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Status of Farm Automation, Advances, Trends, and Scope in India

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Abstract: ***Farm automation, in particular, has brought about tremendous changes in agriculture as a result of the rapid growth of technology. This study investigates farm automation's current state, recent developments, new trends, and potential applications in India. The study illustrates the effects of automation on agricultural productivity and sustainability by looking at the integration of modern technologies like robotics, precision farming, and the Internet of Things. A consideration of governmental regulations, technical advancements, and the contribution of academic institutions to the automation movement are all included in the study. The findings indicate that automation in India has increased crop yields by 25–40% and that automation levels are lower in northeastern areas and greater in northwestern regions. The study also identifies important trends, like the shift toward environmentally friendly solutions and the expanding significance of digital technology in agriculture. Although automation has great potential, the study also discusses the technological, societal, and economic obstacles that prevent it from being widely used. Lastly, it offers strategic insights and policy recommendations to accelerate farm automation adoption, with the ultimate goal of supporting India's agriculture industry.***

Keywords: Farm Automation, Precision Agriculture, Agricultural Mechanization, Sustainable Farming, Crop Yield Enhancement

1. Introduction

1.1 Importance of agriculture in India

The Indian economy is based mostly on agriculture, which employs over 58% of the workforce and generates 17–18% of the nation's GDP (Ministry of Agriculture & Farmers' Welfare, 2023). Millions of small and marginal farmers depend on this industry for their income and sustenance; it is essential to their way of life. Because of its varied agroclimatic conditions, India is one of the world's leading producers of food grains, fruits, vegetables, milk, and spices. It also allows for the cultivation of a wide variety of crops. Rice, wheat, sugarcane, cotton, and legumes are among the major crops. The nation's enormous population, which is expected to be the largest in the world by 2027, depends heavily on agriculture to ensure food security (United Nations, 2019). The agricultural industry does, however, confront a number of difficulties, such as low productivity, wasteful resource use, fragmented landholdings, and susceptibility to climate change. Conventional farming practices frequently result in lower-than-ideal yields and higher labor expenses [1]. In order to reduce poverty, increase agricultural output, and accomplish sustainable development goals, these issues must be resolved.

1.2 Farm mechanization

The use of machinery and technology in agricultural processes, such as plowing land, planting, harvesting, and post-harvest processing, is known as farm mechanization. Using tractors, plows, seeders, harvesters, irrigation systems, and other equipment used to increase farming production and efficiency falls under this category. Farm mechanization is important because it has the ability to change how cultivation is carried out. Mechanization has the potential to dramatically increase crop yields while lowering production costs by decreasing the need for manual labor and increasing the accuracy and speed of processes [2]. Furthermore, mechanization can support sustainable farming practices by assisting in the effective management of resources, such as the optimal use of water, fertilizers, and pesticides.

Farm mechanization also addresses the issue of labor shortages, which are becoming more common as a result of urban migration and the aging rural workforce. Farmers can overcome these labor limitations and maintain or even increase their output levels by implementing mechanical methods [3]. Additionally, mechanization helps farmers accomplish tasks on time, which is essential for increasing crop output and reducing losses. For example, the use of combine harvesters reduces the danger of damage from unfavorable weather conditions by enabling the quick and effective harvesting of crops [4].

1.3 Objectives of the study

The purpose of this study is to present an in-depth assessment of farm mechanization in India, including its current state, advancements, trends, and prospects. The study aims to evaluate the present state of farm mechanization in India's various crop categories and geographical areas. This involves looking at the kinds of machinery that are frequently employed, the degree of mechanization in different geographical areas, and the variations in mechanization levels between distinct crop categories. It also aims to investigate current developments and technological breakthroughs in agricultural automation. The study will emphasize important technological advancements and their effects on agricultural operations, including automation, drone use, precision farming, and the Internet of Things (IoT). The study will recognize new developments in agricultural mechanization and their potential. This involves looking at changes in favor of environmentally clean and sustainable mechanization solutions, the incorporation of digital technology, the function of service providers and bespoke hiring centers, and assessing the difficulties and impediments to farm mechanization adoption. The study will identify the social, technological,

and economic constraints preventing mechanization from being widely adopted and offer feasible solutions and best practices to get past them. It will offer strategic insights and policy recommendations aimed at boosting farm mechanization adoption in India and recommend policies and tactics to assist farmers in using mechanized solutions in order to increase agricultural output and sustainability, based on the findings.

2. Farm Automation in India

2.1 Automation levels

The degree of farm automation varies greatly between India's regions, depending on things like crop varieties, technological accessibility, and local economic conditions. Due to their extensive cultivation of wheat and rice, which greatly benefits from automated solutions, northern states like Punjab and Haryana have higher levels of agricultural automation. These states have comparatively higher income levels and well-established infrastructure, which allows farmers to invest in automated technology [5]. Conversely, significant degrees of automation are seen in southern states like Tamil Nadu and Karnataka, especially in high-value industries like horticulture and sugarcane. Precision farming instruments and automated irrigation systems are among the technologies that these areas are progressively implementing [6]. Due to smaller farms, budgetary constraints, and less established infrastructure, eastern and northeastern states like West Bengal and Assam lag behind in automation. But programs to encourage automation in these areas are starting to take off (Ministry of Agriculture and Farmers' Welfare, 2023). **Fig. 1** illustrates percentage automation levels in various states and regions, of India emphasizing the differences and pointing out the places with the highest and lowest adoption rates.

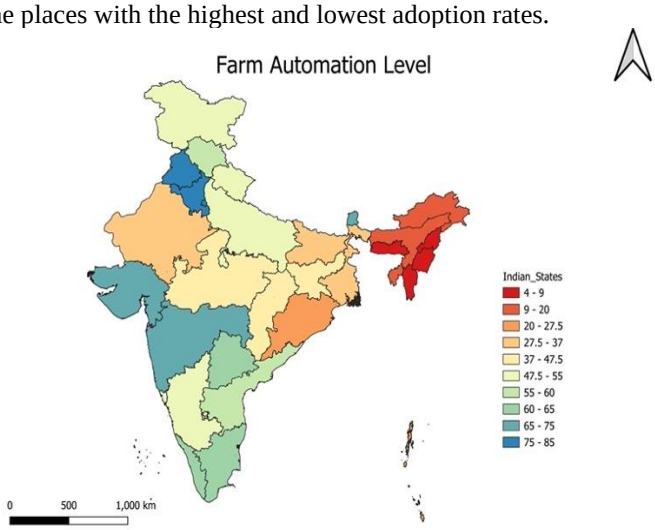

Figure 1: Thematic map of farm automation adoption rates (%)

2.2 Types of automated machinery and systems

India's agricultural sector is implementing a number of automated machines and systems.

Robotics: Automated systems are employed in planting, weeding, and harvesting operations. Robotic harvesters and weed-controlling machines that are highly accurate and efficient are two such examples [7].

Sensors: A range of sensors are used to keep an eye on the growth of crops, environmental conditions, and soil health. Due to the real-time data collection that these sensors provide, farmers are able to make informed decisions about pest control, fertilization, and irrigation. To enhance soil health monitoring, novel strategies are being investigated, such as the use of electrode materials for the electrochemical detection of in-situ soil fertilizer content [8].

Automated irrigation systems: These systems make the most of sprinkler and drip irrigation technology, which is frequently controllable by timers or sensors, to maximize water use and increase irrigation efficiency. In areas with scarce water supplies, automated irrigation is extremely prevalent [9].

Unmanned aerial vehicles: The usage of drones for pesticide spraying, crop monitoring, and aerial surveillance is expanding. They give farmers access to high-resolution data and photos, enabling them to more efficiently manage vast fields [10].

Precision farming tools: These comprise variable rate technology (VRT) and GPS-guided tractors, which enable the accurate application of inputs including pesticides, fertilizers, and seeds. The goal of precision farming is to increase output while minimizing resource waste and is changing as a result of the use of automated all-terrain vehicles, which increase accuracy and efficiency [11]. These vehicles can be customized to carry out operations like planting, spraying, and harvesting on their own, saving labor expenses and enhancing output.

2.3 Automation rates in various crop segments

The various crop segments exhibit varying levels of automation adoption.

Cereals: Especially in the northern states, automation rates are comparatively high for cereal crops like rice and wheat. There is widespread usage of mechanized instruments like threshers, seed drills, and combine harvesters [12].

Pulses: Compared to cereals, pulse farming involves less automation. However, more machinery is being used to plant and harvest pulses in states like Madhya Pradesh and Maharashtra [13].

Horticulture: Fruits and vegetables, as well as other high-value horticulture crops, are increasingly embracing automation. According to Khan et al. (2021), technologies including robotic harvesters, precision irrigation, and automated greenhouses are becoming progressively more widespread [14].

Cash crops: With the advent of automated harvesters, planters, and irrigation systems, crops like cotton and sugarcane have seen a large level of automation. Two prominent states where these technologies are frequently utilized are Maharashtra and Gujarat [15].

2.4 Government policies and schemes

The Indian government has introduced a number of policies and programs to promote farm automation and mechanization.

Sub-Mission on Agricultural Mechanization (SMAM): SMAM was established in 2014–15 with the goal of reaching small and marginal farmers with farm mechanization by providing financial support for the purchase of agricultural machinery. In order to make machinery accessible to farmers who cannot afford to buy it outright, the program also encourages the creation of Custom Hiring Centers (CHCs) (Ministry of Agriculture & Farmers' Welfare, 2023).

Through direct financial transfers, *PM-Kisan (Pradhan Mantri Kisan Samman Nidhi)* encourages farmers to invest in contemporary agricultural technologies, like automation instruments, even if their primary purpose is income support (PM-Kisan Portal, 2023).

The National Mission on Sustainable Agriculture (NMSA) aims to improve soil health and water use efficiency through the promotion of sustainable agricultural methods, such as precision farming and automated irrigation systems (NMSA, 2023).

Initiatives for Digital Agriculture: eNAM (National Agriculture Market) and AgriStack are two examples of programs that seek to digitize agriculture by giving farmers access to automated solutions and data-driven insights for improved crop management (Digital India, 2023).

These initiatives show how committed the government is to modernizing agriculture through the adoption of automated systems and cutting-edge technologies in order to increase productivity, sustainability, and farmer incomes.

3. Advances in Farm Automation

3.1 Technological innovations

Significant technological advancements in India have influenced traditional agricultural techniques through farm automation. *Precision farming* is the practice of applying inputs like water, fertilizer, and pesticides as efficiently as possible by using sensors, GPS technology, and data analytics. This approach minimizes its adverse impacts on the environment, reduces waste, and increases production. Technologies for precision farming make it possible to manage crops according to their individual needs on a site, enabling farmers to adjust their techniques accordingly [16]. The usage of *drones* for pesticide spraying, crop monitoring, and aerial surveillance is growing. Drones with high-resolution cameras and sensors may gather precise information on pest infestations, soil conditions, and crop health. Farmers are able to manage their crops more effectively and produce higher yields attributable to the real-time information available to them [17]. The integration of numerous internet-connected devices and sensors enables real-time data gathering and monitoring. Smart irrigation systems, weather stations, and soil moisture sensors are a few examples of *IoT* uses in agriculture. Farmers can lower operating costs, enhance crop health, and maximize resource utilization with the use of these technologies. The growing use of Raspberry Pi image processing systems with Python-based algorithms for real-time plant target identification greatly enhances precision agriculture [18].

AI tools are being used to evaluate massive datasets and give farmers valuable data. AI-powered technologies are able to detect diseases, forecast agricultural yields, and suggest the best dates and techniques for planting. Machine learning algorithms, which assist in the analysis of complex patterns and trends, make more precise and effective agricultural techniques possible [19].

Advanced data analysis and decision-making capabilities offered by machine learning and artificial intelligence (AI) vision applications in all-terrain vehicles are enabling farm automation [20]. In order to develop more effective and adaptable machinery that can work with a variety of crops and soil types, researchers are looking into the potential of 3D printing in the design of all-terrain vehicles for agricultural applications [21]. **Fig. 2** shows the automation techniques and procedures of application of sensors, data processing and decision making in precision agriculture.

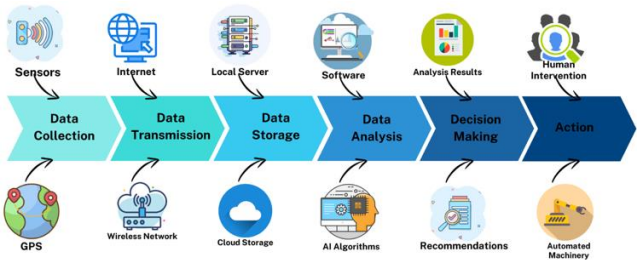

Figure 2: Precision agriculture workflow in automation

3.2 Development and adoption of advanced automation systems

The modernization of Indian agriculture has been largely attributed to the development and implementation of advanced automated technology. Among the significant developments are:

Tractors with GPS capability offer accurate field mapping and navigation. These tractors have great accuracy for operations like planting, harvesting, and plowing, which minimizes overlap and guarantees resource efficiency. In low visibility situations, including at night or in foggy weather, they also allow farmers to continue working [22].

Automated harvesters have been developed to harvest crops with minimal human intervention. Grain, fruit, and vegetable harvests can all be processed using these devices. They minimize crop losses from human error, lower labor expenses, and improve harvesting efficiency. Examples are robotic fruit pickers for orchards and combine harvesters for cereals [23].

Robotic weeders find and eradicate weeds from fields using sophisticated sensors and algorithms. With their ability to discriminate between weeds and crops, these robots provide accurate weed management without endangering the plants.

Robotic weeding promotes sustainable farming practices by reducing the need for chemical pesticides [24].

3.3 Role of Research Institutions and Universities in Promoting Automation

From conducting innovative studies, creating new technology, and offering farmers extension and training services, research institutes and universities are crucial in advancing farm automation. Among the significant contributions are:

The Indian Council of Agricultural Research, or ICAR, is the highest authority for organizing, supervising, and controlling agricultural research and education. It has played a significant role in the development and promotion of numerous automation technologies, including automated machinery and instruments for precision farming (ICAR, 2023).

State Agricultural Universities (SAUs) produce technology appropriate for regional farming conditions and carry out research relevant to their regions. In order to inform farmers about the advantages and applications of automation technologies, they frequently organize workshops and training courses.

Innovative automation solutions have been developed as a result of *collaborations* among universities, research centers, and private businesses. Joint ventures concentrate on tackling particular farming issues and increasing the use of novel technologies [25].

3.4 Successful automation stories

Unmanned agricultural vehicles are proving to be especially helpful for increasing efficiency in hill farming [26]. A number of successful automation projects in India demonstrate the potential of these technologies to transform agriculture. Successful application of precision farming methods for the production of wheat and rice has taken place in Punjab. Increased yields, lower input costs, and better water usage efficiency are the outcomes of farmers' use of GPS-enabled tractors, automated seed drills, and precision irrigation systems [27]. A project in Andhra Pradesh used drones for crop monitoring and pest management in paddy fields. The drones' provision of real-time data on insect infestations and crop health made timely actions possible. As a result, crop yields increased, and pesticide consumption was significantly reduced [28].

Horticulturalists in Maharashtra have installed automated greenhouses with climate control systems and IoT sensors. These greenhouses maximize temperature, humidity, and irrigation, resulting in higher-quality produce and higher productivity. Gujarati farmers are cultivating cotton using robotic weeders. By efficiently suppressing weeds without endangering crops, the robots lessen the need for chemical herbicides and encourage environmentally friendly agricultural methods [29].

4. Trends in Farm Automation

4.1 Sustainable and eco-friendly automation solutions

In order to solve environmental issues and support long-term viability, India's agriculture sector is progressively implementing sustainable and environmentally friendly automation technologies. Utilizing methods and technology that reduce adverse effects on the environment, preserve resources, and improve soil health are all part of this movement. For instance, by permitting focused applications based on real-time data, precision farming techniques help prevent the overuse of pesticides and fertilizers [30]. Additionally, automated irrigation systems, such as sprinklers and drip systems, minimize water waste and increase water use efficiency, both of which are crucial in areas with limited water resources. Advanced technology makes the application of conservation tillage techniques simpler and encourages sustainable land management by preserving soil structure and reducing erosion [31]. **Fig. 3** shows how the automation and mechanization level in India has seen slow and steady growth in each sector in terms of no of units added in subsequent years from 2014 to 2023.

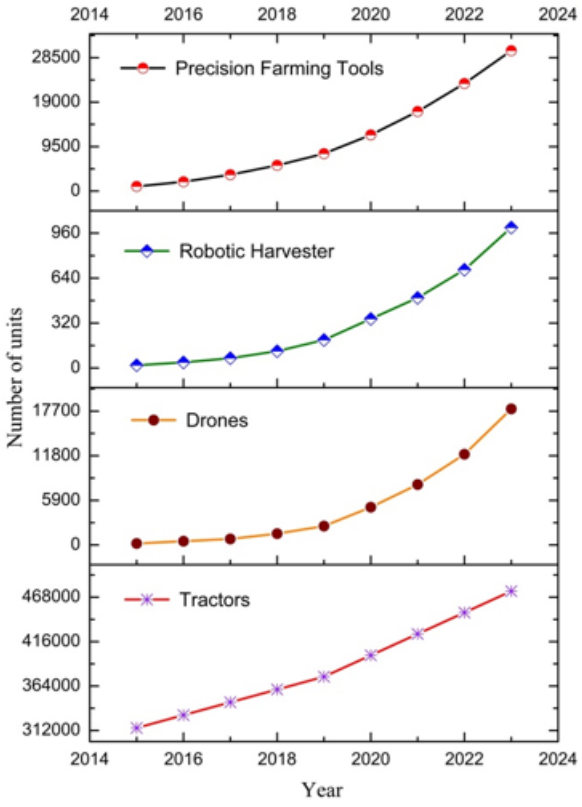

Figure 3: Growth of mechanization and in farm automation

4.2 Renewable energy sources

Utilizing renewable energy sources especially solar power in farm automation is becoming more and more popular. The utilization of solar-powered devices, like electric fences, irrigation systems, and water pumps, is growing in popularity because of its economic and ecological advantages. For example, solar-powered pumps offer a dependable and environmentally friendly irrigation solution, particularly in remote, off-grid locations [32]. Additionally, the government has been encouraging the use of solar energy in agriculture by

offering a number of programs and incentives. In order to give farmers access to inexpensive and clean energy, the PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) initiative intends to install grid-connected solar power plants and solar pumps in rural regions (MNRE, 2023). A major development in precision agricultural technology is the design of semi-autonomous vehicle sprayers that are based on the IoT [33].

4.3 Integration of digital technologies

Smart farming, or the incorporation of digital technologies into agriculture, evolves the way farming operations are planned and carried out. Digital solutions that help farmers optimize their operations include software platforms, cloud-based systems, and mobile apps that give them access to real-time data and data analytics. A variety of services, such as weather forecasts, market prices, crop advice, and pest control advice, are available through mobile apps for farmers. These apps help farmers increase productivity, manage their crops more effectively, and make intelligent choices [34]. Precision agriculture techniques are further made possible by smart farming technologies, including IoT devices, AI-driven analytics, and remote sensing. Farmers can use inputs more effectively and sustainably thanks to these technologies' assistance in monitoring crop health, soil conditions, and environmental parameters [35]. To increase the effectiveness and accuracy of agricultural sprayers, solenoid-controlled pressure regulation systems based on the IoT are being developed [36]. Integrating digital technology and automation has substantially enhanced the crop yield for various crop ranging from 25% to 40% in the last decade (**Fig. 4).**

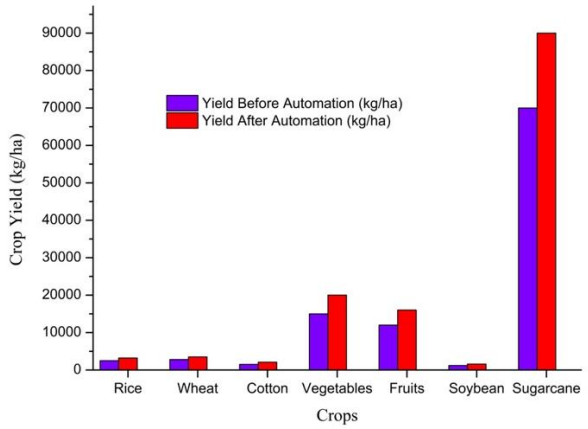

Figure 4: Effect of digital technologies on crop yield

4.4 Rise of custom hiring centers and service providers

In India, the idea of custom hiring centers (CHCs) and automated machinery service providers is becoming more popular. Small and marginal farmers who might not be able to afford to buy new technologies can now have access to them due to CHCs' rental services for a variety of agricultural apparatus and equipment [37]. These facilities rent out tools like harvesters, tractors, irrigation equipment, and seed drills. This concept guarantees that machinery is used effectively and maintained appropriately, in addition to reducing the financial strain on farmers. Under programs like the Sub-Mission on Agricultural Mechanization (SMAM), the government has been providing financial support and subsidies to facilitate the creation of Community Health Centers (CHCs) (Ministry of Agriculture & Farmers' Welfare, 2023).

4.5 Importance of small and marginal farmers

The bulk of Indian farmers are small and marginal farmers, and they are becoming more widely acknowledged as important players in the adoption of agricultural automation. A lot of work is going into making automation technologies available and reasonably priced for these farmers because they are essential to raising the general productivity and sustainability of agriculture. New finance schemes, such as subsidies and micro-loans, are being put in place to help small farmers buy automated equipment. In addition, efforts are being made to inform farmers about the advantages and applications of automated technologies through awareness campaigns, training courses, and extension services. Furthermore, there is a growing movement towards the creation of affordable and expandable automation solutions that cater to the requirements of small and marginal farmers. Examples of devices that can help farmers with their daily tasks include simple smartphone applications, inexpensive sensors, and portable solar-powered pumps [38].

5. Scope and Future Prospects

5.1 Potential for growth

Even with the advancements in farm automation, under-automated areas still have a lot of room to expand, especially in the eastern and northeastern states of West Bengal, Assam, and Bihar. These areas frequently struggle with issues including smaller farms, poorer incomes, and restricted access to advanced technologies. Investments and targeted interventions in these areas have the potential to greatly increase farmer incomes and productivity. In order to close the automation gap, initiatives such as funding support, infrastructure improvement, and the promotion of locally relevant technology are undertaken. Adoption rates can be increased, for example, by offering affordable, scalable solutions designed to meet the needs of marginal and small farms. Furthermore, expanding communication and road networks can facilitate increased access to markets and technologies [39].

5.2 Addressing labor shortages and improving productivity

Automation is essential for reducing labor shortages and raising agricultural output. The need for labor-saving and efficient technology is increasing due to the aging farmer population and worker migration to metropolitan areas. Relying less on manual labor, automated machinery, and systems can carry out operations like planting, weeding, and harvesting with little assistance from humans [40]. By facilitating accurate and timely agricultural operations, automation raises productivity. Precision farming, robotic harvesters, and automated irrigation are examples of technologies that maximize input use, cut waste, and boost crop yields. Farmers benefit from increased productivity and profitability as a result of these developments [41]

5.3 Private sector investment and public-private partnerships

Farm automation presents a significant opportunity for public-private partnerships (PPPs) and private-sector investment. In the areas of financial solutions, extension services, and the creation and promotion of modern technology, private businesses can be extremely important. PPPs have the potential to improve agricultural results, foster innovation, and increase technology adoption by utilizing the strengths of both the public and private sectors [42]. Investment potential includes building specialized employment centers, designing cost-effective automation solutions, and developing precision farming digital platforms. Furthermore, partnerships between government organizations, academic institutions, and commercial businesses can hasten the creation and application of innovative technologies (ICAR, 2023).

5.4 Training and capacity-building for farmers

Farm automation technology must be successfully adopted and implemented, which requires training and capacity-building. In order to use digital instruments and automated technology efficiently, farmers must possess the necessary knowledge and abilities. Workshops, training courses, and extension services can close the knowledge gap and encourage farmers to adopt contemporary farming methods . Programs like mobile training units, demonstration plots, and farmer field schools can offer real-world instruction and experience. To further improve farmers' ability to use automation technologies, digital literacy initiatives, and smartphone apps can provide them with access to real-time data, advisory services, and market insights [43].

5.5 Policy recommendations

In order to facilitate the expansion of farm automation, a number of policy suggestions should be taken into account.
Financial support: Increase financial aid and subsidies for the acquisition of automated machinery and equipment. This could involve providing low-interest loans and credit facilities, as well as growing programs such as the Sub-Mission on Agricultural Mechanization (SMAM) (Ministry of Agriculture & Farmers' Welfare, 2023).

Funding should be increased for agricultural automation technology research and development. Encourage cooperative projects between academic institutions, commercial enterprises, and research centers that promote innovation and create solutions unique to the region (ICAR, 2023).

Infrastructure Development: To enable improved access to markets and technology, and improve rural areas' roads, electricity, and internet connectivity. To guarantee the timely availability of machinery and inputs, reinforce supply networks and logistics [44].

Implement thorough *training and capacity-building* programs for farmers, with an emphasis on the usage and upkeep of digital and automated tools. Encourage farmer awareness and education initiatives that emphasize the advantages of automation.

Public-private collaborations: Promote public-private collaborations to take advantage of both sectors' resources and experience. Encourage cooperation in the creation and expansion of automation technologies, the creation of specialized hiring locations, and the provision of extension services [45].

Encourage the application of *digital technologies*, such as IoT, AI, and precision farming, in agriculture. Encourage the creation of mobile apps and digital platforms that give farmers access to markets, advice services, and real-time information [46]

6. Challenges and Solutions

6.1 Economic barriers

High cost of automation systems: The high cost of automated machinery and systems is one of the main financial obstacles to farm automation in India. Drones, robotic harvesters, and GPS-enabled tractors are examples of advanced technologies that need a large upfront investment and may be unaffordable for small and marginal farmers. Farmers find it challenging to use these technologies due to their high cost, which also includes operating and maintenance costs [47].

Restricted finance access: For many farmers, obtaining finance at a reasonable rate presents a major obstacle. Strict collateral requirements, high interest rates, and low financial literacy make it difficult for farmers to get loans to invest in automation. Farmers are unable to implement current innovations that could increase their output and profitability due to a lack of funding [48].

The government and financial institutions can increase subsidies and financial aid for the purchase of automated machinery in order to eliminate these economic impediments. Automation can be made more widely available by growing programs like the Sub-Mission on Agricultural Mechanization (SMAM) and offering low-interest loans and credit facilities. Furthermore, encouraging cooperative banking and microfinance can assist small farmers in obtaining the capital they require (Ministry of Agriculture and Farmers' Welfare, 2023).

6.2 Technical barriers

Lack of awareness: One of the main technological obstacles is farmers' ignorance of sophisticated automation systems. Due to the fact that many farmers are unaware of the benefits and uses of automated machinery, adoption rates are low. In isolated and impoverished areas, this knowledge gap is especially noticeable [49].

Inadequate infrastructure, which includes poor road connectivity, unstable electrical supplies, and constrained internet access, hinders the implementation and use of automation technologies. The timely availability and maintenance of automated machines depend on effective supply chains and logistics [50].

Comprehensive training and capacity-building initiatives are necessary to get past technical obstacles. Practical experience and hands-on instruction can be obtained through farmer field schools, demonstration plots, and extension programs. Enhancing access to markets and technologies requires improving rural infrastructure, which includes roads, electricity, and internet connectivity .

6.3 Social and Cultural Barriers

Because of social and cultural considerations, farmers frequently show *reluctance to change*. Since traditional farming methods have been practiced for many generations, new innovations are frequently met with mistrust. The high frequency of small landholdings in India makes it difficult to adopt large-scale automated technology. Plots that are dispersed and fragmented make it challenging to operate machinery effectively. Moreover, it might not be financially feasible for small farmers to invest in expensive automation systems [51].

In order to share the costs and benefits of automation, small farmers might pool resources by promoting communal ownership and cooperative farming models. Cooperatives can help make machinery more accessible and affordable by facilitating its purchase and upkeep. The development and promotion of affordable, scalable solutions for small landholdings can also speed up adoption [52].

6.4 Solutions and Best Practices

Financial incentives and government subsidies are essential for promoting the use of farm automation. Farmers' financial burdens can be alleviated by granting tax benefits and direct subsidies for the purchase of automated machinery. Affordability can be improved by adding new support mechanisms and expanding current programs (Ministry of Agriculture and Farmers' Welfare, 2023).

Farmers can jointly own and operate automated equipment through *cooperative farming* methods, which lowers individual expenses and maximizes resource use. In addition to guaranteeing appropriate maintenance and facilitating information sharing among members, cooperatives can bargain for lower equipment pricing [53].

Through the provision of small loans, *microfinancing programs* enable farmers to make investments in automation technologies. Small and marginal farmers can obtain these loans since they frequently have lower interest rates and flexible repayment schedules. To help farmers better grasp their lending possibilities, microfinance organizations can also provide financial literacy classes .

Farm automation adoption can be increased by putting best practices into effect, such as focused extension services, awareness campaigns, and farmer education initiatives. Successful implementation requires working with private businesses and academic institutions to create technologies tailored to a particular area as well as offering farmers ongoing support and direction (ICAR, 2023).

7. Conclusion

This article offers an in-depth study of farm automation in India, emphasizing both the necessity for modernization and its important role in the nation's economy. According to the study, mechanization and automation range from 15% to 50%, depending on the location. However, as crop yields rise from 25% to 40%, automation is being adopted more and more. A comprehensive strategy that includes funding, infrastructure development, education, and regulatory changes is required to encourage agricultural automation. This entails offering extensive training programs, upgrading rural infrastructure, and increasing subsidies for the purchase of automated machinery. Modern technologies can become more widely available and reasonably priced through public-private partnerships and cooperative farming models. Transitioning to modern agricultural practices will go more smoothly if social and cultural barriers are addressed through education and awareness initiatives.

It will take an integrated strategy that incorporates financial, technical, social, and policy solutions to remove current obstacles and encourage the wider use of agricultural automation. This strategy will guarantee that farmers in all areas profit from technological breakthroughs, resulting in increased agricultural productivity, sustainability, and profitability. India's agricultural automation industry has a bright future ahead of it, full of opportunities for expansion and innovation. Research and development in robotics, AI, and precision agriculture will propel these technologies forward. Farmers will need to use creative financing strategies, such as cooperative banking and microfinance, in order to get access to credit that is affordable for automation projects. The establishment of cooperative activities, including knowledge-sharing and capacity-building programs, improved public-private partnerships, and supporting legislation, is imperative for policymakers and stakeholders in order to promote an environment that is conducive to farm automation.

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