

Middleware Data Platform in Agricultural Supply Chain

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Abstract— Demographic and climatic changes, changes in resource distribution and soil condition of compost, depleting water resources, greater demand for customized products, need for traceability to maintain food safety and hygiene; all warrant the use of sophisticated modern technologies all along the food supply chain (SC). The integration of IoT, AI and such other technologies with blockchain can significantly improve operational efficiency of agriculture, allowing traceability and ensuring safety and quality control. Such integration also helps to realize maximum benefits from application of modern technologies to make entire agri SC more resilient. Successful application of various technologies hinges on efficient data analytics and technology integration and can be achieved using middleware for technology integration and seamless data flow within the SC. Though promising, it presents significant challenges that need to be handled to realize its full potential. This article establishes middleware data platform's potential in integrating AI, IoT and blockchain technologies and enhancing operational efficiency of agri SC through enhanced transparency, efficiency, and security. Using a systematic AI-driven data analytics platform Middleware provides diagnostic intelligence to the farmers. Realizing middleware's potential and utilizing it can greatly enhance functionality and performance of ASC, making it an essential tool for both developers and users. However, the technology being nascent, there is significant dearth of data, literature and evidence regarding the user experience and success rate of middleware, hence a significant knowledge gap. This article contributes towards bridging the gap, setting the floor for further research.

Keywords— *Middleware, Blockchain, agricultural supply chain, ASC, supply chain management, SC, artificial intelligence, AI, SC, IoT.*

1. Introduction

The agricultural supply chain (ASC) is unique in nature for the existence of such factors as dependency of production on weather, product perishability, and lack of standardization in product quality and/ or size. Besides handling the sustainability issue, agricultural businesses are always under tremendous pressure for their duty towards ensuring food safety and security [1]. The safety, security and reliability that consumers perceive in the ASC particularly hinges critically on traceability as has been highlighted by earlier researches [2,3].

A sizable portion of the ASC belongs to the unorganized sector giving rise to inadequate recording and maintenance of important data. Bulk of the data is unstructured and inaccessible and hence not useful in decision making. These factors magnify the complexity of management of ASC as compared to the SC for manufactured goods. However, the evolution of agriculture and ASC over time to its modern avatar demands the application of sophisticated contemporary technology in most aspects. The sourcing, structuring and analysis of relevant data hence become inevitable and imperative. Middleware is a potential solution. Its application in agriculture can facilitate data management and communication amongst the numerous systems involved in smart agriculture, enabling seamless incorporation of different agricultural technologies and allows interoperability.

With the intensification of digitalization in the agricultural sector, the studies in the discipline which address adoption and implementation of digital technologies in farming and agriculture have also grown in number. This study adds to the pool of literature that address the need for and use of data-driven multiple modern technologies in optimizing agricultural supply chain and the

platforms that facilitate such application and adoption. This paper focuses on the pivotal role played by middleware data platform in adoption of AI, Blockchain and IoT (Internet of Things) technologies in agriculture.

2. Literature Review

2.2 Rapid Evolution of Agriculture

Human survival over the ages was made possible by farming, as humans nestled and inhabited hospitable terrains and began producing their own food. The application of and role played by farming technology can be traced back to the stone age when humans invented their first tools. Gradually, with increase in population, humans saw the need for enhancing productivity which created huge scope of further development that was aided by the creation and larger production of tools through the copper, bronze, and iron ages [4].

Of late, the agri industry is seeing significant transformation, as technology has started becoming increasingly pivotal to its scalability and operational efficiency. This rapid evolution of agriculture is aided by the significant and revolutionary advancements in farming procedures methodologies over time, resulting in expansion in the volume and improvement of quality of food production along with modifications in agricultural systems. Scientific discoveries, technological innovations, modifications in societal needs and changes in consumer demands have been the key factors driving this evolution. The emphasis of modern agriculture is on sustainable exercises and procedures that are capable of minimizing environmental impact, though soil and water conservation, waste management, lower use of pesticide use, etc.

2.3 Adoption of Key Digital Technologies in Agricultural Supply Chain

Modern agriculture is evolving and transitioning rapidly – moving away from established practices to a data-driven and more technically advanced approach that focuses not just on increased yields but also on better efficiency and sustainability. The implementation of digital technology in agriculture is now growing tremendously [5]. This inclination is transmuting conventional farming techniques, that will ultimately lead to more efficient resource management and superior productivity [6]. Innovations are at the forefront of this transformation. Precision farming, artificial intelligence (AI), and Internet of Things (IoT) are

key technologies that can be integrated to work towards optimization of crop growth and resource management. Precision farming applies such technologies as sensors, drones, and GPS for amassing real-time data related to weather patterns, soil conditions, and crop health.

2.4 Need for Adoption

It must always be kept in mind that agricultural supply chain management (ASCM) is different from SCM of other products. Though it deals with the relationship between the raw materials supply, manufacturing processes, logistics management distribution to retailers and delivery to consumers [7], the key differentiator is the ASC's complexity that demands extreme levels of efficiency at the operational level to ensure high coordination between activities as it deals with perishable goods [3, 8]. Time is of essence here. Time is of utmost importance. Hence all activities must be timed perfectly to ensure products never get spoiled in transit from the farm to the consumers' plates. Delays need to be avoided at all cost. It is also necessary to ensure that wastage be reduced to the minimum and one of the most effective ways of doing it producing in quantities that match demand very closely if not completely. Hence forecasting becomes essential which in turn requires analysis of massive volumes of data. Speed, agility and precision are some of the key attributes imparted by technology [8].

Among the widely used technologies, presently the focus is on automation solutions that, besides being user-friendly, reduce workload of the farmers. For less developed and developing countries where the agri sector is still unorganized and bulk of the agricultural activities still occur in small-scale, it is essential that contemporary equipment and technology trends in agriculture be correctly identified so as to ensure that digitalization can be promoted through robust policy endeavors [5]. This article focuses on three of the most popular technologies that are being adopted in modern agriculture.

2.4.1 AI

Artificial Intelligence or AI is capable of significantly transforming ASCM through efficiency enhancement, waste reduction, and superior overall productivity levels. Cost rationalization and better resource allocation can be achieved through application of such AI-powered tools as predictive analytics, demand forecasting, and optimizing logistics. AI has robust transformative potential from the perspective of logistics optimization, waste reduction, and

agricultural product distribution. It can bring in significant cost rationalization and improvement in operational efficiencies. AI-driven models can optimize logistics through demand forecasting, superior inventory management, and transportation route streamlining, which in turn will reduce costs while expediting deliveries. Through crop quality monitoring and spoilage prediction, AI enhances precision in harvesting and helps create distribution schedules; AI algorithms are able to enhance waste reduction efforts.

Another reason why these technologies should be adopted, is their ability to contribute meaningfully towards better equitable distribution since they can ensure efficiency, timeliness and consistency in bringing the agri products to the markets. The Food and Agriculture Organization (FAO) reports that the food supply chain (FSC) is about to become the key contributor to greenhouse gas (GHG) emission from the agricultural food system. In addition, it claims that nearly 14% of total global food production is lost along the supply chain before it reaches the retailers. It can happen during activities on farms, storage, and delivery [9]. This footprint is created due to energy consumption, food loss and waste, and the production of fertilizers and other materials that support the entire ASC, furthering climate change and negatively impacting food security. Integration of AI with ASC, besides improving operational efficiency, also reinforces sustainability through the reduction in adverse environmental impact of production and distribution of agri products. [10].

2.4.2 Blockchain

Among the top concerns in public health is the issue of food safety. Blockchain technology has exhibited a lot of promise in this respect. Applying the technology, users can record the origin and flow of products successfully, accurately and economically. This helps to reduce harmful food fraud significantly, if not eliminate completely. Experts' estimates indicate that 1% of the global food industry is affected by food fraud. The yearly financial impact amounts to nearly \$10-\$15 billion, although certain recent expert estimates indicate that the cost could be substantially higher at around \$40 billion per year [11]. Such development can benefit consumers by providing them with conversant, latest and verifiable data pertaining to the origins and delivery routes of products that they purchase [1]. Hence, Blockchain need to be integrated into the ASC to ensure enhanced "transparency, traceability, and trust".

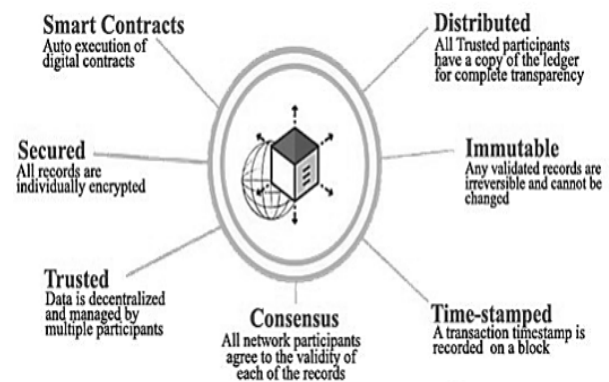


Figure 1: Blockchain Technology – Characteristics [12]

The technology offers certifiable real-time record of the origin and journey of a product which allows the customers to verify claims relating to specific origins, organic sourcing, and ethical practices [13]. Every transaction and movement of goods is recorded on a decentralized ledger, which makes blockchain an ideal choice of technology for agri supply chain management ensuring transparency and traceability [14]. The decentralization ensures greater accessibility of agricultural data, since the information fed into the system does not belong to any single entity but is shared by all those who are parts of the blockchain, however small [14]. The data cannot be tampered with and hence is immutable which ensures credibility.

Every activity that ever occurs in the food production network will be recorded in the Blockchain for viewing by all entities. This transparency enables combating such issues as food fraud through product origin and authenticity verification. In so doing it safeguards brand reputation while increasing consumer confidence. Blockchain allows real-time product tracking throughout the supply chain thus enhancing traceability, a capability that becomes particularly indispensable while ensuring food safety. By allowing swift identification of contamination incidents it ensures rapid response which in turn reduces the possibility of foodborne disease outbreaks [15].

Globally per year CO₂ generation from food waste reaches 3.3 billion tons approximately. Blockchain technology can help achieve a more sustainable and low-carbon economy in the food supply chain [16]. As has already been highlighted, ASC creates significant carbon footprint. The global agricultural food system contributes nearly 31% of total greenhouse gas emissions caused by human activities, and a sizable part of it comes from the SC itself, which includes

post-farm activities like transportation, processing, and distribution [17]. Blockchain technology increases SC management efficiency through processes rationalization, lower need for intermediaries, and reducing the paperwork to the minimum, thus resulting in cost cutting and faster turnovers and deliveries.

2.4.3 *IoT*

Real-time data tracking and collection is made possible by Internet of Things (IoT) – a novel technology that works through the application of several communication tools and facilities and information processing technology that are accessible using a variety of possible networks to achieve the universal connection of objects and objects, objects and people, to attain a vastly intelligent sensing, detection and management of purposes and procedures in the environment [18]. IoT, hence, refers to the technology applied to embedded systems, in which various devices are connected to the internet, and includes network connectivity, actuators, transducers, and sensors enabling these devices to assemble and mutually exchange data [19].

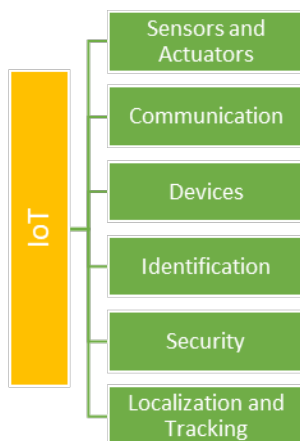


Figure 2: Features of IoT [19]

There are various factors that warrant the application of IoT in agriculture. Contemporary farming and agriculture can be modernized and revolutionized using this technology [20]. IoT-enabled devices allow modern farmers to collect real-time data pertaining to environmental conditions, examine equipment performance, and undertake info-based decisions capable of improving crop cultivation as well as livestock management [6]. Drones, sensors, and Machine Learning are some of the IoT technologies that can be used effectively in agriculture to rationalize water usage, cut down waste generation, and improve yields of crops [18, 21]. As per the World Bank, agriculture makes up for almost 70% of

global freshwater withdrawals, and nearly 60% of this water is wasted, mostly because of inefficient applications, according to the UN's Food and Agriculture Organization (FAO) [22].

IoT also plays an important part in supervision and management of agricultural environment to enhance productivity and efficiency while ensuring integration with the international agricultural markets. IoT technology integrates interconnected sensors, devices, and data analytics, and in the process creates unparalleled scope for the adoption of precision agriculture, application of resource optimization practices, and facilitates predictive decision-making [23]. The success of smart agriculture, therefore, hinges critically on the effective integration and deployment of cutting-edge sophisticated technologies, such as IoT, in the agricultural sector with the primary objective of improving both quality and yield of crop production [19]. Precision irrigation systems powered by IoT have exhibited improved crop yields and reduction in water use by about 30% by enabling precision and timeliness of irrigation reinforced by real-time data on soil moisture and weather [24]. This improves crop yields, while conferring the dual benefits of efficiency and sustainability.

Agricultural IoT can be displayed in real time using a number of different instruments or participate in automatic control [18]. From the macro perspective, IOT technology has an important role to play in digitization of agricultural info and efficient management of ASC as is evident from the leading role it played in 'informationization' of agricultural in the Chinese economy [25]. It helped in judicious use of ICT to develop field technology by modifying the conventional method of planting and promoting intelligent and refined planting methods in agriculture [23]. At the micro level, it can assist human beings in recognizing, managing and controlling different systems, processes and elements in agriculture in a more detail-oriented and dynamic manner, that greatly enhances human knowledge about the fundamentals of agricultural plants and farm animals. Human cognitive ability pertaining to the nature and lifecycle of agricultural plantations and farm animals, smart and dynamic regulation of complicated agricultural ecosystems, and the capacity to handle agricultural emergencies can be greatly improved using the technology [18]. The application of the technology spans miscellaneous areas, comprising monitoring of soil and crop, automated irrigation, tracking health of livestock, and disease prevention, permitting farmers to enhance resource usage while boosting productivity [26].

2.5 Impediments to Adoption

Technology adoption in agriculture while necessary, is not easy. Identifying the appropriate technology for the leg of the supply chain, implementing it successfully and integrating various technologies is neither easy nor inexpensive. Several problems and impediments crop up.

Besides the high cost factor, major problems in AI implementation in ASC are dearth of skilled labor, low or no digital literacy, insufficient rural infrastructure and connectivity especially in the developing and less developed countries, inadequacy of high-quality data, data privacy and security, and job displacement. Particularly the small-scale farmers, struggle with the substantial initial investment and integration of novel technologies with conventional procedures, thus slowing overall adoption. Similarly, the adoption of blockchain technology in ASC faces challenges, including the need for appropriate technological infrastructure, significant implementation cost, and the need for extensive stakeholder collaboration [15]. Several challenges persist and needs addressing for fully leveraging of the technology.

The emergence of smart agriculture that applies IoT is benefiting farmers by providing greater control over their operations, than earlier. However, implementing IoT in ASC poses several important questions, especially related to technical expertise, connectivity, and costs involved. The same issues emerge - poor internet connectivity in rural areas, daunting upfront expenditures and ongoing costs, and absence of requisite specialized knowledge for management and interpretation of data amassed from IoT devices. These incumbent widespread technology adoption. Data security, interoperability between devices, and data accuracy continue to create significant hurdles [6]. Other concerns include integration costs and the dearth of comprehensive regulatory frameworks that cover technological, economic, and social environments [19]

3. Methodology

The article draws theories from various books and published articles in international and reputed journals such as the International Journal of Supply Chain Management. Charts and diagrams have been used to vividly demonstrate academic concepts. Contemporary data have been drawn from reliable sources such as reputed newspapers, government publications and websites.

4. Discussion

AI and Blockchain technologies when combined with IoT devices present a formidable solution for superior data collection and traceability in ASC. Decentralized networks and AI-driven automation enhance smart agriculture by making it accessible to a wider range of farmers and agri businesses [27]. While blockchain enhances traceability and provenance across a complex SC, its integration with IoT imparts better SC functionality to blockchain [28].

Smart agriculture utilizes IoT applications for improving operational competence and profitability while ensuring environmental sustainability [29]. For the successful implementation to happen, a plethora of challenges including limited availability of resources and the effects of climate change, must be negotiated. These challenges together with an ever-growing population, urge the agricultural industry to transform. An integration of modern technologies has the potential to transform this sector completely, but the complete impact remains uncertain as this is still in its infancy. While an efficient integration has the potential to immensely transform agriculture in a positive way, there is always a possibility that the applications may backfire. The extent of damage under such circumstances may be devastating as it will affect the lifeline of the entire global population – the food supply chain. Hence the need for rigorous analysis of relevant information.

Sensors, RFID tags and other IoT devices can collect massive volumes of data pertaining to different stages of ASC, including soil conditions, crop growth, weather patterns, and the transportation and storage conditions of agricultural products [30]. The data collected can be documented on a blockchain, to ensure that it remains secure, tamper-proof, and accessible to all stakeholders [28]. Blockchain being decentralized in nature, ensures that data collected by IoT devices is transparent and immutable. Hence the record provided is reliable and is useful for tracing the origin and movement of agricultural products throughout the SC.

The keywords here are technology adaptation and integration. Multiple technologies are used in tandem to bring about maximum efficiency of the supply chain. Modern era is the era of data. Application of various technologies are their successful implementation and continued running are heavily dependent on the availability and usability of relevant data. The huge volume of data generated in the course of any transaction needs to be harnessed in such a manner so as to generate

valuable insights that can become useful while making the supply chain technologically robust and enhance its efficiency in a cost-effective manner.

5. Middleware as the Solution

Middleware offers a possible solution to this problem of integration and communication. It is software that helps to close the gaps between different applications, tools, and databases with the purpose of providing unified services to users. Middleware permits integration by playing the role of a mediator and "bridge" between various different applications, databases, and systems, which allows them to communicate effectively amongst each other, share data seamlessly, and act as one, unified system. Middleware performs the function of a translator, that ensures all components work harmoniously and in tandem, despite being built on diverse technologies, the outcome being middleware's emergence as a crucial element in modern software architecture [31]. In simple terms, Middleware refers to a software that makes multiple types of communication or connectivity amongst various components or diverse applications possible in a distributed network, basically creating "software glue" capable of binding various systems together [32].

From the perspective of agriculture, middleware acts as the critical software layer that connects such

disparate systems as sensors, farm management platforms, and data analytics which enhances interoperability, data management, and communication that are essential for precision agriculture and smart farming. It translates a variety of different data formats, eases real-time sensor data analysis, and allows seamless integration amongst software, hardware, and cloud-based services which in turn helps in process optimization, in making informed decisions, and permits management across the complete agri value chain from remote [33].

Middleware in agriculture indicates a software that acts as an intermediary, enabling seamless data exchange in the aggrotech sector by connecting diverse systems. It solves the compatibility issues amongst various different agricultural software, sensors, and devices, and in the process enables real-time data analysis, allows superior decision-making, and creates interoperable "system of systems" thus making precision agriculture and farming convergence possible. The adoption is primarily driven by speedy adoption of IoT devices, interoperability needs, and the requirement of secure data infrastructure that can analyze Agri IoT applications.

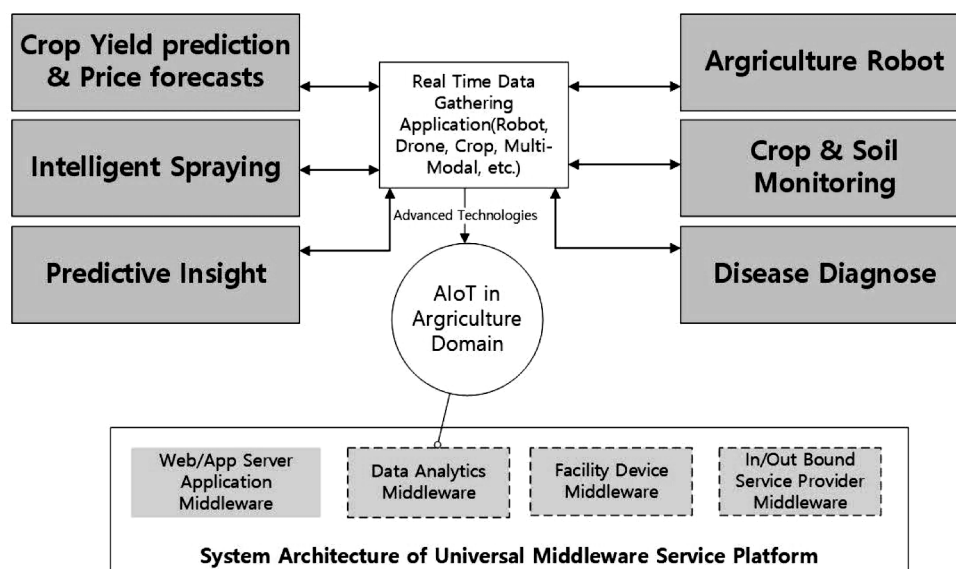


Figure 1: Middleware Structure [34]

In essence Middleware is software acting as a bridge, to enable communication and data management amongst various applications, systems, or services, providing a tier of abstraction, allowing seamless interaction between diverse components despite being built with diverse

technologies. It is akin to the "plumbing" connecting various parts of a software system.

Certain Key Features of Middleware

- Middleware, in its most basic form, allows developers to fabricate applications that do

not need to a unique integration every time there is need to link with devices, data sources, computational resources, or services.

- For achieving this, developers offer services that facilitate communication amongst different applications and services using standard messaging frameworks, which includes web services, XML (extensible markup language), REST (representational state transfer), JSON (JavaScript object notation), and SOAP (simple object access protocol) [31].
- These services allow inter-communications of components developed in different languages, including PHP, Python, Java, and C++.
- It can carry out authentication using its ability to challenge requests made by front-end applications for credentials (password and username) or digital certificates. This can be done over several servers, on-premises or in the cloud, depending on application demand surges.

Globally middleware is gradually coming to play a crucial role in digital transformation strategies by allowing integration of modern applications with legacy systems, thus enabling easier data exchange between various systems, and supporting the implementation of such novel technologies as AI, Blockchain and IoT.

The size of the worldwide middleware market was estimated at US\$ 33.8 billion in 2023 and is poised to grow at a CAGR of 10.8% from US\$ 37.45 billion in 2024 to US\$ 85.07 billion by 2032 [35]. It indicates a robust growth potential of the market which is backed by global organizations who are increasingly adopting digital transformation to remain viable in a competitive and highly dynamic market that has to constantly meet ever-evolving consumer demands

5.2 Application of Middleware in Agriculture

In the context of an organization, the need for middleware arises to connect and integrate the broad array of technologies, systems, and applications, that business organizations adopt. Through the provision of a unified communication and data exchange platform, middleware simplifies the complexity existing due to heterogeneous IT environments. Additionally, adoption of cloud computing services, including software-as-a-service (SaaS), platform-as-a-service (PaaS), and

infrastructure-as-a-service (IaaS), create the need for middleware solutions to act as a bridge between on-premises systems and cloud environments. Middleware facilitates effortless, easy and efficient integration as well as communication between the existing infrastructure and cloud-based applications.

In the agricultural and farming environments, there exists a basic workflow which is particularly important to farmers while in the early stages of adoption. Crafting or purchasing application maps, which are transferred to the machine, performing the task followed by closing the loop by uploading the “as-applied” map back to their documentation system. Practical experience reveals that, even now this data transfer to the machine takes place using flash drives instead of a wireless transfer, which poses significant threat for error especially when the operations are large. There exist significant problems related to the availability and compatibility of flash drives, leave aside user error such as loss, breakage and covering long distances in case wrong application map is used [33]. This is just an instance of how technology is applied in agriculture to transfer important information related to farming, sowing, irrigation etc. Due to the existence of human intervention for coordination, and transferring information into machine-readable formats so that the task-controller translates the information to machinery control commands, there is a significant chance of error. Drawbacks and Shortcomings start to appear when live information from sensors or cloud systems need to be considered for creating the ground truth and adjust the data to a device-validated environment in real-time. The problems become particularly pronounced when alongside an application, further optimization software is required to be run on the machine such as live optimization of a fertilizer spreader pattern, data-logging in the background, or the automated control of balancing and control systems pertaining to tire pressure [31]. This is exactly the circumstance in which complex middleware ecosystem become relevant and applicable as it offers similar kinds of functionalities and enable the machine to stream those programs parallelly in the form of digital services which are made possible by the IoT ecosystem architecture of the middleware technology.

5.2.1 Pros

In agriculture middleware provides the much-needed data analytics platform. It offers systematic platforms that uses AI and data analytics to provide diagnostic intelligence to the farmers through the analysis of massive volumes of data that is

generated by different sources such as sensors, drones, and satellites. Demographic changes, climatic changes, changes in the distribution of food resources, changes in soil condition of compost, depleting water resources, need for traceability to maintain safety, security and hygiene of food, all warrant the use of sophisticated modern technologies all along the food supply chain [36]. Multiple technologies must work closely together and middleware helps coordinate and integrate these technologies. Data scientists are actively working to merge IoT and AI technologies, creating AIoT convergence, for improving "smart farming" by providing insights for superior seed production, improved crop protection, and optimum use of fertilizer. Such integration permits real-time data collection from farm sensors, data processing using AI, and generation of actionable recommendations for farmers that will increase agricultural output, enhance operational efficiency, and ensure sustainable practices. Middleware, thus, offers a number of key advantages in agriculture.

Key advantages of using middleware are the following.

- Middleware can be utilized for a wide range of software systems spanning across distributed elements and components to message-oriented communication as well as mobile application support
- Middleware provide real-time access to information amongst systems in a network.
- It acts as a translator and facilitator between different agricultural systems and data sources
- It helps in process simplification and increases efficiency.
- It enables interoperability and real-time data integration from different sensors and platforms
- It helps in preserving integrity of information among several different systems existing on a network as it eases system communication.

5.2.2 Cons

- Exorbitant development expenses hence it is very difficult for not just farmer but also agriculture-based companies to sustain and later expand Middleware's potential.
- The technology being new there are not enough evidences and experiences that can be helpful for background study before implementation.
- There are limited benchmarks for Middleware performance levels since benchmarks are yet to be established.
- Majority of middleware tools are still in the development stage, hence not ready for

maximum use

- There exist several technology platforms that are not currently supported by Middleware

6. Conclusion

The growing world population creates an ever-growing demand for food, but now the consumers are more inclined towards ensuring that the food they consume or the agri product that they use is safe. This along with concerns such as depleting natural resources, falling productivity, depletion of soil nutrients, and climatic changes have created the need for application of sophisticated modern technology along the entire supply chain.

A plethora of benefits can flow from the application of ICT along the ASC. While enhancing productivity it also ensures minimization of wastage, lower carbon footprint and optimization of resources usage which leads to cost rationalization. IoT and AI technologies have been vastly successful in this regard. Integrated with blockchain technology they provide users the facility to record the origin and flow of products successfully, accurately and economically. This helps to reduce harmful food fraud significantly, if not eliminate completely. But problem arises in technology integration, especially where multiple different technologies need to work in tandem. Middleware has a high potential in solving this issue. There is significant scope for research to secure a middleware solution based on blockchain technology integration that will help to effectively protect the consistency, integrity, and availability of IoT data through the utilization of auditing and tamper-proof features of the blockchain. By virtue of being decentralized, blockchain also provides better visibility and superior access to relevant data for all stakeholders. This paper while establishing the need for integration of blockchain with other technologies, also proposes a solution to the impediments in adopting and integrating technologies along the agri supply chain – middleware.

Middleware is pivotal to modern software development for agriculture, as it allows seamless cooperation, collaboration and communication amongst various applications and systems. By simplifying complex integration tasks, it improves efficiency, while ensuring smooth interactions among the components despite being built on different technologies. Realizing middleware's potential and utilizing it can greatly enhance functionality and performance of ASC, making it an essential tool for both developers and users. However, the technology being in the budding state there is significant dearth of data, literature and

evidence regarding the user experience and success rate of middleware. There persist significant knowledge gaps with respect to real-world economic and environmental impact of the technology. This article while adding to the pool of literature sets the floor for further research. Collaborative efforts between stakeholders is crucial for addressing the limitations and facilitating evidence-based implementations of middleware in agricultural.

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