disorders due to repetitive hand labor, and even more frequently, accidents involving heavy machinery. These risks discourage many potential workers from entering or remaining in the agricultural workforce. While mechanization and automation offer solutions to labor shortages in agriculture-related manufacturing, their adoption has been uneven, particularly in developing regions where manual labor still dominates. The main problem is the initial investment required in tractor mechanization, harvesters, and processing equipment; this is very costly for most small-scale farmers and manufacturers. This is further contributing to the use of hand labor concentration and leading to persistent labor shortages, since the number of workers is not enough to meet demands during the period of peak production level (Kraft & Kellner, 2022). For instance, small-scale food producers in Europe have to face serious difficulties due to various regulatory requirements across EU member states, especially those in short food supply chains (Zivkovic et al., 2022). Most developing countries lack consistent agricultural regulation-the uncertainties for manufacturers still exist. Whereas in some regions the food safety and quality standards may be well implemented, other regions apply more lenient rules or poorly enforced standards. This inconsistency creates inequity in the playing field and makes the local farmers/manufacturer unable to do their long-term planning for which they need stable conjunctures. Agriculture manufacture involves bureaucratic procedures that often become very complex, especially in permitting processes or in compliance with environmental and food safety regulations; all of this contributes to the emergence of many delays. Obtaining licenses to expand operations or introduce new technologies, for example, may be an extremely long and costly procedure, since one will have to make considerable investments in order to achieve the required standards of compliance. Innovation in manufacturing with regard to agriculture is important for productivity, sustainability, and competitiveness. In many cases, regulatory frameworks cannot keep pace with rapid technological changes in areas such as genetic engineering, biotechnology, and precision agriculture. For example, strict EU regulations concerning genetically modified organisms and gene editing significantly hinder the diffusion of such technologies. Even though gene editing is positioned to open up prospects for higher crop yields and food security, respective restrictions imposed by regulatory authorities prevent agricultural manufacturers from fully exploiting such novelties in their practice (Smyth, 2020). Delays in regulatory approval of new agricultural inputs, such as fertilizers and pesticides or herbicides, greatly affect the manufacturing process. Whereas new inputs are continuously developed to meet emerging challenges-for example, resistance or climate change-the same regulatory bodies take years to approve their use. This delay leaves manufacturers using outdated inputs, which can reduce productivity and increase environmental impact. In emerging fields such as blockchain technology and artificial intelligence (AI) in supply chains, there is often a lack of regulatory clarity. For example, while blockchain can make agricultural supply chains more transparent with less fraud, further uptake is discouraged by ambiguous regulations concerning data protection, Internet security, and standards for the technologies

introduced (Kraft & Kellner, 2022). All these are heightened by the financial costs regarding regular inspections and audits performed by regulatory authorities. However, to the small manufacturers, these costs could be way too high (Adriant et al., 2021). As much as they would want to operate within the lawful stipulations put forward by the food regulating bodies, they are often forced either to operate at a loss or to risk being non-compliant. Indeed, small-scale producers and manufacturers bear a disproportionate regulatory burden and in general do not have such financial and administrative resources as are associated with larger firms to manage compliance efficiently. Large agribusinesses can mostly bear these costs much more easily in comparison to smaller farmers or manufacturers; hence, this disadvantage creates an unlevel playing field, which is one factor that diminishes competition (Zivkovic et al., 2022). This has been seen in the case of small supply chains across Europe where small-scale producers cannot keep up with regulatory demands, while multinational companies will sweep away the shares. Isolation of international trade regulations may either facilitate or create a barrier to market access. Trade policies, such as tariffs and import quotas, can greatly influence the competitiveness of agricultural products in international markets. For example, sudden rises in tariffs can increase the cost of exportation of agricultural commodities, thereby reducing demand and profitability for manufacturers. Similarly, high import requirements for markets like the EU or the U.S. reduce the possibility of producers in developing countries entering their markets (Smyth, 2020). These include measures that are put in place to protect human, animal, and plant life by regulating the importation and exportation of agricultural products.

Agricultural manufacturers are required to meet a wide range of environmental regulations, including limits on water usage, waste management, and emissions from processing plants. These regulations often require significant investments in new technologies and infrastructure to comply with environmental standards. For instance, in the cases of waste reduction and efficient energy use, processes may be too time-consuming and costly for manufacturers to afford, especially when there are no financial incentives or governmental supports in place (Mohseni et al., 2022). The rise in consumer interest in the origin of food products and the methods behind their production has meant an increase in the number of regulatory policies thrown at agricultural manufacturers to participate in or utilize sustainable behavior. Nevertheless, huge preliminary investment and reorganization are required to replace such sustainable methods in organic farming, carbon-neutral production, or circular economy models (Kumar et al., 2021). Such a transformation may not be easy for small manufacturers lacking the capital or know-how to do so. It often creates unfair competition, as those manufacturers that do not adhere to set environmental regulations are able to edge out other manufacturers that invest much in compliance with stringent regulatory standards (Abirami et al., 2023). Though subsidies, grants, or other financial incentives are provided by most governments to ease the burden of agricultural manufacturers in their effort to comply with agreed regulations, accessing them is quite cumbersome, as most programs face bureaucracy. For example, small manufacturers may not be able to make their way through complicated application processes or meet the eligibility criteria of government support and, therefore, will not have the developed financial resources that are needed to renew equipment or a technology base.

8. SUSTAINABILITY AND ENVIRONMENTAL CONSIDERATIONS

Manufacturing related to agriculture is one of the productive sectors in the global economy, but it simultaneously faces challenges in areas concerning sustainability and environmental footprints. Its environmental impacts include a wide array of areas: greenhouse gases, water pollution, soil degradation, and deforestation. Nevertheless, there is growing recognition of the need for sustainable practices and innovations that will reduce these environmental impacts while maintaining economic viability.

8.1 Environmental Impacts

Agriculture-related manufacturing has significant environmental implications, particularly due to its reliance on natural resources and the generation of waste and emissions. Agriculture is a significant contributor to global greenhouse gas emissions, primarily through methane emissions from livestock, nitrous oxide from fertilizers, and carbon dioxide from land-use changes such as deforestation. Manufacturing related to agriculture is one of the productive sectors in the global economy, but it simultaneously faces challenges in areas concerning sustainability and environmental footprints. Its environmental impacts include a wide array of areas: greenhouse gases, water pollution, soil degradation, and deforestation. Nevertheless, there is growing recognition of the need for sustainable practices and innovations that will reduce these environmental impacts while maintaining economic viability.

Of greatest concern is the intensification through application of chemical fertilizers, pesticides, and heavy machinery. Agriculture is one of the biggest manufacturers in freshwater use. Poor management practices result in over-extraction, shortage of water, and water pollution. Application of fertilizers and pesticides in agriculture contributes to water pollution by running off into rivers and lakes and causing eutrophication, causing damage to aquatic ecosystems. Besides, most of the agricultural activities, in particular irrigation and processing, involve volumes of very large water (Pretty, 2018). This generates competition for water supplies, particularly in areas that have low levels of water supply. The intensive agriculture and manufacturing practices have led to large-scale degradation of soils through erosion, loss of fertility, and desertification. Heavy use of chemical inputs with unsustainable land management practices strips off the soil of its very nutrients and diminishes the capacity to support plant life. Accordingly, in agriculture manufacturing, sustainability has increasingly been identified in efforts toward reduction of the impact on the environment and long-term sustainability of the sector. Green process innovations can thus be duly adopted in cutting down on wastes while conserving energy with minimal use of harmful chemicals. For instance, most the manufacturers are investing in energy-efficient technologies and renewable sources of energy that power operation, hence reducing carbon footprint. A study that focused on cement and plastic manufacturing industries in Pakistan and India found that green process innovation and productivity have contributed a lot to sustainability,

especially when combined with running environmental awareness programs. The developing world faces massive prospects regarding circular economics applicability and governance. Agriculture intensification, herein taken to mean increased productivity while ensuring a reduced environmental impact (Cheng et al., 2023). Sustainable intensification refers to the process of increasing agricultural productivity while reducing environmental impacts. This can be achieved by integrating agroecological practices, such as crop rotation, integrated pest management, and organic farming. With water scarcity becoming an increasing concern in many parts of the world, sustainable water management practices are critical for agriculture-related manufacturing. These techniques include drip irrigation, rainwater harvesting, and the use of water-efficient machinery that minimizes the amount of water applied, consequently reducing the risk of water pollution. With better water efficiency, manufacturers can reduce their ecological footprint and guarantee availability for other users (Liu et al., 2020). That improving water use efficiency reduces the impact of such industries on the environment. Product design and manufacturing process innovations increasingly allow agricultural related industries to reduce their ecological footprints. Where green product innovations relate to the elaboration of environmentally friendly goods, such as biodegradable packaging and the use of sustainable materials, green process innovations target the optimization of the industrial process itself, focusing on waste reduction, energy consumption, and gas emissions. Hence, new studies show that companies embracing these green innovations improve not only their environmental performance but also achieve a competitive advantage in view of meeting the growing demand for sustainable products (Gomes et al., 2023). The basic philosophy of the circular economy model is to recycle and reuse materials with minimum wastage, thus minimizing the environmental impact of manufacturing. In manufacturing based on agriculture, it could be in the form of agricultural residues, such as crop by-products, for the production of bio-based products (Amato et al., 2021). The potential wastes from rice straw, wheat straw, and tomato pomace can be transformed into biofuels, bioplastics, and other value-added products intended for various purposes in sustainable and circular agriculture. One of the most changing trends in innovation with agricultural digital technologies involves precision farming and smart agriculture. Precision farming also involves the use of GPS, IoT sensors, and data analytics to optimize resource usage regarding water, fertilizers, and pesticides. This greatly reduces waste and environmental impact, improving yields within crops. Smart agriculture technologies also allow manufacturing to better monitor and optimize their operations so that they can reduce further their environmental footprint (Elias & Marsh, 2020).

9. FUTURE OUTLOOK AND OPPORTUNITIES

These are emerging technologies, policy changes, and emerging demand from world markets all put together that place the farm manufacturing industry of India at the threshold of change. As the second-largest agricultural producer in the world, India indeed has a bigger potential for growth in agro-processing and value-added agricultural manufacturing.

9.1 Emerging Technologies in Agriculture-Related Manufacturing

These are emerging technologies, policy changes, and emerging demand from world markets all put together that place the farm manufacturing industry of India at the threshold of change. As the second-largest agricultural producer in the world, India indeed has a bigger potential for growth in agro-processing and value-added agricultural manufacturing.

Precision agriculture, working on a plain base of data-driven technologies that include GPS, IoT sensors, and drones, is gradually shaping up as a transformative force across the agricultural scenario in India. These technologies support efficient use of water, fertilizers, and pesticides, hence keeping productivity high at lower environmental costs. Digital platforms for farm management, weather forecasting, and soil health analysis are increasingly becoming accessible to farmers and agro-manufacturers. Precision agriculture has been and will, in fact, continue to enhance crop yields per unit area while minimizing input use, especially in regions sensitive to water shortages and soil salinity hazards. Main areas of fast growth in biotechnology include: agricultural manufacturing (Soma et al., 2019). Biotechnological modification of crops, bio-fertilizers, and bio-pesticides are examples of development that can improve yields while minimizing the use of chemical inputs. Bt cotton, already diffused throughout most of India, demonstrates the potential of biotechnology to revolutionize crop production against pest damages and reduce the use of chemical pesticides. Other innovations aside from GM crops aim at improving the nutrition value and hardiness of food crops for different agro-ecological regions in India (Spielman et al., 2014). AgTech startups in India also target the critical gap in the agriculture supply chain: logistics, distribution, and market access. Such startups use digital platforms, e-commerce, and mobile to link farmers directly to consumers and manufacturers, thus bypassing intermediaries and providing better prices for farmers. In the last few years, the scale of AgTech investment has grown multi-fold. A host of startups is working towards farm automation, precision farming, and transparency in the supply chain. Support from the government, both directly and indirectly, through initiatives such as the Digital India program and startup incubators, is also likely to spur further growth of this sector (Dutia, 2014).

9.2 Market Growth Potential in Agro-Processing and Value-Added Manufacturing

India’s agro-processing industry has immense growth potential due to its vast agricultural output and the increasing demand for processed and packaged food, both domestically and globally. The food-processing sector now accounts for roughly 26% of India's GDP and encompasses more than 60% employment, hence making it vital in various aspects of the economy. This sector, being one of India's leading high-priority industries, has been contributed positively since demands for different categories of value-added food products such as ready-to-eat processed foods, milk and dairy products, and beverages are growing sharply in India due to a shift in consumer preference as a result of urbanization and improving disposable incomes (Chengappa, 2004).This is the trend that is driving the expansion of the agro-processing units involved in the conversion process of raw agricultural output into value addition. On top, India enjoys a vast and ever-growing consumer base, thereby

providing the agro-manufacturer with opportunities to scale up and diversification of the product range to satisfy this demand (Rangasamy & Elumalai, 2009). Conclusion India is advantageously positioned to give a significant push to agricultural exports, more so in the high-demand segments such as organic products, spices, and processed foods. The sector, however, should scale up compliance with international standards in terms of food safety and quality in order to tap into the international market.

10. RECOMMENDATIONS FOR STRENGTHENING THE SECTOR

Infrastructure development, particularly in cold chains, warehousing, and transportation, is crucial for reducing post-harvest losses and ensuring the timely delivery of perishable goods. Upgrading rural infrastructure, such as roads, electricity, and irrigation systems, will also enable farmers and manufacturers to increase productivity and access markets more efficiently. Government investment in PPPs can help bridge the infrastructure gap and attract participation of the private sector (Reddy, 2007). "Agricultural technology development needs R&D, which should be accorded highest priority for developing more innovative and productive technology." The government may provide fiscal incentives to stimulate private-sector investment in R&D through tax breaks or subsidies. Also, on account of this collaboration among research institutions, universities, and the private sector, leading-edge technologies and solutions would be developed to suit exactly the peculiar needs of Indian agriculture (Manogna & Mishra, 2021). Small-scale farmers, who happen to be the majority population among the farming communities, usually are faced with development challenges related to market accessibility due to fragmented value chains and poor bargaining power. With strengthened FPOs and cooperatives, farmers would have access to modern markets, and be in a better position to link up with the agro-processing value chains. Farmers' collective actions in FPOs contribute to accessing credit and inputs more efficiently, allow them to bargain for good prices, and pool their resources (Trebbin & Hassler, 2012).

CONCLUSION

The agriculture-based manufacturing sector holds significant importance in India due to its contribution to above-average gainful employment, export potential, and its impact on GDP. The research outlines the growth pattern of interlinkage between agriculture and manufacturing, with a special focus given to the shift from traditional practices to modern mechanized systems through changes in technology and policy intervention. Events involving key governmental initiatives like PM-KISAN, a tribute to famer's fund and Make in India, has improved livelihood opportunities for the farmers, raised farm productivity and reinforced the interrelationship between the agricultural and industrial sectors. Innovating technologies in precision agriculture, Industry 4.0, and digital platforms have transformed business processes in agriculture with the dual focus of enhancing productivity while reducing the impact on the environment. However, mechanization and automation have improved efficiency as well as enabled India to emerge as a significant exporter of agricultural machinery and processed products. The sector, nonetheless, remains bedevilled by a host of deep-rooted problems related to fragmented supply chains, inadequate infrastructure, regulatory barriers, and shortage of manpower. In this regard, lack of adequate cold chain infrastructure and logistics remains one of the critical bottlenecks that results in postharvest losses and reduces export competitiveness. Such problems call for the development of a more cohesive approach that brings in not just the public but also the private players. For increasing competitiveness and making growth sustainable, sustained support from governments in the form of subsidies, tax incentives, and investment in developing infrastructure must come in. Strengthening FPOs will accord small farmers access to improved markets and bargaining powers so that their growth becomes inclusive. Besides, the integration of AI, IoT, robotics, and other upcoming technologies becomes compulsory for maximum productivity, reducing wastage, and environmental sustainability. The future of agriculture-based manufacturing in India depends on how effectively the integration of modern technology with policy support and infrastructural development takes place for the sector to contribute more significantly to economic growth, employment generation, and sustainability within the country and at large in the global market.

REFERENCES

1. Abirami, S., Jaisridhar, P., Kumar, A. P., Sheela, M. S., & Ganapati, P. S. (2023). Pioneering Challenges: Exploring Multifaceted Obstacles in Agricultural Mechanization in Tamil Nadu, India. *International Journal of Environment and Climate Change*, *13*(10), 3745-3753.
2. Adriant, I., Simatupang, T., & Handayati, Y. (2021). The barriers of responsible agriculture supply chain: The relationship between organization capabilities, external actor involvement, and supply chain integration. *Uncertain Supply Chain Management*, *9*(2), 403-412.
3. Amato, A., Mastrovito, M., Becci, A., & Beolchini, F. (2021). Environmental sustainability analysis of case studies of agriculture residue exploitation. *Sustainability*, *13*(7), 3990.
4. Anand, R., & Sah, U. (2020). IMPACT OF SUBSIDIES ON INDIAN AGRICULTURAL SECTOR: AN ANALYSIS. *Journal of Emerging Technologies and Innovative Research*.
5. Arita, S., Grant, J., Sydow, S., & Beckman, J. (2022). Has global agricultural trade been resilient under coronavirus (COVID-19)? Findings from an econometric assessment of 2020. *Food Policy*, *107*, 102204.
6. Arjun, K. M. (2013). Indian agriculture-status, importance and role in Indian economy. International Journal of Agriculture and Food Science Technology, 4(4), 343-346.

7. Arora, D. (2021). Demand prognosis of industry 4.0 to agriculture sector in India. *International Journal of Knowledge-based and Intelligent Engineering Systems*, *25*(1), 129-138.
8. Bakare, S., Shinde, S. C., Hubballi, R., Hebbale, G., & Joshi, V. (2021, March). A Blockchain-based framework for Agriculture subsidy disbursement. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1110, No. 1, p. 012008). IOP Publishing.
9. Bhatia, J. K., Mehta, V. P., Bhardwaj, N., & Nimbrayan, P. K. (2021). Export-import performance of major agricultural commodities in India.
10. Cheng, C., Ahmad, S. F., Irshad, M., Alsanie, G., Khan, Y., Ahmad, A. Y. B., & Aleemi, A. R. (2023). Impact of green process innovation and productivity on sustainability: The moderating role of environmental awareness. *Sustainability*, *15*(17), 12945.
11. Chengappa, P. G. (2004). Emerging trends in agro-processing in India. *Indian Journal of Agricultural Economics*, *59*(1).
12. Chhetry, G. K. N., & Belbahri, L. (2009). Indigenous pest and disease management practices in traditional farming systems in north east India. A review. *Journal of plant breeding and crop science*, *1*(3), 28-38.
13. CHOWDARY, V. Machine Learning Applications for Precision Agriculture: A Comprehensive Review.
14. Dambaulova, G. K., Lilimberg, S. I., Madin, V. A., & Abdrakhmanova, G. T. (2022). Meta-analysis of the potential of Kazakhstani pork in the global market of meat products: Problems and prospects. *Veterinary World*, *15*(11), 2705.
15. De, D. (2003). Indian agricultural machinery export–present scenario and future prospects. Agricultural Engineering Today, 27(3and4), 1-20.
16. Doria, R. (2023). Importance of agriculture in Indian economy: भारतीय अर्थव्यवस्था में कृषि का महत्त्व. RESEARCH REVIEW International Journal of Multidisciplinary, 8(9), 26-32.
17. Dutia, S. (2014). Agtech: Challenges and opportunities for sustainable growth. *Available at SSRN 2431316*.
18. Elias, M., & Marsh, R. (2020). Innovations in Agricultural and Food Systems Sustainability in California. *Case Studies in the Environment*.
19. Emmi, L., Fernandez, R., & Guerrero, J. M. (2023). Robotics for smart farms. *Frontiers in Robotics and AI*, *9*, 1113440.
20. Fountas, S., Mylonas, N., Malounas, I., Rodias, E., Hellmann Santos, C., & Pekkeriet, E. (2020). Agricultural robotics for field operations. *Sensors*, *20*(9), 2672.
21. Gagliardi, G., Lupia, M., Cario, G., Cicchello Gaccio, F., D'Angelo, V., Cosma, A. I. M., & Casavola, A. (2021). An internet of things solution for smart agriculture. *Agronomy*, *11*(11), 2140.
22. Gomes, S., Pinho, M., & Lopes, J. M. (2024). From environmental sustainability practices to green innovations: Evidence from small and medium-sized manufacturing companies. *Corporate Social Responsibility and Environmental Management*, *31*(3), 1677-1687.
23. Goswami, R., Dutta, S., Misra, S., Dasgupta, S., Chakraborty, S., Mallick, K., ... & Majumdar, K. (2023). Whither digital agriculture in India?. *Crop and Pasture Science*.
24. Gulati, A., & Juneja, R. (2020). Farm mechanization in Indian agriculture with focus on tractors. *ZEF-Discussion Studys on Development Policy*, (297).
25. Gupta, S., Kishore, A., Alvi, M. F., & Singh, V. (2020). Designing better input support programs: Lessons from zinc subsidies in Andhra Pradesh, India. *PloS one*, *15*(12), e0242161.
26. Karthikeyan, C., Veeraragavathatham, D., Karpagam, D., & Firdouse, S. A. (2009). Traditional tools in agricultural practices. *Indian Journal of Traditional Knowledge*, *8*(2), 212-217.
27. Kaundal, R. K., & Sharma, M. (2006). Agricultural exports of India in the new economic environment. Foreign Trade Review, 41(2), 3-34
28. Kraft, S. K., & Kellner, F. (2022). Can blockchain be a basis to ensure transparency in an agricultural supply chain?. *Sustainability*, *14*(13), 8044.
29. Krishnan, A., & Swarna, S. (2020, October). Robotics, IoT, and AI in the automation of agricultural industry: a review. In *2020 IEEE Bangalore Humanitarian Technology Conference (B-HTC)* (pp. 1-6). IEEE.
30. Krishnaswamy, K. (2020). Market Provisioning of Technology-Enabled Agricultural Services In India.
31. Kumar, M., Tamhankar, M. B., Mehta, C. R., Babu, V. B., & Bikram, J. (2021). Status of Farm Machinery Manufacturing in Madhya Pradesh: A Case study.
32. Kumar, S., Raut, R. D., Nayal, K., Kraus, S., Yadav, V. S., & Narkhede, B. E. (2021). To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP. *Journal of Cleaner Production*, *293*, 126023.
33. Liu, P., Qi, S., Li, D., & Ravenscroft, N. (2021). Promoting agricultural innovation as a means of improving China's rural environment. *Journal of Environmental Management*, *280*, 111675.

34. Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *Journal of cleaner production*, *112*, 9-21.
35. Mitrofanova, I. V., Shkarupa, E. A., & Batova, V. N. (2021). Export of agricultural products: trends and directions of state support in modern conditions. *Regionalnaya ekonomika. Yug Rossii*, 131-140.
36. Mohseni, S., Baghizadeh, K., & Pahl, J. (2022). Evaluating barriers and drivers to sustainable food supply chains. *Mathematical problems in engineering*, *2022*(1), 4486132.
37. Mulage, B. S. (2017). History of Agriculture System in India: A Legal Perspective. *International Journal of Humanities Social Sciences and Education*, *4*(7), 25-30.
38. Neupane, H. S., Acharya, B., Wagle, P., & Gyawali, B. R. (2023). Agricultural Policies and Practices: Pathways for Transformation. *Nepal Public Policy Review*, *3*(1), v-vi.
39. Oliveira, L. F., Moreira, A. P., & Silva, M. F. (2021). Advances in agriculture robotics: A state-of-the-art review and challenges ahead. *Robotics*, *10*(2), 52.
40. Ponniah, M., & Sri, B. S. (2022). Production and marketing of organic products in India. *International journal of health sciences*, *6*(S4), 8437-8450.
41. Prabha, C., & Pathak, A. (2023, May). Enabling technologies in smart agriculture: A way forward towards future fields. In *2023 International Conference on Advancement in Computation & Computer Technologies (InCACCT)* (pp. 821-826). IEEE.
42. Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science*, *362*(6417), eaav0294.
43. Quy, V. K., Hau, N. V., Anh, D. V., Quy, N. M., Ban, N. T., Lanza, S., ... & Muzirafuti, A. (2022). IoT-enabled smart agriculture: architecture, applications, and challenges. *Applied Sciences*, *12*(7), 3396.
44. Ramaswamy, K. V. (2021). Do size-dependent tax incentives discourage plant size expansion? Evidence from panel data in Indian manufacturing. *Margin: The Journal of Applied Economic Research*, *15*(4), 395-417.
45. Rangasamy, N., & Elumalai, K. (2009). Market opportunities and challenges for agri-biotech products in India. *Agricultural Economics Research Review*, *22*(conf), 471-481.
46. Reddy, T. K. (2007). Challenges to Indian agriculture: future strategy. *Philippine Review of Economics (Online ISSN 2984-8156)*, *44*(2).
47. RL, M., & Mishra, A. K. (2021). Does investment in innovation impact firm performance in emerging economies? An empirical investigation of the Indian food and agricultural manufacturing industry. *International Journal of Innovation Science*, *13*(2), 233-248.
48. Sahoo, K., & Sethi, N. (2012). Investigating the impact of agriculture and industrial sector on economic growth of India. OIDA International Journal of Sustainable Development, 5(5), 11-21.
49. Saini, S., Kishore, A., & Alvi, M. (2020). *Regressing forward: agriculture mechanization subsidy modalities in Bihar and Odisha* (Vol. 16). Intl Food Policy Res Inst.
50. Shaik, S., Kwame, A. A., & Sakouvogui, K. (2020). Soybean trade report: Trend and risk analysis.
51. Shaila, M., & Begum, N. (2021). Ancient farming methods of seed storage and pest management practices in India—A Review. *Plant Arch*, *21*, 499-509.
52. Singh, A. K., Upadhyaya, A., Kumari, S., Sundaram, P. K., & Jeet, P. (2020). Role of Agriculture in making India $5 trillion Economy under Corona Pandemic Circumstance: Role of agriculture in Indian economy. *Journal of AgriSearch*, *7*(2), 54-58.
53. Singh, G., Daultani, Y., Rajesh, R., & Sahu, R. (2022). Modeling the growth barriers of fresh produce supply chain in the Indian context. Benchmarking: An International Journal, 30(2), 653-677.
54. Singh, K. P. (2012). Growth and Development of Agricultural Education, Research, and Libraries in India. *DESIDOC Journal of Library & Information Technology*, *32*(1).
55. Sivertsson, O., & Tell, J. (2015). Barriers to business model innovation in Swedish agriculture. *Sustainability*, *7*(2), 1957-1969.
56. Smyth, S. J. (2020). Regulatory barriers to improving global food security. *Global food security*, *26*, 100440.
57. Soma, M. K., Shaheen, M., Zeba, F., & Aruna, M. (2019, February). Precision Agriculture in India-Challenges and Opportunities. In *Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Amity University Rajasthan, Jaipur-India*.
58. Spielman, D. J., Kolady, D. E., Cavalieri, A., & Rao, N. C. (2014). The seed and agricultural biotechnology industries in India: An analysis of industry structure, competition, and policy options. *Food Policy*, *45*, 88-100.
59. Tangjang, S. (2009). Traditional slash and burn agriculture as a historic land use practice: A case study from the ethnic noctes in Arunachal Pradesh, India. *World Journal of Agricultural Sciences*, *5*(1), 70-73.

60. Tian, X., Engel, B. A., Qian, H., Hua, E., Sun, S., & Wang, Y. (2021). Will reaching the maximum achievable yield potential meet future global food demand?. *Journal of Cleaner Production*, *294*, 126285.
61. Trebbin, A., & Hassler, M. (2012). Farmers' producer companies in India: a new concept for collective action?. *Environment and Planning A*, *44*(2), 411-427.
62. Tripathi, G., Dhodia, A., Giri, A., Rathore, V., Verma, A., Shukla, A., & Verma, L. K. (2023). Government Agriculture Schemes in India: A Review. Asian Journal of Agricultural Extension, Economics & Sociology, 41(11), 58-67.
63. Tyagi, V. (2012). India's agriculture: challenges for growth & development in present scenario. International Journal of Physical and social sciences, 2(5), 116-128.
64. Verma, S. (2015). Role of agro-industries for sustainable agricultural development in India. Indian Journal of Economics and Development, 11(1), 277-284.
65. Viramgami, H. S. (2021). Journal of Educational Research.
66. Volkava, K., & Mickiewicz, B. (2022). Main trends of dynamic development of the vegetable products and fruits global market. *VUZF Review*, *7*(3), 78.
67. Wagh, R., & Dongre, A. P. (2016). Agricultural sector: status, challenges and it's role in Indian economy. Journal of Commerce and Management Thought, 7(2), 209-218.
68. Waseem, K., & Ahmad, A. S. (2018). Does agriculture matter for economic growth of Uttar Pradesh (India)?. Экономика региона, 14(3), 1029-1037.
69. Zivkovic, L., Pesic, M., Schebesta, H., & Nedovic, V. (2022). Exploring regulatory obstacles to the development of short food supply chains: Empirical evidence from selected european countries. *International journal of food studies*, *11*, SI138-SI150.