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Towards Digitalization of Fruits and Vegetables Supply Chain: Digital Twins and Internet of Things Approach

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Index Terms: *digital twins, food-supply chain, internet of things.*

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Towards Digitalization of Fruits and Vegetables Supply Chain: Digital Twins and Internet of Things Approach

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Abstract- The consumption of fruits and vegetables is known to confer numerous health benefits to individuals, owing to their remarkable nutrient density as agricultural produce. Rapid decay of perishable items leads to a reduction in quality and nutrient content. Additionally, these items are highly susceptible to spoilage. The implementation of cold chain technologies has resulted in a reduction of quality loss experienced by fruits and vegetables during their transportation from the farm to the consumer. Despite efforts to minimize waste, a considerable proportion (50%) of fresh agricultural products is still lost during the processes of packaging, pre-cooling, transportation, and storage. The quality loss experienced by perishable foods like fruits and vegetables during packaging, storage, and transit along the cold chain is the primary focus of this article. Existing research points to digital twins and the Internet of Things (IoT) as two possible technological intervention paths for linked supply chains. Using a digital twin, or a virtual clone of a farm, has the potential to increase productivity and efficiency while decreasing resource use. The provision of approximative assessments of food temperatures after harvest is one example of how the Internet of Things (IoT) could help with quality monitoring and management. The aforementioned advancements will facilitate the detection and mitigation of supply chain challenges that have the potential to undermine the freshness and quality of perishable goods. The objective of this research is to present a conceptual model for the integration of supply chain in urban food systems, with a specific focus on digital technology interventions. Furthermore, this study aims to provide insights into the potential areas of investigation for future research on the digitization of the food supply chain.

Index Terms: digital twins, food-supply chain, internet of things.

I. Introduction

One of the primary global challenges pertains to the assurance of food security for the expanding global populace, while simultaneously ensuring sustainable development in the long run. As per the Food and Agriculture Organization's report, it is imperative for the agricultural and food sectors to expand in order to cater to the global populace, which is estimated to reach approximately 10 billion by the year 2050 [54]. The matter of food security, sustainability, productivity, and profitability has gained greater significance owing to the rise in global population and the market's inclination towards elevated product quantity and quality standards. Moreover, the agricultural industry is facing mounting economic pressures, as well as challenges related to labor, the environment, and climate change [17]. In recent years, there has been a widespread consideration of the integration of smart technologies and techniques to enhance efficiency [27].

Investments in food packing, transportation, and storage are severely depleted when food is lost in the postharvest supply chain [21]. Approximately a quarter to a third of the food produced worldwide is lost during the transition from on-farm production to storage at retail establishments, primarily due to inadequate chain management and spoilage [3]. Fresh agricultural produce, such as fruits and vegetables, frequently undergoes significant losses (up to 30% per year) during postharvest handling [15]. Reducing food insecurity from these perishable goods can be achieved by drastically reducing losses from physical biochemical, physiological and microbiological degradation processes. Losses sustained by fruits and vegetables along the postharvest supply chain can be reduced through the use of cutting-edge technology. If these losses could be reduced, more perishable fruits and vegetables would be made available. [38].

The incorporation of refrigeration is a crucial factor in improving the caliber of freshly harvested agricultural products and prolonging their shelf life, thereby facilitating their sufficient distribution to a progressively urbanized global population [49]. It is important to note that a significant proportion of perishable commodities, comprising over 90%, have not yet been subjected to refrigeration. Insufficient refrigeration infrastructure or limited access to energy sources results in a loss of perishable goods that surpasses 20%. The production processes entail significant amounts of energy and water wastage, coupled with the release of carbon dioxide emissions [33]. The implementation of sustainable cold chain

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technologies is crucial due to their ability to enhance resource efficiency, optimize product quality preservation, and minimize food waste caused by external factors [12].

Numerous investigations have been carried out concerning the postharvest cold chain of fruits and vegetables, with the aim of acquiring a more profound understanding of how to tackle the technological and developmental obstacles linked to it. The utilization of refrigerated containers set at a temperature of 4°C resulted in a decrease in the degradation of both mass and nutritional qualities of various fruits, such as strawberries, raspberries, red currants, drupes, cherries, and sour cherries, when compared to their storage at ambient temperature [16]. Various packaging techniques have been employed to mitigate the deterioration of quality in cherry tomatoes, kiwifruits, guava, mushrooms, cucumbers, and berries throughout the cold chain procedures. The techniques encompass active modified atmosphere packaging (MAP) [7], nano-composite based packaging (NCP) [34], polypropylene/polyethylene bags, and edible coating. Oxygen scavengers, ethylene absorbers, moisture regulators, and intelligent packaging are just some of the components that have been included into modern active packaging systems. In order to accomplish its goal, the latter makes use of modern technologies including chemical sensors, temperature and gas indicators, barcodes, and radio frequency identification devices (RFID) [56]. This techniques have been devised with the objective of enhancing the safety and maintaining the quality of recently harvested agricultural commodities.

Multiple factors, including slow metabolism, extended shipment duration [55], a wide variety of fruits and vegetables, and insufficient use of advanced packaging materials [32] and monitoring technology [45], contribute to the rising rates of food loss in the postharvest supply chain of these products. In the realm of cold chain logistics, it is frequently observed that there are notable variations in temperature and relative humidity at different stages throughout the transportation of commodities [55]. The diverse characteristics of refrigeration machinery, food attributes, and packaging materials frequently result in notable fluctuations in the approach air velocity of distinct types of fruits and vegetables [36]. Variations in these variables could potentially affect the final decrease in mass, overall quality, and remaining shelf life of recently gathered agricultural produce.

In recent decades, a variety of technological advancements have been implemented to improve the efficiency of the agricultural and food distribution system. The implementation of innovative solutions has become necessary due to the emergence of novel challenges resulting from demands in emerging markets, regulatory changes, and cost considerations. In contemporary times, there has been a noteworthy emphasis on tackling the improvement of productivity by means of proficient and cohesive intelligent technologies and methodologies, including digital twins (DTs) and Internet of Things (IoT). Fig 1 depicts novel technologies used in food system. The interdependence of the physical and virtual domains is reliant on the progress of the digital twin technology [30]. This specific component enables the transfer of information among systems that coexist in virtual as well as physical environments. The information obtained from the tangible system is analyzed and applied to revise the condition of the digital system. Furthermore, the virtual system provides feedback that is transmitted to the physical realm. The process of choosing connection components is dependent on various factors such as the source, type, and size of data, the speed of data transmission, and the minimum time gap between data acquisition and responses. The amalgamation of wireless and Internet of Things (IoT) techniques has been utilized to create digital simulations of agricultural systems, which enable the connection between the tangible and intangible realms. The ability to simulate multiple operations and anticipate critical scenarios in advance enables swift response and process adaptation, thereby enhancing resilience.

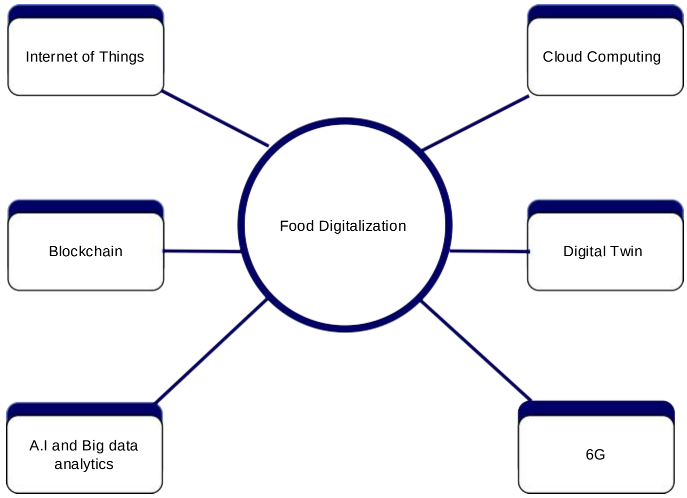

Fig. 1: Food Digitalization

The aim of this research is to examine plausible tactics for reducing food wastage in the postharvest supply chain of fruits and vegetables. The present study centers on the contemporary developments in monitoring and optimizing cold chain systems with the aim of reducing quality degradation in fruits and vegetables throughout their packaging, transportation, and storage processes. This research investigates the application of nascent technologies, including the Internet of Things (IoT) and digital twins, in mitigating food waste. Next, we discuss a potential outlook developed to lessen food waste throughout the entire packaging, warehousing, and distribution process.

a) Internet of Things (IoT) Technology in the Postharvest Supply Chain of Fruits and Vegetables

The Internet of Things (IoT) is a subject of ongoing interest due to its capacity to intelligently and efficiently perceive the environment via a network of intelligent devices, and facilitate a range of intelligent applications [39]. The Internet of Things (IoT) has been designed to facilitate intelligent applications, including but not limited to smart cities, smart transportation, smart homes, smart vehicles, smart hospitals, and smart agriculture [6]. The Internet of Things (IoT) is comprised of a series of interconnected networks of tangible objects that are equipped with embedded technology designed to detect, transmit, and engage with either their internal conditions or the surrounding external environment [18]. IoT enables uninterrupted interconnectivity and communication among individuals, objects, and entities, irrespective of their temporal or spatial constraints. As per the European Commission Information Society, the Internet of Things (IoT) is distinguished by a multitude of objects that exhibit comparable and virtual identities, and possess the capability to interconnect and interact with one another in a smart setting through advanced interfaces, all while operating within the confines of social, economic, and user contexts [22], The fundamental components that facilitate a conventional Internet of Things (IoT) system comprise Radio Frequency Identification (RFID) [44], printed sensors [19], web services, Machine-to-Machine (M2M) communication [35], Wireless Sensor Network (WSN) [23], imaging systems [43], multi-sensors [14], cloud computing, blockchain technology [51], albeit not always in conjunction.

The food industry has shown a notable inclination towards the utilization of IoT in recent times, primarily for the purpose of product tracking [4], traceability [25], and environmental condition monitoring such as temperature [46], humidity [20], weight loss [20], and overall quality loss in the postharvest supply chain. This is evident from various studies conducted on the subject. The food industry has shown considerable interest in utilizing this technology for the development of intelligent packaging [28]. The implementation of intelligent packaging entails the utilization of a variety of sensors, including biosensors, printed sensors, chemical sensors, and gas sensors, as well as indicators such as time-temperature indicators [20], freshness indicators [52], gas indicators [57], and integrity indicators [37]. These tools are employed to detect alterations in the biological, chemical, or gaseous composition of fresh produce that has been packaged. RFID tags with built-in sensors can monitor changes in temperature, carbon dioxide levels, light exposure, fruit and vegetable pH, and other variables along the post-harvest supply chain. Using the timely data collected by the package system, the relevant parties in the logistics network might be made aware of any incident that might endanger the packing material or the perishable produce inside.

As demonstrated by Chen et al.,2020 [11], IoT in various cold chain processes generates a sizable amount of real time data, which can enable novel computational approaches like big data analytics and artificial intelligence. The aforementioned information is set to aid various supply chain actors in managing and developing cold chain technologies to reduce quality loss. It will also help stakeholders make educated choices in regards to food safety. However, there is still not enough use of the Internet of Things (IoT) in the administration of cold chain technology to reduce fruit and vegetable spoilage during transport.

Karim et al., 2018 [20] show that the Internet of Things (IoT) has been used to track and monitor temperature and food quality changes during the transportation of product such fruits and vegetables. Integrating sensors for things like temperature, humidity, light exposure, and global positioning system (GPS) is a key part of using IoT technology in product transportation. These sensors are used at various points in the distribution chain for perishable goods like fruits and vegetables. The sensors are positioned in the containers to monitor changes in air temperature, air velocity, light exposure, and relative humidity along the cold chain. The use of sensor data fusion, in particular soft sensors, allows for this to be accomplished. The gadgets link wirelessly to computers in order to improve supply chain communication with control centers, manufacturers, and other key participants. The collected information can serve as baseline information for future studies examining the effects of different preparation methods on food properties as satiety, freshness, shelf life, and flavor. It should be emphasized that numerous sensors, such as chemical sensors, biosensors, imaging systems, Enose, spectroscopy, and AIR, can be utilized to instantly assess alterations in the qualitative attributes of fresh produce at any point in the postharvest supply chain. With the help of IoT sensors, controllers can keep tabs on the operational conditions of food and make educated judgments. Taking any one of these measures might drastically cut down on wasted food. IoT's potential as a reliable and long-term solution to lowering food waste has been bolstered by the falling prices of wireless software and hardware as well as digital sensors, all of which can now be integrated into the shipping, packing, and storage of food.

b) *Digital Twin in Food Supply Chain*

Digital farming techniques have the potential to enhance post-harvest processes by mitigating losses, optimizing food processing, storage conditions, marketing, and transportation through effective monitoring. The implementation of digital solutions enables the real-time monitoring of the agri-food supply chain, thereby enhancing its robustness and resilience [31] Additionally, it aids in reducing food waste and losses [5].

1) *Implementation of Digital Twin:* The primary and essential step in the implementation of digital twins entails the identification of physical entities. The concept of a "physical entity" is a relative construct that refers to the concrete product or system that a virtual design thinking model replicates in the real world. This may comprise a spectrum of nomenclatures, including but not limited to "vehicle", "component", "product", "system", "artifact", and the like. Digital twins of fruits, farms, and supply chain networks are commonly observed in the agri-food supply chain. To create a virtual entity, it is imperative to produce a digital depiction that precisely mirrors the tangible features, traits, behaviors, and guidelines of the corresponding actual entity. Moreover, service platforms play a crucial role in the execution of models. For optimal performance of the virtual entity, it is essential to provide it with authorization to access cloud-based applications, data, and information.

There is a growing trend among supply chain professionals to incorporate real-time data, as well as demographic data sourced from various stakeholders within the supply chain, in order to obtain valuable insights into logistics. The aforementioned data can be employed to monitor the paths taken by trucks, distribution centers, sales locations, and customers, among other factors, in order to improve the understanding of the supply chain. The data mentioned above can be easily integrated into databases, such as the Enterprise Resource Planning (ERP) database and the production system. This integration process can aid in the development of a digital twin through the utilization of a simulation tool. Furthermore, it is worth noting that digital twins possess the ability to utilize data obtained from transportation management systems and customer relationship management systems. Incorporating internal data from actors' systems with external data sources, such as weather, traffic, and competitors' prices, is a feasible alternative. The factors mentioned above form the basis for creating digital twins of the supply chain. These digital twins aim to construct a model that is both accurate and precise, enabling the performance of analyses and simulations that depend on reliable data. Achieving maximum efficiency in the implementation of supply chain digital technologies requires the essential prerequisites of astute analysis and the integration of data that is both abundant and of superior quality. The adoption of supply chain digital transformation necessitates certain fundamental prerequisites. These include visibility and transparency, frequent updates, data collection and analysis, simulation capabilities, decision support capabilities for planning, and the ability to manage disruptions.

2) *Implementation Steps:* Digital twin methodologies have been employed in post-harvest processing to provide ongoing monitoring of the products and revise the processing stages [29]. A digital twin utilized in post-harvest processes refers to a virtual model that is constructed to represent harvested agricultural products [?]. This model is generated

through the collection and analysis of pertinent information obtained from the products. The digital twin concept of food processing [29], encompasses several components. Firstly, data is collected from a physical system, specifically a food process operation, through the use of sensors that measure various properties and variables of both products and environmental parameters [50]. Secondly, an IoT platform is utilized to facilitate sensor communication, data storage, big data analytics, high-performance computing, and connection to the digital twin assets. In order to execute digital twin scenarios within the agri-food supply chain, a variety of sensors have been utilized. Temperature and gas sensors have been employed for the purpose of monitoring the state of fresh products throughout the logistics and storage phases, as well as for representing inventory and grain quality as it moves through a plant Lastly, a simulation platform is employed to optimize, test, and validate models using input data from the physical system, and to provide decision support in the virtual realm. To optimize food processing through the creation of digital twin models, it is imperative to incorporate precise data that accurately reflects the production processes involved in the product, such as equipment and labor, and to construct realistic models that account for all existing boundaries and obstacles [1]. According to a report by Defraeye et al., 2021 [?], a digital replica of a mango fruit was created to model and assess the thermal and related biochemical characteristics of the fruit during its journey through the post-harvest supply chain. The development of the digital twin concept involved the incorporation of environmental air temperature as input, and the emulation of real supply chain conditions through mechanistic finite element models [13].

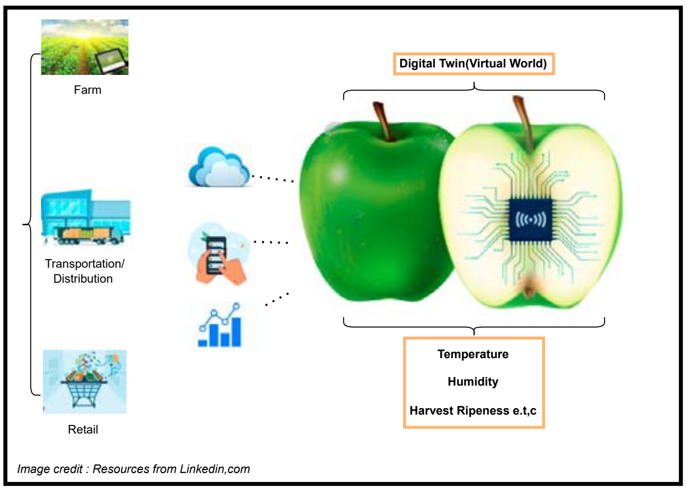

Fig. 2: Fruit Digital twin during postharvest supply chain

Furthermore, the digital twin took into account the effects of increased air velocity on the longevity of storage, duration of the cold chain, and temperature of air during delivery, with regards to the quality of the fruit [42]. Implementation of digital twin technology enables the monitoring and prediction of temperature-dependent fruit quality losses, leading to enhanced refrigeration and logistic processes, ultimately resulting in a reduction of food losses [47]. According to Verboven et al., 2020 [47], implementation of digital twin technology has the potential to enhance the post-harvest lifespan of horticultural products. Additionally, it can be utilized to predict the shelf-life of agricultural products during the cold chain process. The extant digital twin paradigm has the potential to facilitate the monitoring of products, logistics, and marketing decisions for both food consumers and business owners [24]. Nonetheless, further refinement of this concept is required to incorporate additional biochemical and physical attributes. According to Burgos et al., 2021 [10], The digital twin that has been created encompasses several key components. Firstly, it incorporates a network that is informed by knowledge derived from a range of sources, such as customers, suppliers, and factories. Secondly, it includes a number of parameters that are relevant to production, transportation, warehouses, sourcing, shipment costs, and policies. Finally, the digital twin incorporates a variety of operational parameters, including demand, quality, target inventory, and vehicle capacity. The study revealed that the digital twin that was created has the potential to be utilized for the purpose of optimizing, simulating, and analyzing the modifications in the operation and performance of the food supply chain.

As per the findings Verboven et al., 2020 [47], digital twin models in the post-harvest domain can be classified into three categories, namely mechanistic, statistical, and intelligent models. However, the study suggests that mechanistic digital twin models based on physics principles are more effective in assessing the quality of fresh agricultural produce compared to the other two categories. According to Shoji et al., 2022 [41], digital twins based on physics were created for 331 shipments of four types of fruits (namely cucumber, eggplant, strawberry, and raspberry) in cold chain environments. The utilization of digital twin concepts has revealed that the pre-delivery quality of fruits may be impacted by a range of factors, resulting in a potential reduction of approximately 43-85%. In recent years, the utilization of digital solutions has led to enhancements in post-harvest processing. The digital twin paradigm is gaining increased attention in post-harvest food processing as it offers the potential for predicting future product quality and reducing costs. Future studies may involve the development of a digital twin for post-harvest processes [?]. This twin would serve to model, optimize, represent, and characterize various design and operational parameters, including quality, safety, ingredients, shelf-life, and product status. Such considerations are essential for researchers in this field [47]. The implementation of digital twins entails a variety of phases, including defining the procedures, recognizing pertinent data sources, selecting suitable technology, constructing models, coordinating the system in real-time, performing simulations, refining the process, and evaluating the outcomes [9]. Furthermore, there exist alternatives that can facilitate the expansion and enhancement of the system. Several methodologies are available to address planning-related inquiries, including those related to determining the quantity to procure, transport, or manufacture. When engaging in modeling, it is recommended to create the digital twin with a primary emphasis on achieving long-term goals. Furthermore, it is imperative that the framework enables the modeling and analysis of alternative processes, optimization of asset performance, and prediction of future events [26].

The utilization of prescriptive, predictive, and advanced analytics in harnessing digital supply chain twins to influence decision-making has a wide range of potential applications, encompassing both strategic and operational domains. By incorporating models, operations, and assets, simulations and optimizations can be conducted to acquire valuable insights, assess various potential scenarios, or adapt to unexpected disruptions. The dissemination of results throughout the organization is crucial to ensure that all levels are informed of the suitable courses of action. The application of various parameters to the digital twin of cloud computing's simulation module facilitates the prediction of future events in the physical supply chain. Ultimately, it is crucial that digital twin exhibit the ability to be extended to incorporate multiple entities, thus enhancing comprehensive supervision across the entire spectrum of supply chain activities. Enterprises possess the capacity to establish linkages with suppliers and consumers that extend beyond their internal operations. The enhancement of Digital twins performance can be achieved through the integration of supplementary real-time data points derived from internal sources, third-party entities, and industry groups. Fresh-produce supply chains can benefit greatly from digital twins due to their ability to estimate the remaining shelf life days based on the produce's physical, biochemical, microbiological, or physiological states reaction. The digital duplicate can be used to stamp a "use by" date on each box or pallet of agricultural goods. Consumers can use this date as a guide while shopping for groceries in an effort to waste less food. Consumers may become confused when such ideas are combined with a use-by date (or expiration date). Each shipment's digital twin provides retailers and consumers with useful information that can be put to use. Using physics-based digital twins has advantages over traditional methods, such as providing average fruit pulp temperatures rather than just point measurements and allowing for the simultaneous evaluation of several other quality parameters that are sensitive to temperature. With such precise tracking of perishable goods' quality over time, it might be possible to pick fruit when it's at its peak of flavor and aroma and monetary value.

3) *Challenges for Digital Twins Implementation:* The incorporation of Digital Technologies (DTs) into the agricultural and food sectors remains a challenging endeavor. The deployment of Internet of Things (IoT) technology in agricultural systems encounters notable obstacles, primarily stemming from the requirement for an uninterrupted power source to sustain operations. While it is true that alternative energy sources, such as solar and wind, have the potential to fulfill energy requirements, their adoption may result in a significant escalation in expenses. The absence of dependable internet connectivity in geographically isolated and sparsely populated regions presents an added obstacle. Sufficient broadband capacity is a prerequisite for ensuring the efficient transmission of data in accordance with the prescribed service requirements. Furthermore, it is imperative to provide farmers with guidance regarding the integration of fundamental computer systems and tablets, along with a comprehensive understanding of the Internet of Things (IoT).

The task of creating an up-to-date and all-encompassing depiction of the supply chain through mapping presents a formidable undertaking in practice. As noted by Wagg et al., 2020 [48], the concurrent validation of all parameters of model output presents an extra difficulty in the application of digital twinss within supply chain contexts. In addition, stakeholders involved in the cold chain, such as retailers, necessitate empirical substantiation to endorse the advantages of implementing particular digital technologies with regards to the extension of product lifespan. Regrettably, the undertaking of pilot studies to obtain such validations can be both financially and temporally arduous. The execution of the system is confronted with additional obstacles related to insufficient methodology and standards, insufficient data governance, and challenges in gathering and retaining large datasets [53].

As noted by Shahzad et al., 2022 [40], the absence of established modeling standards for digital twins can result in compatibility challenges when integrating models that have been developed independently. This study encountered several noteworthy obstacles, such as the creation of a data acquisition system, synchronization difficulties, modeling a multifaceted system, limited knowledge, hesitancy of companies to embrace technology, and difficulties in constructing, comprehending, administering, and simulating real-time modifications within the system. The utilization of digital twins is confronted with obstacles such as the amalgamation of heterogeneous domains of expertise and the availability of sufficient data. According to Bhatti et al., 2021 [8], the implementation process may encounter various hindrances such as alterations pertaining to management education and knowledge dissemination, precise depiction, data precision, expenses, safeguarding of intellectual property (including apprehensions regarding data ownership, identity verification procedures, and user access control), cyber security, and compatibility. In addition, the incorporation of Digital Twins within the agricultural industry is impeded by ethical considerations, along with possible societal and safety consequences [2].

4) *Potential Applications of Digital Twins in Food Systems: Food Traceability:* Many postharvest supply chains lack full transparency, but recent blockchain initiatives aim to remedy this. In this case, the digital twin can play an important role in documenting the postharvest journey of the fruit and telling its biological tale. The use of digital twins would improve cargo tracking by revealing instances of improper hygrothermal management. The data generated by the digital twin may be safely stored and easily accessed by all parties involved thanks to blockchain technology's elegant digital thread storage mechanism. In turn, computational statistics or machine learning approaches can leverage the ledgers of digital twin populations to pinpoint present bottlenecks and optimize the supply chain.

Supply Cooling Chain: Thermal sensors have the potential to predict not only the ambient temperature and humidity, but also the fruit pulp temperature and its consequential impact on quality attributes throughout the fruit. This includes the loss of moisture, which can result in a decrease in the weight of the fruit that is available for sale. Accelerometer sensors enable the computation of thermal damage potential at extreme temperatures, including chilling injury, and mechanical damage resulting from bruising. In order to furnish this functionality, it is necessary to augment the digital twin with submodels that account for these processes and their corresponding quality standards. This enhanced comprehension proves valuable in the remote analysis of the reactions of perishable food items in every consignment across the refrigerated supply chain. This facilitates timely identification of issues and the consequent execution of preemptive measures. Enhancing the dependability of cold chain notifications constitutes a measure in this regard. Digital twins have the potential to be utilized for the purpose of real-time monitoring and management of cold chain operations in the future Digital twins have the potential to be employed in prospective endeavors, such as forecasting alterations in food quality based on available data regarding the anticipated conditions of the cold chain and working environment. The integration of digital twins and model predictive control algorithms can enable their performance to resemble that of a weather forecasting model. Furthermore, digital twins have the potential to enhance the protection of importers and exporters against accusations of mishandling the shipment by providing supplementary information to regulatory bodies, such as plant-quarantine or invasive-species inspection services.

II. Conclusion

Many perfectly edible fruits and vegetables are lost before they even reach the consumer because of poor postharvest handling. Refrigeration is commonly recognized as the most effective way for extending the storage life of perishable items. This study digs into the postharvest cold chain for fresh produce and how cutting-edge technology is being used to reduce spoiling and ensure a safe food supply. Processing of perishable commodities is highly dependent on Internet of Things monitoring and control, which improves decision making for many parties involved.

Perishable items' quality can be tracked with each shipment, and their shelf life can be predicted with the help of digital twins. The goal of this research was to assess the current state of digital twin implementation within the framework of the contemporary agri-food supply chain. This analysis sheds light on the efficiency of the supply chain as a whole, including its performance, resource allocation, cooperation, and information exchange. It examines the region's advantages, classifications, levels of inclusion, key components, and procedural stages, as well as the problems encountered during implementation. The agri-food supply chain stands to benefit from digital twins by boosting transparency, decreasing bottlenecks, being better prepared for the unexpected, and optimizing what is currently in place. Until the scientific community agrees on what a digital twin actually is, terms like "digital twin," "digital model," and "digital shadow" will continue to be used interchangeably. Furthermore, both theoretical and applied work in the agri food sector are still in their infancy. A deeper comprehension of how new technologies might be applied would assist future studies of the cold chain for freshly produced agricultural items.

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