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Agriculture 6.0 Leveraging AI, IoT, Machine Learning, and Blockchain for a Sustainable Future

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Abstract

The Internet of Things (IoT) and smart computing technologies have transformed every facet of the twenty-first century. There are numerous applications for these technologies, ranging from real-time crop conditions, water quality, and soil moisture monitoring to the use of drones to support responsibilities like bug application. An era of agriculture 6.0, sometimes referred to as sustainable and smart agriculture, has been ushered in by the broad integration of modern Information Technology (IT) and traditional agriculture. Smart agriculture addresses automation and intelligence in agriculture. However, information security issues cannot be ignored, given how contemporary digital technology has advanced agriculture. The article starts by giving a summary of the advantages, disadvantages, and difficulties of agriculture's progress from 1.0 to 6.0. In addition to identifying problems and presenting the demands and future opportunities in agriculture, this study concentrated on layered architectural design. Furthermore, we suggested a thorough overview for agriculture 1.0–6.0 that incorporates fog computing, blockchain technology, IoT, AI, ML, and software-defined networking.

Keywords: Agriculture 1.0 to 6.0, smart farming technologies, sustainability, Trends.

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1. Introduction

Demand for food and agricultural goods has increased due to the world's population expansion, fierce rivalry, resource exploitation, climate change, environmental problems, and natural disasters. These factors have also put agricultural output and urbanisation at serious risk. By 2050, there will be 10 billion human beings on earth, 7 billion of whom will live in cities, according to the Food and Agriculture Organisation. This means that 70% more food needs to be produced to feed everyone. New ideas known as "Smart Agriculture" have emerged as a result of incorporating cutting-edge technologies into agricultural methods to increase productivity and produce the required food demand. Smart agriculture, also referred to as “Precision Agriculture”, is an idea that combines state-of-the-art Digital technologies, mechatronics, autonomous systems, protocols, data-driven results, and computational standards to optimise resource utilisation, advance agricultural developments, and boost farming practices' productivity, sustainability, and efficiency (Ali et al.,2024).

As shown in Figure 1, the agricultural sector has changed over time in tandem with the technological advancements of all industrial revolutions. The first agricultural revolution was stated as "Agriculture 1.0," and an existing one is known as "Agriculture 6.0," which denotes new development that the agricultural sector will follow in the years to come. The idea behind Agriculture 6.0 is specifically to integrate the latest developments in smart technology to expand the effectiveness and eco-friendly sustainability of agricultural production methods (Symeonaki et al., 2024).

A new approach to agriculture known as "Smart Agriculture" integrates modern IT, comprising IoT, Big Data, and more, to provide individualised services. To put it briefly, innovative style is an intelligent agricultural clarification that integrates agriculture with recent information technology. While recent information technology presents novel opportunities for agricultural productivity advancement, it also poses serious challenges and raises high expectations on privacy and security from the perspective of smart agriculture (Louta et al., 2024).

In Agriculture 5.0, agricultural production systems was entirely data-driven thanks to the rapid advancement of cutting-edge technologies like as real-time sensing and wireless sensor networks (WSNs), edge computing, big data analytics, artificial intelligence (AI) and machine learning (ML) (Rahu et al., 2023 & Shah et al., 2024), and the Internet of Things (IoT) as part of Agriculture 4.0. To achieve sustainable development goals, this will raise awareness of the idea of Digital Twins (DTs) (Nie et al. 2022) and their useful uses in the agriculture sector (Symeonaki et al., 2024).

As agriculture enters an innovative era called Agriculture 6.0, it is evolving rapidly these days. To address problems that current agriculture faces, like diseases, climate change, excessive resource use, etc, and to reduce threats while improving production effectiveness and protection, Agriculture 6.0 aims to use new technologies and methods. The market for Agriculture 6.0 is expected to grow significantly in the upcoming years because of the ongoing evolution and the growing demand for food. AI technologies, like IoT (Rahu et al., 2024) and WSNs (Rahu et al., 2022 & Patil et al.), are extensively used in agriculture and provide farmers with several advantages, including forecasting yield, identifying crop diseases, monitoring various environmental parameters, and lowering labour costs (Padhy et al., 2023).

As agricultural transformation and technological advancements have increased in

In recent years, people have steadily integrated many sophisticated and smart algorithms with agriculture, giving rise to terms such as "Smart Agriculture," "Precision Agriculture," "Digital Agriculture," "Decision Agriculture," and "Agriculture 6.0". In response, the idea of Agriculture 5.0 and, consequently, Agriculture 6.0 often suggests that animal production systems be fully digitalised. These comprise IoT, edge computing, big data analytics, WSNs, AI (Aghababaei et al., 2025) and other cutting-edge technologies. Technological developments are making daily lives smarter and more suitable for ordinary people; Smart Society 5.0 and Agriculture 5.0 are even-handed some instances of how existence is changing quickly (Taj et al., 2022).

Annexure (A)

Evolution of Agriculture

Technological developments and modifications to farming methods brought about agriculture's transition from 1.0 to 5.0 revolutionised the production, distribution, and consumption of food. Five stages of agricultural evolution have occurred, with improvements introduced at each level (Ali et al. 2024).

Agriculture 1.0 is the term used to describe traditional farming methods from antiquity, when farmers mostly used local implements such as the agricultural tools of the late 19th century, including the sickle, pitchfork, and hoe. Such farming requires abundant human labour; however, the results were quite low. Agriculture 2.0, or enhanced agricultural production at the beginning of the 20th century, was brought about by the introduction of agricultural technology for seedbed provision, planting, irrigation, hoeing, and reaping, building on the gains made during the first Industrial Revolution (Industry 1.0), which lasted from 1784 to about 1870. Food output was significantly increased by mechanised agriculture, which also decreased manual labour.

The second industrial revolution took place in the 20th century and was dubbed Industry 2.0. The foremost energy source, steam, was switched to gas and oil. Long-distance shipment of agricultural products was made possible by the agri-food supply chain, which was largely made possible by new energy sources and transportation industry improvements.

Then, during the Industry 3.0 era, advancements in software engineering, embedded systems, and communication technologies greatly increased the automation possibilities of production gear. Furthermore, research was being done on green renewable energy sources like photovoltaics, hydroelectricity, and wind. The upgraded agricultural revolution, dubbed Agriculture 3.0, was sparked by the aforementioned advancements and sought to investigate information technology for precision agriculture through guided farming systems, yield monitoring, and variable rate applications.

So, agricultural operations were progressively altered by the three preceding industrial revolutions. Traditional labour-intensive agriculture has been switched to industrial agriculture through the application of industrial production designs, industrial production techniques, and industrial supply chain management. Because industrialised food production and delivery are more efficientand economical, it currently controls the global agriculture sector (Liu et al., 2020).

The idea of automating agriculture fits into the larger framework of the Industrial Revolution. The fourth Industrial Revolution, or "Industry 4.0," refers to the wave of technological development. In a similar vein, agriculture has evolved gradually throughout time, with significant turning points that correspond to several industrial revolutions. This timeline illustrates important changes from Agriculture 1.0, which was marked by antiquated farming practices that relied on human work and animal power, to Agriculture 4.0, where digital technology is transforming the agricultural industry. A pivotal period known as "Agriculture 2.0" saw an overview of agricultural machinery to enhance food output and reduce manual labour. Agriculture 3.0, also referred to as precision farming, arose, improving agricultural systems' operational performance and resource efficiency. Similar to the impact of Industry 4.0 on other industries, Agriculture 4.0 is an innovative revolution in which digital technologies are smoothly incorporated into farming methods. This convergence of agricultural innovations and industrial revolutions highlights the importance of agricultural automation in influencing crop production in the future and resolving issues with contemporary farming methods. However, the prosperity of farmers will be greatly impacted by Agriculture 5.0, especially in the post-pandemic period. Integrating new technologies and alternative energy sources with farming methods is known as "Agriculture 5.0." Green energy sources combined with Agriculture 5.0 can result in lower costs, more energy-efficient operations, and the creation of sustainable energy-smart farms (Bazargani et al., 2024).

2.1 Agriculture 1.0: Pre-Industrial Era

Between 1784 and 1870, Agriculture 1.0, similarly stated as the pre-industrial period, was described by the following: (a) a significant trust in human and animal labor; (b) the usage of vital hand tools, like digs, sickles, and digging sticks for planting and harvesting; (c) the majority of farming was for limited depletion with simply small extra for skill; (d) a variety of harvesting systems for food security; (e) limited farms operated by people; and (f) use of basic channels or loads to water farms. Due to this ancient agricultural method, there is a significant dependence on natural weather patterns, low technological innovation, and low production and efficiency (Taj et al., 2022). Agriculture 1.0: The primary issue with agriculture throughout the old-style agricultural period (1784–1870), when human and animal resources predominated, was its inefficiency in terms of operations. With a focus on labour and animal power, Agriculture 1.0 refers to the traditional farming era. With low productivity and a high proportion of human labour, farmers mostly used local implements for agriculture, such as pitchforks, sickles, and hoes. Agriculture 1.0 marked the commencement of agricultural activities and was typified by crude, archaic methods that heavily relied on manpower and animal power. A low rate of output resulted from the rudimentary tools utilised at the time, which persisted till shortly before the 1950s and emphasis on providing for local people (Neves et al. 2023). This stage, known as Farming 1.0, dates back to the Neolithic Revolution around 10,000 B.C., when human effort became the main resource in agriculture, and the implements utilised were crude. Crop rotation, intercropping, and slash-and-burn agriculture were all progressively developed during this period as ways to control soil fertility and reduce the chance of complete crop failure. Low productivity was caused by both human and animal labour. Vulnerability: Diseases, pests, and weather exposure as risk factors. Knowledge Gap: There was little formal understanding of soil science and plant biology, and the majority of agricultural knowledge was transmitted orally. Despite several limitations, this phase built the framework for long-standing networks of permanent settlements and trade (Singh et al., 2024).

2.2 Agriculture 2.0: Industrial Era

The 18th century until the start of the 20th century was stated to be "Agriculture 2.0," or the "Industrial Era." To increase agricultural yields and livestock breeding, it was illustrious by (a) overview of machinery such as steam-powered tractors, mechanical reapers, and seed drills; (b) increased productivity and efficiency due to mechanization; (c) use of fertilizers, and machines, and improved seeds in larger-scale farming to create extra for craft; (d) application of scientific ideas. Food security and economic prosperity were increased by machinery, which also increased agricultural output and decreased the demand for human labour. Environmental damage, chemical pollution, resource waste, and excessive energy use became problems (Ali et al. 2024). Agriculture 2.0: Resource waste was a significant issue during the 20th century's automated agriculture era. The advent of mineral fertilisers, herbicides, hybrids, and highly productive machinery that raised yields and profitability marked the beginning of the Green Revolution in agriculture, which lasted from the late 1950s until the 1990s. Even though Agriculture 2.0 improved farm labour productivity and efficiency, it also brought with it issues like chemical contamination and harm to natural resources. With the introduction of agricultural machinery, the modernisation of agriculture brought about by the "Green Revolution" advanced into Agriculture 2.0. During this time, the efficiency of activities resulting from scientific advancements significantly increased. Chemical pesticides, synthetic inputs, and new technologies were developed to increase productivity on a big scale and lessen reliance on environmental factors. However, the extensive use of this technological package to boost crop productivity and production has prompted consideration of the implications for the economy, society, and environment. Increased soil erosion, worsened groundwater and surface water contamination, and altered sites with the damage of traditional, cultural, and tourism assets were all consequences of increased natural resource exploitation (Neves et al., 2023).

2.3 Agriculture 3.0: Green Revolution

The Green Revolution, or Agriculture 3.0, began to take shape in the middle of the 20th century (1940s–1960s). During this time, chemical fertilizers, pesticides, and herbicides were widely used to increase crop productivity; irrigation techniques were improved and expanded; tractors, combines, and other machinery were used more frequently; high-yield, disease-resistant crop varieties were developed, increasing the amount of food produced worldwide; farm management practices were improved; and earth observation satellites, Global position systems (GPS), biotechnology, and computer science technologies were used in {agriculture.

These developments decreased food shortages and increased food production. Because of the increased usage of chemicals, it also has negative effects on the environment and human health. Crop genetic modification to boost production and disease resistance was made possible by biotechnological advancements (Ali et al., 2024). Agriculture 3.0: Lack of intelligence was the main issue during the 1992–2017 period of rapid growth in automated agriculture. Agriculture 3.0 ushered in an innovative period of more intellectual and effective machinery-performed tasks in the 20th century. Solutions like data management, sensors and control, and satellite navigation are all part of precision agriculture. Furthermore, Agriculture 3.0 suggests a prototype change in agriculture by emphasising soil life and resilience rather than productivity and "sustainability". As computers and electronics advanced, agriculture 3.0 arose. Additionally, farm guidance systems and remote sensing technologies are used to streamline operations and conserve resources since they provide a more detailed understanding of field requirements (Neves et al., 2023).

2.4 Agriculture 4.0: Digital Revolution

Agricultural 4.0, also known as the Digital Revolution or an Agricultural Revolution Era, occurred between 2015 and 2023, or the end of the 20th and the start of the 21st century. To improve farming practices, increase productivity and efficiency, make well-informed decisions about crop management and resource allocation, automate various farm tasks, reduce environmental impact, support sustainable development, and monitor and control crop and livestock health in real-time, it brought together state-of-the-art technologies like precision agriculture, virtual and augmented reality, big data analytics, 3D printing, IoT devices, quantum computing, drones, satellites, cloud computing platforms, AI, blockchain, and robotics (Ali et al. 2024). Agriculture 4.0, sometimes called "smart agriculture," is categorized by the use of modern information technology to upkeep and perceptively enhance agriculture. Agriculture 4.0 offers means of improving farming efficiency. To properly preserve crops, it also allocates resources and optimises irrigation to use the available energy and water. This would be made possible by combining smart gadgets, forecasting, and environmental monitoring. By improving agricultural systems, smart farming's innovative technology (Karim et al., 2025) can improve cultivation while efficiently employing natural resources. Agriculture, the biggest industry in the world, makes a substantial contribution to both economic expansion and social stability. Resolving the tension between population growth and limited food production is the driving force behind an increasing number of smart agriculture studies. The development, which is based on the visualisation for forthcoming engineering and is known as "Industry 4.0," is comparable to changes in the industrial sector. Utilising cutting-edge technologies like data analytics and aerial photography can optimise crop production, boost productivity, lower expenses, and boost yields. To maximise output, lower risk, and transform data into actionable knowledge, new algorithms have been created. The quantity of facts produced in the field so far cannot be called Big Data, Kokale et al. 2024 & Petrović et al. 2024

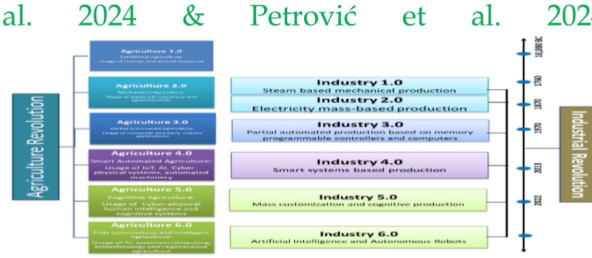

Figure 2. Revolution of Agriculture 1.0 to Agriculture 6.0

Expansion of numerous digital technologies, including sensor networks, IoT, drones, software systems, satellite image processing, cloud computing, robotics, extensive/big data analysis, and mobile apps, is what defines the shift to Agriculture 4.0. Data gathering, processing, and analysis are the hallmarks of this phase, which offers diagnostics to help producers make more strategic and proactive decisions. From production, processing, and distribution to the end user, the entire agribusiness chain becomes more efficient when a digital ecosystem with real-time management is established. By centralising data to link different systems and agents along the production chain, the activities transform into an assimilated network of interior and exterior activities. Additionally, companies may now more easily use these technologies thanks to enhanced and less expensive sensors, low-cost CPUs, and long-range cellular connections (Neves et al., 2023).

2.4.1 Advantages of Agriculture 4.0

Production volume: The number of goods produced on a farm can be greatly increased by utilising smart technologies. This will help feed an expanding population.

Production quality: The quality of food produced can have a major impact on the nutrition and general well-being of people from all socioeconomic backgrounds in the country. Better food will help a nation's citizens live longer and be healthier, which will increase their cost-effective influence.

Efficiency of farming methods and reserve utilisation: Smart technologies can expand the effectiveness of traditional agricultural processes. This, in turn, promotes the more effective use of agricultural assets.

Reducing waste: Massive amounts of food and further secondary means that are wasted are mostly the result of the farming sector, which is one of the major economic sectors. This waste might be tracked and reduced with the use of smart technologies.

Ecologically sustainable:

The environmental and ecological footprint is immediately decreased by decreased agricultural waste and increased agricultural process efficiency.

Efficient Use of Time: Smart agriculture may reduce losses and produce timely, high-quality agricultural output by ensuring that the required pesticides, fertilisers, and other chemicals are delivered on time.

2.5 Agriculture 5.0: Sustainable and Smart Agriculture

Agriculture 5.0, the next phase, is based on production processes that include robotics, wireless sensor networks, autonomous decision systems, crewless vehicles, ML, and AI algorithms. Known as "Smart Agriculture," it offers solutions that enhance data analysis by better comprehending precise, pertinent, and trustworthy data (Neves et al., 2023).

"Agriculture 5.0," or "sustainable Agriculture," uses cutting-edge technologies and creative approaches to address issues facing the agricultural sector while increasing sustainability, efficiency, and production. To maximize resources, boost productivity and sustainability, enhance food security and climate resilience, improve transparency and efficiency in the food supply chain, and boost consumer engagement and trust in food systems, it makes use of AI and ML, IoT, big data, and analytics, vertical and urban farming, advanced robotics and automation, biotechnology and genetic engineering, non-terrestrial networks, and blockchain technology. A prototype shift toward a more data-driven, technologically advanced, and sustainable farming method has been brought about by Agriculture 5.0, which can meet growing food demand while lessening the environmental impact of agriculture. To reduce overall agricultural (Rahu et al., 2024) expenses while benefiting the environment, it also integrates green ideas and extensive use of renewable energy and energy harvesting technology (Ali et al., 2024).

IoT, self-driving autonomous devices (such as robots and drones), and AI have enabled the widespread use of robotic systems in a variety of field tasks, ushering in a new era in agriculture. Over time, difficulties carrying out agrotechnical work have surfaced due to novel certainties in agriculture, which are reflected in a sharp decline in the amount of labour available. Robots have long been used in agriculture; for instance, they can be used
to automate the milking of cows in dairy farms or to pick fruits from plants in protected
regions (Petrovićet al., 2024).

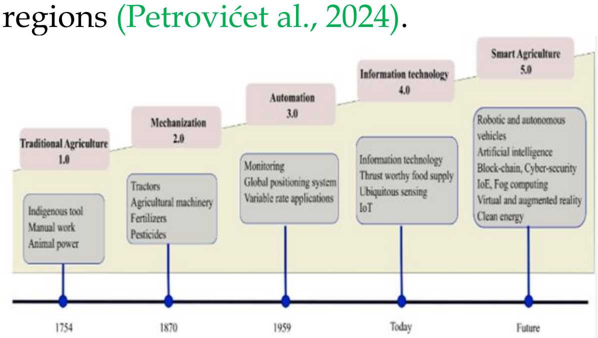

Figure. 3 Evolutionary progression from agriculture 1.0 to 5.0 (Petrović et al. 2024)

2.6 Agriculture 6.0: Autonomous & Regenerative

The future of farming, known as Agriculture 6.0, aims to create a completely autonomous, sustainable, and intelligent agricultural system. To increase output while reducing environmental effects, it incorporates state-of-the-art technologies comprising AI, quantum computing, biotechnology, and regenerative agriculture. The future of completely automated, intelligent, big data, smarter, and sustainable agriculture is embodied by Agriculture 6.0. It seeks to end food hunger, lessen environmental harm, and establish globally self-sufficient food production systems.

The technological advancement of agriculture is now consolidating this period. To leave a natural legacy deserving of future generations, Agriculture 6.0 reinforces the need for sustainable progress and the gradual, prudent use of the globe's resources. In the years to come, maintaining peace among all living things will depend heavily on how humans, agriculture, and nature interact (Neves et al., 2023).

Figure 4: The technological evolution of agriculture throughout history

In Figure 4, the aforementioned highlights the key points of the "Agriculture 6.0" plan by contrasting it with earlier models and the technologies and procedures that were integrated into livestock and agricultural production systems, as well as other production chain linkages. It is important to remember that to develop an integrative and more sustainable system of Agriculture 6.0, technologies that arose in earlier phases, particularly intelligent tools offered by Agriculture 5.0, must be further improved (Neves et al., 2023).

2.6.1 Emerging Innovations in Agriculture 6.0

1. AI-driven self-repairing crops (genetic editing for climate resistance).

2. Vertical and cellular agriculture (lab-grown food, indoor precision farming).
3. Autonomous nano-drones & swarms (self-learning pest control).
4. Decentralised food production (hyper-localised and AI-optimised food supply chains).
5. Quantum-powered climate models (ultra-accurate weather and soil predictions).

2.6.2 Key Advancements over Time

1. Agriculture 1.0 → 3.0: Increased efficiency through mechanisation and chemicals.
2. Agriculture 4.0: Smart technologies, data-driven precision farming.
3. Agriculture 5.0: AI-driven autonomous farms, sustainability focus.
4. Agriculture 6.0: Fully regenerative, AI-managed, self-sufficient, and climate-resilient agriculture.

2.6.3. Comparative summary and operational Boundaries of Agricultural phases 1.0 to 6.0

The main revolution in Agriculture 5.0 is incorporation of cutting-edge digital technologies like AI to robotic and Big data analysis to boost efficiency, productivity, and sustainability, its operational boundary is generally limited to automation, data driven management and resources optimization with current agricultural systems, in contrast Agriculture 6.0 extends beyond technologically optimization to fully autonomous, interconnected and ethically governed agri eco systems, while decentralized data plateforms like blockchain, Digital twins, cyber physical systems operates across from production to consumption, policy and global sustainable goals. Agriculture 6.0 extends its operational boundaries to data governance, ethical AI, social ecological resilience, circular economy integration, and interoperability across worldwide plateforms indicates agriculture as the digital sovereign, human AI evolutionary system, and adaptive rather than a digitally enhanced sector. The evolution of agriculture from conventional practices to the most recent AI-driven sustainable farming is compared in this table.

Annexure (B)

Table 1: Evolution of Agriculture

3. Case studies on the digital transformation of agriculture

This study looks at how digitisation affects agribusiness enterprises' green transformation, with a focus on agribusiness corporations. The study investigates how digitisation affects these businesses using fixed-effect and mediated-effect models. This study shows that there is a non-linear link between digitisation and green transformation in agriculture, with a certain level of digitisation required before it has a positive impact on green transformation. The effect of digitisation on green transformation varies depending on the kind of corporate possession, firm size, supply chain flexibility, and local environmental limitations. This Study demonstrates how digitisation impacts green transformation through several elements that support economies of scale, technological modernism, and essential changes. Although digitisation-derived economies of scale don't immediately promote green transformation, they do make it easier for technical advancements and structural changes to improve agribusiness's green ambitions (Yuan et al., 2024).

One of the main causes of challenges in agricultural digital transformation is a lack of cooperation and participation from stakeholders. Nevertheless, there is a dearth of research that actively reveals the factors that motivate and hinder agricultural digitisation from the viewpoint of stakeholders. Rise in proceeds and prospect budgets of not taking part in agricultural digital transformation are the main motivators. The significant exogenous cause supporting agricultural digital transformation is government incentives. In the context of agricultural digital transformation, it also offers theoretical justification for the explanation of phenomena like path dependence, multiple equilibria, and irrational behaviour (Sun et al., 2024).

Agriculture 5.0 advocates the most recent cutting-edge blockchain, AI, and IoT technology for smart agriculture. AI-based algorithms and remotely sensed data at numerous levels, including in-situ, aerial, and satellite, enable applications such as crop monitoring, real-time weed and dangerous bug finding and exclusion, plant disease identification, and targeted action use (Ivanovici et al., 2024).

A key role of this study is to determine the most important significances for the advancement of agricultural production in response to contemporary hazards and dangers that adapt appropriately to the current socioeconomic climate. The authors offer three primary strategies for addressing the contemporary issues and dangers facing agriculture. The first strategy involves expanding agricultural production through modernising existing land use, raising more cattle and poultry, extending the area under cultivation, etc. The development of endowment agriculture, which prioritises government assistance for agricultural production, is responsible for the second strategy. The deployment of cutting-edge digital production technologies and the newest digital monitoring and control systems constitutes the third strategy, which is characterised by the digital transformation of the agricultural region. It makes sense that there aren't any substitutes for the digital transformation of agricultural production that can effectively address the dangers and challenges facing agricultural development today. The universal reaction to current agricultural dangers and difficulties is known as the digital transformation of agricultural production (Nemchenko et al., 2022).

Large-scale farms benefit more from digital agriculture technologies, but small-scale farms in developing nations have faced several obstacles in their digital transformation. This study examined the potential involvement of small farmers in the transition from mechanisation to digitalisation.

The research's limitations are as follows: This study did not collect data for a measurable exploration of each participant's situation and part in the digital ecosystem, even though it offered a conceptual picture of a procedure and mode of operation of smallholders' connection in digital agriculture. As a case study, it hasn't done a quantitative analysis of how digital agriculture affects smallholders' income or agricultural output. The resolution of the two aforementioned problems will be advantageous for future studies (Xie et al., 2021).

The study fills the knowledge gap in the expanding field of literature on AI-driven business models through empirical analysis. The instance of "zero," a business associated with an advanced environment of Ca' Foscari University of Venice, Italy, is examined in this study. The semi-structured survey, conversations, and a review of community bulletin articles about the business model presented in a case study under analysis were used to gather the empirical data. The study found that AI can help with decision-making, which can improve output, efficiency, product quality, and lower costs. Through local manufacturing, ongoing learning, and the potential for price reductions aimed at achieving zero-kilometre food with fresh items, AI helps raise these parameters. To gather enough data to support ongoing learning and development, it must be used in conjunction with other gadgets like robots, sensors, and drones. The creation of ecosystems connecting farms, technological companies, legislators, academic institutions, research facilities, and local consumer communities is the main implication. Given the paucity of empirical case studies on AI-supporting business models in agriculture in the corpus of existing literature, the study is significant. The study also has important strategic implications for the Regulations that should be implemented to support the creation of new business models in agriculture (Cavazza et al., 2023).

To evaluate how agricultural technologies, specifically Blockchain, AI/ML, IoT, and recommendation systems, optimise agricultural marketing, this Systematic Literature Review (SLR) looks at 99 peer-reviewed articles (2019–2025) from Scopus, Web of Science, and IEEE Xplore. The review follows PRISMA guidelines and assesses implementation readiness and computational performance, with a focus on the smallholder farmer context (Arzuaga-Ochoa et al. 2026).

4. Discussion:

Blockchain, AI, ML, IoT, and recommendation systems are among the agricultural technologies that agricultural marketing is progressively incorporating. However, there are still a few systematic assessments of computational maturity and implementation readiness. In order to evaluate assessment techniques and Technology Readiness Levels (TRLs) for agricultural marketing applications, this Systematic Literature Review (SLR) looked at 99 peer-reviewed articles (2019–2025) from Scopus, Web of Science, and IEEE Xplore using PRISMA protocols. While blockchain implementations (15.2%) demonstrate quick transaction speeds (<2 s) but limited real-world acceptance, hybrid recommendation systems (28.3%) dominate current research, attaining accuracies of 80–92%. IoT systems exhibit >95% data transmission reliability. This shows a change to multi-tier evaluation frameworks that incorporate contextual, adoption, and impact validation under actual deployment conditions in light of the ongoing validation-deployment gap in digital agriculture (Arzuaga-Ochoa et al. 2026).

Technological empowerment creates a systematic and multi-layered model in the context of building digital villages. The frameworks provide how resources, user behaviours, and structures interact to propel transformation. In any development, each layer has a distinct function that guarantees the efficient interaction of infrastructure, technology adoption, and governance to promote equitable and sustainable growth (Liu et al. 2026).

This paper explicitly discusses and addresses data governance, ethical considerations of agriculture 1.0 to 6.0 and interoperability. Detailed frameworks, privacy, ownership, and security in AI and digitally driven agriculture show the importance of interoperable standards and platforms to enable whole data, and mention ethical concerns like algorithm bias, digital technology access and socio-economic impacts on small-scale farmers. The enhanced Agriculture 6.0 will ensure the technological advancement aligned with secure, transparent and inclusive data practices.

Table 2: Key Technologies

Layer	Core Technologies	Key functions	Applications
Base Layer	IoT, 5G,	Connectivity, real-time data collection, and monitoring	Crop monitoring, IoT, telemedicine.
Application Layer	AI, Blockchain, Big Data	Data-driven decisions, smart management	Fertilisation, smart irrigation, blockchain-based traceability
Governance layer	Digital and community platforms affairs,	Processes, streamlines, engagements	Efficient governance, one-step solutions.

5. Conclusion

An outline of the primary resources for Metaverse virtual food and farm systems is provided in this study, including the interactive platforms for all parties involved, the virtual settings for food production and distribution, and the improved consumer awareness and experience. Farmers benefit from increased operational efficiency and food supply chain transparency when this technology is used. Despite the difficulties and constraints, the use of Metaverse virtual agriculture and food systems has the potential to entirely transform conventional agricultural and food systems. New developments and trends present chances for more efficient and sustainable food production. Surprisingly, agricultural and production systems have changed as a result of technological advancements over time. Numerous tools, methods, practices, and technologies have made it feasible to increase production productivity, efficiency, and sustainability. In keeping with what future generations desire for a higher standard of living, it should be no surprise that the trends that have been emerging and will likely become apparent in the years to come represent a paradigm change in how we now think about agricultural production. Governmental and corporate entities need to take Agriculture 6.0 seriously if they want to keep innovating and investing in new technologies that produce a sustainable global supply of food, textiles, bioenergy, and other agro-products. This new integrated model seeks to improve our interaction with the earth and how we use the resources that are available by balancing the well-being of people and the environment.

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Annexure (A)

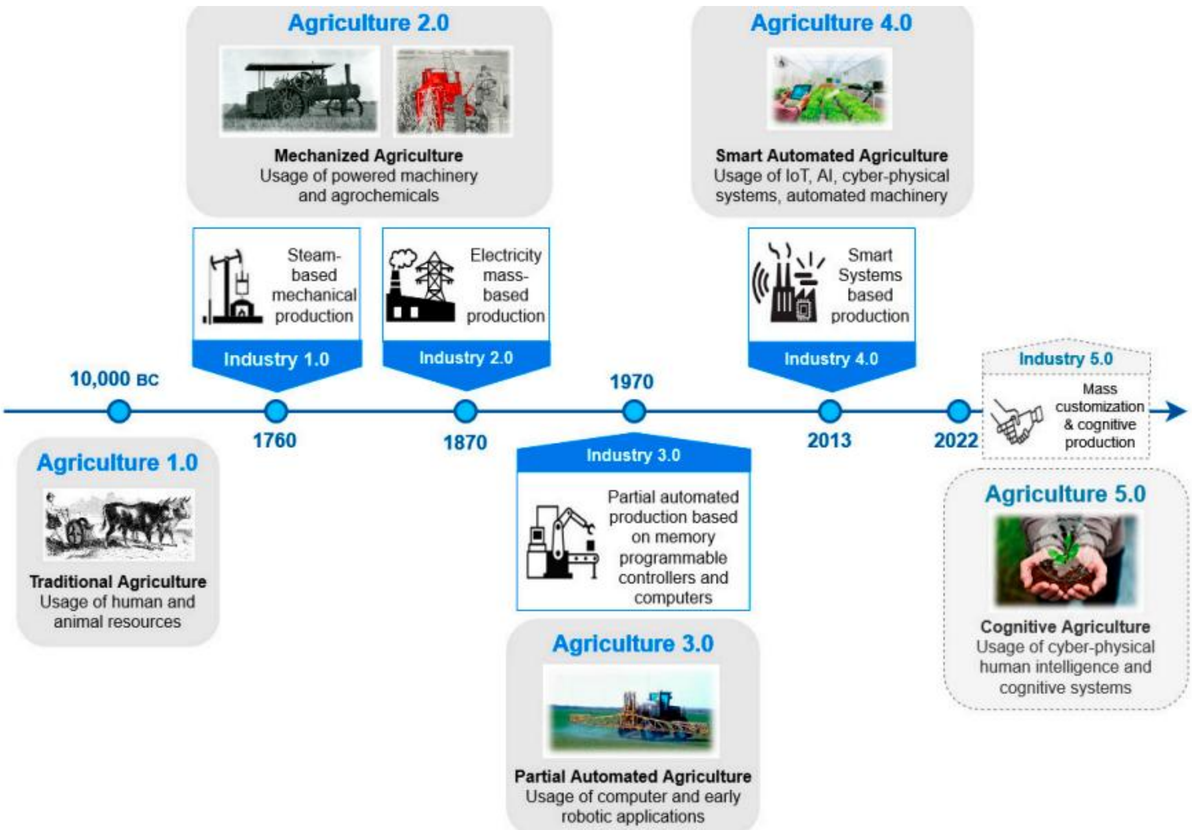

Figure 1. Timeline of industrial and agricultural revolutions (5)

Annexure (B)

Feature	Agriculture 1.0 traditional	Agriculture 2.0 Mechanical	Agriculture 3.0 Green Revolution	Agriculture 4.0 Smart & Precision	Agriculture 5.0 AI & Sustainable	Agriculture 6.0 Autonomous & Regenerative
Time period	Pre-industrial era	Late 19th-Mid 20th century	Mid 20th Late 20th century	Early 21st century-Present	Future-oriented (2030s)	Beyond 2040
Technology	Manual tools, animal labor	Tractors, Irrigation systems	Chemical Fertilisers, Pesticides	IoT, Drones, Robotics	AI, Blockchain, Autonomous Farming	AI, Quantum Computing, Bioengineering.
Labor Intensity	High (human and animal labour)	Reduced due to machines	Moderate (Mechanised with manual control)	Low (Automation & Sensors)	Very low (fully Autonomous)	Fully Autonomous & self-repairing systems
Yield Efficiency	Low	Moderate	High	Very high	Optimised with AI	Ultra-high, AI-optimised
Environmental impact	Sustainable but inefficient	Soil degradation, water-intensive	High chemical usage, soil erosion	Reduced impact, precision farming.	Regenerative carbon neutral	Net-zero emission, Biodiversity-focused

Data Utilization	No data use	Basic record keeping	Some data used in breeding and production	Big data, cloud computing,	AI-driven real-time decision-making	Quantum-powered climate & Soil models.
Connectivity	None	Limited	Limited	IoT & cloud-based connectivity	Fully interconnected smart farms	Decentralised blockchain-based food networks
Farming Methods	Manual ploughing, natural fertilisers	Mechanised Ploughing, Artificial Irrigation	Hybrid seeds, synthetic fertilisers	Precision Farming, smart irrigation	AI-Driven farming, vertical farming	Self-learning AI farms cellular agriculture
Sustainability	Natural but low productivity	Moderate	Declining due to chemical reliance	Improved sustainability	High sustainability with circular economy principles	100% renewable, climate adaptive.
SDG's	Aligned with SDG 2, zero hunger through basic food production	Aligned with SDG 2 & 8, Decent work by increasing productivity	Aligned with SDG 9, Industry Innovation, 7, SDG 12, Responsible consumption	Aligned with SDG 13 Climate action & SDG 15 Life on Land	Both Agri 5.0 & 6.0 Targets SDG 2, 9, 12, 13, and 17	Both Agri 5.0 & 6.0 Targets SDG 2, 9, 12, 13, and 17