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A Review of Emerging Information and Communication Technologies for Smart and Future Horticultural Supply Chain

Yuvaraj M [1], Jothi Basu R[2]

[1]*Research Scholar, Department of Mechanical Engineering, Presidency University, Bangalore, India*
[2]*Associate Professor, Department of Mechanical Engineering, Presidency University, Bangalore, India*

Email: yuvarajmohanselvam@gmail.com

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Abstract

Fruits, and vegetables (FVs) are an important element of a human's healthy diet since they include essential minerals and vitamins. The WHO recommends that 400 grams of FVs be ingested daily in the human diet to reduce the risk of chronic disorders. However, according to the UN, almost half of all FVs produced globally are thrown out each year. It is vital to use modern technology, particularly information and communication technology (ICT), to decrease food waste and ensure food safety from farm to fork. The aim of this study is to review the current status of trending ICT implementation in the horticultural supply chain (HSC) and propose recommendations to both researchers as well as practitioners. This study uses a systematic literature review (SLR) technique, and a novel framework is created for this purpose. Articles published in this area between January 1, 2011, and October 31, 2022, are considered for evaluation. After applying filtering criteria, the final eligible 39 articles were thoroughly reviewed and analyzed. The gap in the adoption of ICTs in HSC, and vegetables are less researched, and objective such as food security are not explored, which are key findings of this research work

1. Introduction

The world population has grown rapidly, from around 2.5 billion in 1950 to an estimated 8.5 billion in 2030. According to the UNEP research, however, 931 million tonnes of food waste were created in 2019, with 61% of it originating from residences, 26% from food service, and 13% from retail.

Ensuring food safety and food security for all is a major challenge from a supply chain (SC) perspective given the perishable products involved such as FVs. FVs have high nutritional value but are considered more susceptible to food safety problems due to spoiling, posing a rising difficulty in SC (Dizon, Josephson, and Raju). The United Nations has recognized 2021 as the "International Year of Fruits and Vegetables" in order to raise global awareness about the significance of nutrition (Fao).

FVs may be rejected on the farm because they don't meet marketing standards. They often end up in the trash until they can be used for processing, juicing, or other things at a lower cost (Blanke). The loss of FVs during storage and transportation is now a critical issue that must be addressed globally. Monitoring and maintaining optimal conditions at each stage of the SC will extend the shelf life of FVs and guarantee a high-quality product reaches the customer (D. Bogataj, M. Bogataj, and Hudoklin). To keep the HSC running as efficiently and effectively as possible, a continuous assessment based on both current and previous quality data such as temperature and humidity is necessary (Jedermann et al.). While data collecting is pervasive across the HSC, there is a bottleneck in data transmission and integration that might be overcome by integrating different technologies (Durrant et al.).

To meet customer expectations for a consistent supply of high-quality, safe, and nutritious foods, as well as to instill new public trust in the food chain, the development, and implementation of fully backward and forward traceable SC from farm to fork has become an important component of the overall food quality guarantee system (S. Li). Farmers, postharvest handling operators, marketers, research practitioners, and policymakers all need a good understanding of SC traceability concepts and implications to help develop and implement appropriate technological interventions to meet consumer demand for traceable HSC (Balamurugan). Implementing a well-planned traceability system based on cutting-edge technology not only improves product quality and safety but also enhances HSC's efficiency and cost-effectiveness (Q. Li, Y. Li, and Wang). The use of ICT increases the efficiency with which SC processes are monitored, and sharing information across the value chain may benefit all parties involved in the long term (Dubey et al.). Therefore, ICTs must be utilized to assure food safety and food security from farm to fork. To cope with food waste, bulk production, food crises, preservation concerns, fraud prevention, anti-counterfeiting, and food adulteration, food must be traceable, which is possible with the use of ICT-enabled supply chain management (SCM) systems (Tongzon and Nguyen).

This work systematically reviews the research trends by examining the papers accessible in three main worldwide databases (Scopus, Web of Science, and ScienceDirect) to present a comprehensive picture of ICT applications utilized in HSC and to bridge the gaps between ICT and SCM. The remainder of the article is structured as follows. The second section goes through the research methodology used for this study. Section 3 examines the literature on ICT in HSC based on the proposed framework. Section 4 contains the results and discussion. Finally, conclusions and research limitations are drawn in Section 5.

2. Methodology

Research Approach

In the study, the SLR technique is employed, which is based on a well-defined and well-planned procedure. Creating a search strategy, choosing target journals, developing inclusion and exclusion criteria, doing the review, and recording results and insights are all part of the SLR process (Tranfield, Denyer, and Smart). In contrast to conventional narrative reviews and meta-analyses, a systematic literature review is guided by a reliable and transparent scientific technique for locating literature and obtaining information. To examine the current level of scientific knowledge connected to ICT applications in the HSC, a number of defined processes were done to ensure the relevance of the recovered literature, the absence of research bias and errors, and the reliability of the quality evaluation.

TABLE 1. Details of Data Collection

Research online database	Scopus, Science Direct, and Springer
Keywords used	As shown in Table 3
Search fields	Title, abstract, keywords
Date range	01/01/2011 to 31/10/2022
Publication types	The scope of the search was confined to journal publications.
Language	Only English-language publications were taken into account.
Inclusion criteria	The selection was confined to papers that investigated ICT applications in HSC.
Exclusion criteria	Publications with a strong and solely technical focus were barred. Papers that looked at ICT outside of the contexts of business, SCM, food, and agriculture were rejected.

The details of data collection for the systematic literature review are shown in Table 1 and the keywords used to retrieve the articles are shown in Table 2. The keywords were improved by including particular technologies along with 'fruits OR vegetables' AND 'supply chain OR value chain'. Throughout the search process, extra attention is made to verify that the articles acquired are related to the current study's topic.

Collection of Data

The first search query, using the terms specified in Table 2, produced 176 articles. Individually, the articles acquired are evaluated for relevance using the qualifying criteria provided in Table 1.

To identify the initial relevant articles, titles, abstracts, and keywords were carefully analyzed, and 86 articles were obtained for full-text study.

Finally, 39 papers were determined to be appropriate for inclusion and further review. All of the chosen papers contributed to the current study's scope by presenting various discussions on ICT via the lens of SC. The data-gathering technique is depicted in Figure 1.

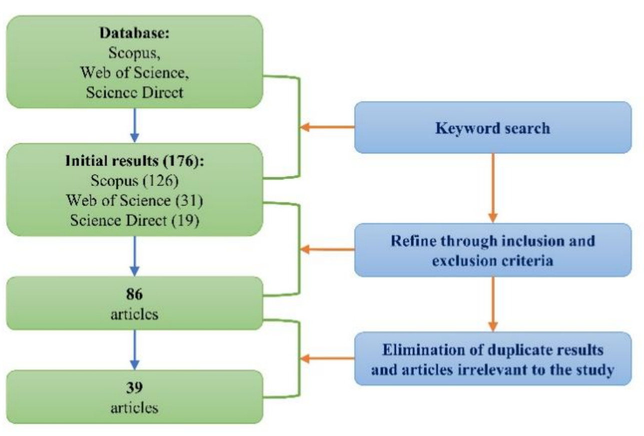

FIGURE 1. Schematic representation of data collection

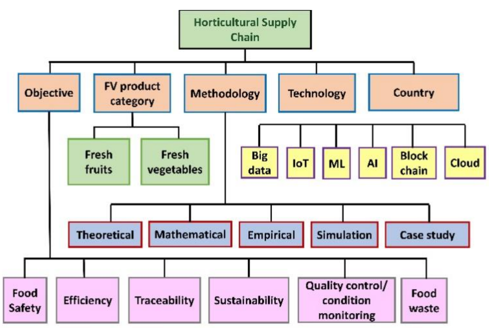

FIGURE 2. Framework for review

The 39 articles that were shortlisted were reviewed and analyzed using the framework depicted in Figure 2. The framework has been proposed in terms of the work's aims, FVs considered, methodology used, the technology employed, and country-specific.

3. ICT-Based Review as Proposed in the Framework

3.1. *IoT*

The Internet of Things (IoT) is expected to be a significant differentiator in the food and agriculture industries (Verdouw et al.). The IoT incorporates several new technologies, the most important of which are RFID, sensor technology, network communication technology, and cloud computing (Lu et al.). IoT technology operates behind the scenes, dynamically responding to how people want "things" to behave. China created the Agricultural Internet of Things (AIoT) by combining cutting-edge technologies to increase food supply safety (Liu et al.). An IoT-enabled system for real-time monitoring of temperature, relative humidity, brightness, and gas concentration is installed to minimize operating costs or boost FVs profits (Afreen and Bajwa Ruan et al.). An IoT system provides useful information for strengthening the logistics network and evaluating the environmental advantages (Accorsi et al.). IoT provides immense potential for achieving the sustainability objectives of the economy, environment, and society as a whole (Wolfert and Isakhanyan). Many challenges remain in adopting an IoT-based HSC, including the need for new business possibilities, information management, ownership solutions, and security and privacy (Brewster et al. Tagarakis et al.).

3.2. *Machine Learning and Big Data*

Machine Learning (ML) and big data reduce the uncertainty of production planning while also providing important information on the performance of individual components that may be used to detect problems and help maintenance in the food industry (Souza and De Garre, Ruiz, and Hontoria). ML prediction algorithms may be conveniently applied in both in-situ and post-harvest fruit maturity forecasts by combining meteorological, agronomic, and economic factors [26 - 28] (Bouzembrak and Marvin Haselbeck et al.). The intelligent greenhouse system based on ML configures nutritional solutions for the various growth phases of various vegetables, which overcomes the problem of illnesses and insect pests impacting vegetable growth (Lin et al.). ML is a potential choice for developing and implementing non-destructive assessment and grad-

TABLE 2. Retrieved Articles Using Keywords

Keywords	Retrieved articles		
	Scopus	Web of Science	Science Direct
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (blockchain)	19	4	1
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (”internet of things” OR ”iot”)	37	7	9
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (”artificial intelligence” OR “AI”)	21	1	0
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (”big data”)	12	5	1
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (”machine learning”)	21	10	6
(fruit OR vegetable) AND (”supply chain” OR ”value chain”) AND (cloud)	16	4	2

ing systems for various cultivars, with the goal of minimizing harm and maximizing efficiency in sustainable crop management (K. Cho et al. Manthou et al. Kumar, Esakkirajan, and Bama). The ML models were deployed as a low-cost approach to identify crop quality and maturity during harvest, storage, and distribution with the help of smartphone cameras (Cavallo et al. B.-H. Cho et al.). Using a mix of ML algorithms and X-ray Computed Tomography, a non-destructive automated internal quality grading of apples is demonstrated (Van De Looverbosch et al.). Big Data is used in some startup firm models to enhance an already-existing linear supply chain and reduce food waste (Cicculo et al.). Contamination of FVs during production, processing, and storage is anticipated and managed in real-time based on experimental data collected with non-destructive sensors using big data to study and manage risk in the food value chain (Donaghy et al. Osinenko et al.).

3.3. Blockchain

Blockchain technology (BCT) ensures good quality across the value chain and bridges the information gap between producers and end consumers (Villari). The originality of the technology, the characteristics of the SC, open data issues, economic feasibility, and the engagement of public stakeholders are all important factors influencing the application of BCT in the fresh produce value chain (Osei et al.). The advent of BCT has disrupted the traditional traceability technique of HSC by developing authentication (Hu, Huang, and Qin Khan et al.). Another advantage of adopting BCT is a smart contract, in which the transaction is carried out automatically and the identity secrecy of its members is safeguarded (Xu et al.). Customers using BCT may make more reasonable and responsible food business decisions by having access to and trusting product information (Rainero and Modarelli). A traceability system based on a dual storage structure of ”database” + ”BCT” for storing and retrieval of product information is recommended to assure the validity and reliability of sharing private information in HSC (Yang et al.).

3.4. Cloud computing and Artificial Intelligence

Cloud computing is an emerging technology that has the potential to be used in developing countries’ HSC. It sends SMS-based information and services to mobile phones, such as marketing information, weather predictions, prices, pesticides, sicknesses, and government subsidies (Qian et al. Sharma et al.). To estimate the supply and price of agricultural goods, Artificial Intelligence (AI) -based intervention models may be used to analyze the influence of government subsidies on FV inputs, price support to farmers, and the impact of pest and disease outbreaks (Chitikela et al.). A Fog-Cloud approach is intended to provide real-time quality monitoring from the field to distribution centers, enhancing efficiency and decreasing waste in the supply chain for blackberries (Musa and Vidyasankar). The experiment used cloud-based AI models that operate as soft sensors in estimating mango shelf life, allowing retailers, growers, and distributors to make dynamic pricing and logistical choices (Dutta, Deshpande, and Rai).

4. Results and Discussion

4.1. Publications by year

The 39 articles were chosen from a total of 11 years of consideration (2011/01/01-2022/10/31). Despite the fact that the World Summit on the Information Society addressed e-agriculture in 2003, making the use of ICT in agricultural development a top priority, scholarly interest has only lately been revived. Figure 3 shows that there were no publications until 2014, with the first coming in 2015. Papers discussing the potential of ICT for HSC may be found on a continuous basis beginning in 2015. The increase in the number of ICT studies between 2020 and 2021 signifies a high point in academic knowledge creation as well as an extraordinary interest in technology.

Researchers and practitioners are becoming more aware of and participating in the exploration of ICT applications in the HSC to bring value to SCM. The

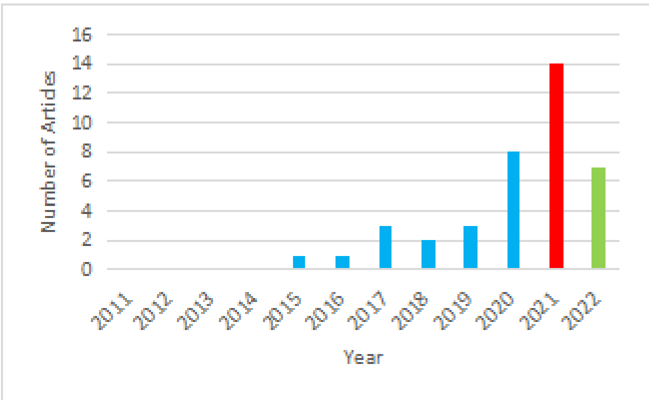

FIGURE 3. Distribution of publications over the years

tendency toward Agriculture 4.0 may justify this growing attention. Though it is growing, the number of articles is still very limited when compared to the number of HSC researchers worldwide.

Based on objective

Food quality is evaluated by how FVs are treated at each HSC node. A high level of visibility and robust traceability tools are required for proper product flow management. This may be performed by continually monitoring and recording the location

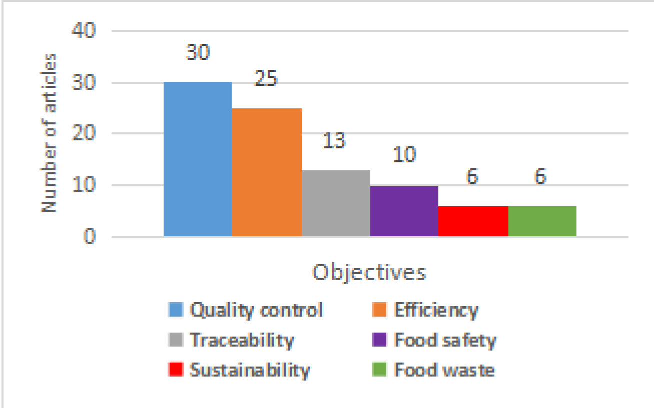

FIGURE 4. Publications based on objectives

and conditions of FVs throughout the SC (e.g., temperature, humidity, O2, and CO2 level). As a result, quality control comes out on top, followed by SC efficiency, product traceability, food safety, sustainability, and food waste reduction as illustrated in Figure 4. No article discusses food security which is a major outcome of this study.

Very few attempts have been made to achieve objectives such as sustainability and food waste reduction. These objectives can help to alleviate global challenges including climate change, biodiversity loss, and pollution, as well as relieve pressure on waste management systems. Also, no articles have discussed food security and nutritional value.

Based on the fruit and vegetable category

Figure 5 illustrates that fruits are prioritized above vegetables. The majority of the articles have focused on fresh FVs, with a few exceptions on processed FVs because the nutritional value is reduced when it is processed.

It has been observed that fresh fruits are given greater prominence than fresh veggies. This might be owing to their sweet flavor and low cost because all fruits can be taken fresh, but very few vegetables can. Since vegetables, like fruits, play an important part in human immunity, they must be prioritized.

Based on the methodological approach

The distribution of the 39 selected publications depending on the methodological approach adopted is depicted in Figure 6. Researchers are frequently

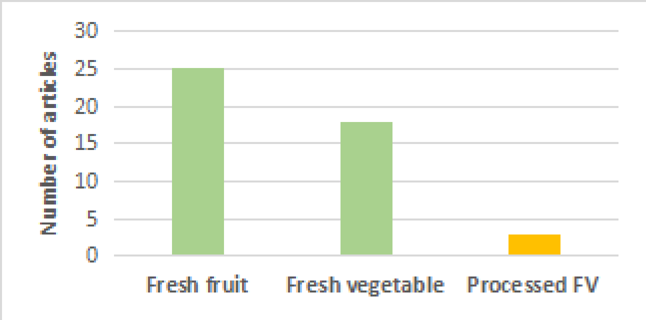

FIGURE 5. **Publications based on commodity**

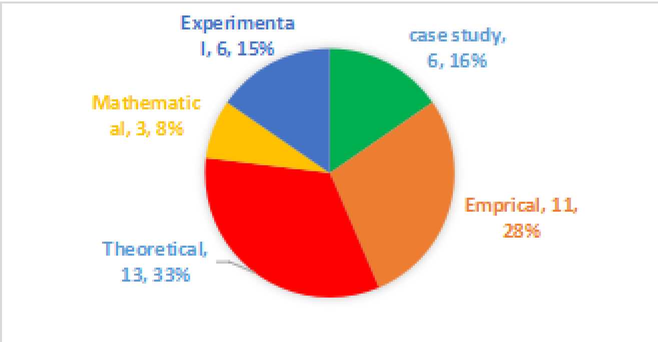

FIGURE 6. **Distribution of articles based on the methodology**

using the theoretical method, which includes conceptual and framework-based publications. The emphasis here is on ICT applications, technological skills, and ICT adoption concerns. There are 11 empirical papers in all, including empirical evidence based on both primary and secondary data. Only six experiments were conducted to test and evaluate SC effectiveness in the HSC and the regional case studies are very limited.

Very few researchers have looked at the mathematical model. The examined publications contain no simulation models. Another key aspect to emphasize is that each FVs variant necessitates a distinct experimental and computational investigation. This necessitates distinct analytical methodologies for various FVs.

Based on technology

Figure 7 shows that the HSC mainly depends on IoT and ML to monitor real-time data. BCT, cloud computing, big data, and AI are under-explored.

BCT is an emerging technology that ensures food safety and quality, reducing losses during the

logistics process. Furthermore, technologies like AI and Big Data are still in their early stages. There is evidence in the literature of BCT and IoT technol-

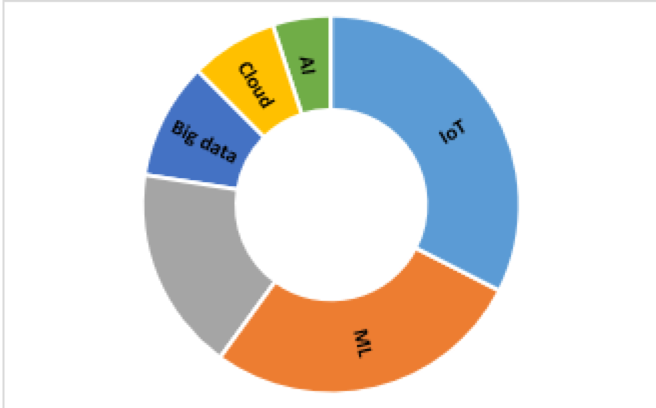

FIGURE 7. **Distribution of articles based on technology**

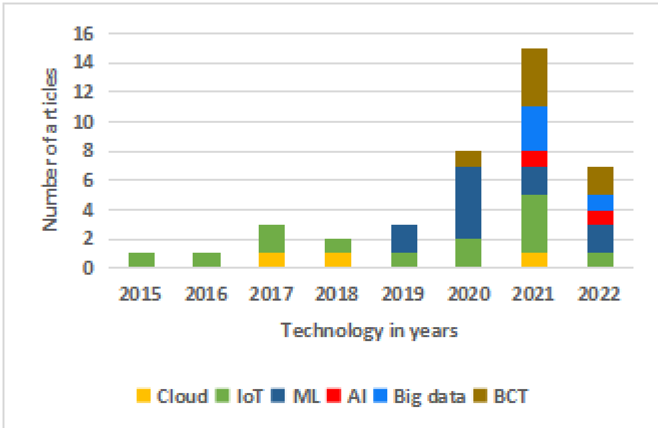

FIGURE 8. **Distribution of technologies during the period 2011-2022**

ogy deployment in SC such as meat, seafood, and dairy. To fight malnutrition, the same level of care must be paid to FVs.

Figure 8 displays the spread of technologies by year. Big data, ML, and AI are well-suited for drastically reducing food waste by analyzing data collected via IoT-enabled sensors and projecting future losses, as well as supporting SC players in making smart decisions. AI and ML should be investigated further since they are capable of monitoring and optimizing irrigation, detecting soil conditions, tracking crop growth, assessing and harvesting traditionally hand-harvested crops, forecasting future growing circumstances, and much more. The blockchain framework ensures that each stakeholder throughout the HSC generates and securely shares data points, resulting in a responsible and traceable system. Large amounts of data with labels indicating ownership may be captured quickly and without modification. As a result, the route of a food item from farm to fork may be tracked in real-time.

5. Conclusion

In this study, we conducted an SLR approach to review existing work on ICT in HSC. For this study, 39 publications were thoroughly assessed. According to the results of the study, the progress of ICT has led to a variety of approaches and strategies to help in the adoption of technology in the FVs sector. Theoretical approaches are the most generally used methodology in the HSC to claim ICT benefits. The majority of the papers discuss the importance of ICT in enhancing the operational efficiency of HSC by increasing food quality, safety, and traceability visualization. To report ICT potential in the FVs firm and drive technology adoption, research methods like case studies, interviews, and surveys are required. There is a gap between ICT adoption and food security and nutrient value.

Academic contribution

There is a scarcity of research aggregating ICT potentials in the HSC, and this study is one of the first attempts to fill these information gaps. Earlier studies on ICT in the FVs sector focused mostly on developing a framework and concepts. Case study-based research on the traceability of the SC system can be explored further. The mathematical models may be created by redesigning an existing SC network to incorporate a proper transportation plan from farmers to hubs and hubs to customers, reducing transportation inefficiencies and increasing farmer income. Furthermore, researchers must focus on storage and logistics for multiple FVs that must be stored under varying environmental conditions, which would be a difficult effort from the company's perspective. Another significant finding is that AI technologies are not widely used in the HSC and no publication has addressed the role of the SC in food security, which is critical in the coming years. Food security can be achieved only when the four phases, namely availability, access, utilization, and stability, are integrated properly. These phases depend on the factors like production, costs, distribution, affordability, nutritional knowledge, economic, political, or environmental factors, etc., Experts may evaluate the extent to which food firms may achieve long-term commercial success, as well as how ICT might be integrated inside to achieve the aforementioned goals.

Managerial contributions

To achieve food security, Big Data and ML ensure food availability by predicting maturity as well as agricultural and economic characteristics and these factors may be utilized to handle dynamic pricing and storage. The provision of dynamic pricing based on the deterioration stage can enhance F&V sales to consumers with lesser purchasing power, contributing to better nutrition for these customers. Furthermore, "BCT" and "IoT" can increase the efficiency of the HSC and traceability system which helps in achieving objectives like food safety, food loss, and distribution. Cloud computing and AI ensure food affordability through logistics decisions and pricing by predicting market information, weather forecasts, government subsidies, etc., ICT helps in real-time decision-making, transparency, and food safety, and, most crucially, increase customer interaction. The potential challenges associated with ICT integration in the HSC should not dissuade practitioners. Instead, they should strive hard to address these challenges in order to maintain competitiveness and exceed client expectations in terms of food quality and safety. Furthermore, switching conventional agriculture to smart agriculture may aid in the achievement of important farming goals such as reducing carbon emissions and boosting productivity by doing more with less by utilizing modern technology.

Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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