UNRAVELING THE ROLE OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN FOOD SYSTEMS

Abstract

India's food processing sector is growing. The food industry, which contributes around 26% of India's GDP, is anticipated to grow significantly over the next several years. This growth requires subsequent management of food production, processing and distribution. The food sector is being pushed more to reveal information about their products in order to maintain quality standards and protect their products from food fraud as the consumers awareness is increasing day by day. Information and communication technologies (ICT) offer a variety of methods for collecting, retrieving, exchanging, analyzing, and transferring digital data. Global food supply chains might be made better by ICT, which also has the ability to cut operating costs, assure sustainable development through productivity gains, and expand market reach and capacity.

Keywords: Information technology, supply chain, food safety, quality

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I. INTRODUCTION

Over the next ten years, it is predicted that the world's food demand will double, making an increase in supply the only viable option. According to the most recent UN estimate, 7.3 billion people live on the earth now; by 2050, that number is expected to rise to 9.7 billion. Together with increased income in developing nations (which prompts dietary changes like eating more meat and protein), this growth is fueling an increment in the world's demand for food. By 2050, the demand for food is anticipated to increase by 59 to 98 percent. Several speculations regarding food production, security, and safety have also surfaced, having an impact on the world's commodities markets and the demand-supply chain. Only two of the issues that the food supply chain faces are an increase in food loss and a decline in food quality as a result of insufficient quality monitoring systems across the whole food production, processing, and transportation stages. The increasing global population and rising food consumption are to blame for these problems. Food safety has become a critical issue for developing countries like India, where the demand for food has grown b 60–90% (Kumar et al. 2019, Schmitz et al., 2017). The dairy business is one of many that contribute to the increase in food demand by wasting products. Ineffective storage facilities, tacky packaging, losses resulting from improper transportation management, and inadequate inventory management are the main causes of food waste (Bravi et al., 2019; Bharucha, 2018; Sheahan et al, 2017).

Production, processing, shipping, and storage all include a number of risks and dangers that might quickly alter quality and cause losses in both quantity and quality. In order to address these sustainability challenges in agri-food systems without diminishing other resources, it is crucial to do so. The food sector is being pushed more to reveal information about their products in order to maintain quality standards and protect their products from food fraud. Examples of information and communication technology (ICT) include desktop and laptop computers, software, external devices, and Internet connections. ICT is a field of study and research that focuses on these and other technologies that are used to process and communicate information. Customers can now immediately address their demands thanks to information technology (IT), and businesses can now manage their supply chains more quickly to satisfy client demand. The role of food integrity assurance may be transformed from one that strictly adheres to compliance to one that addresses a wide range of business-critical concerns, including quality, safety, and authenticity solutions, thanks to recent advances in IT and big data analytics. In the transportation, storage, processing, and packaging of food products, the Internet of Things (IoT) and wireless sensors are becoming more and more significant. A traceability system may be connected to the data obtained by wireless sensor technologies at each stage of the product's lifecycle throughout the supply chain.

Software and hardware standardization—a part of IT application—plays a significant role in the implementation of open systems, not only for supply chain management but also in the packaging industry, given that in affluent nations, equipment and automation are used in the processing and packaging of roughly 90% of foods, including speciality crops and vegetables. (Cheruvu et al., 2008; Mahalik, 2014). Traceability, for instance, might also involve identifying the packing device. Additionally, faulty equipment reduces production. Machine providers keep a close eye on the tools and machinery used in processing and packaging operations in this context.

II. COMPONENTS OF INFORMATION AND COMMUNICATION TECHNOLOGIES

ICT encompasses a number of steps at the industrial scale, from data collection through processing and display (Figure 1). The initial stage in data transmission and ICT processing is obtaining the crucial data from the processing or transportation end points. The target nodes, where the data must be gathered, are equipped with a variety of sensor devices in order to do this. These sensors often gather information in the form of pictures, electrical signal outputs, etc. Applications for chemical and biological sensors are expanding rapidly, and they provide potential applications for quality monitoring across a range of food processing industrial areas. Through the geographical data gathering at the working locations, wireless sensors offer a startling window into the potential of machine-to-machine (M2M) process control, equipment management, robotic mechanical control, and process control systems in the food sectors (Wang et al., 2006). Some common applications for these wireless sensors include environmental monitoring, machine and process control, facility automation, and food traceability systems. A wireless sensor network (WSN) typically consists of radio frequency (RF) transmission and receiving systems, electronic-based sensors, microprocessors, and power sources. The deployment of actual time quality tracking and traceability technologies throughout the food supply and processing chains has generated a deluge of information. Even with the aid of computers and simple mathematical analytic techniques, so large data is challenging to analyse. Recent research has identified two fast developing technologies that are important to ICT: big data and cloud computing. Through the application of big data analysis technologies, extensive data gathering is translated into information that can be used for operational and commercial decision-making. In the chemical processing, pharmaceutical, and food sectors, where vast amounts of data are employed in real-time, big data analysis has unparalleled promise (Chiang et al., 2017).
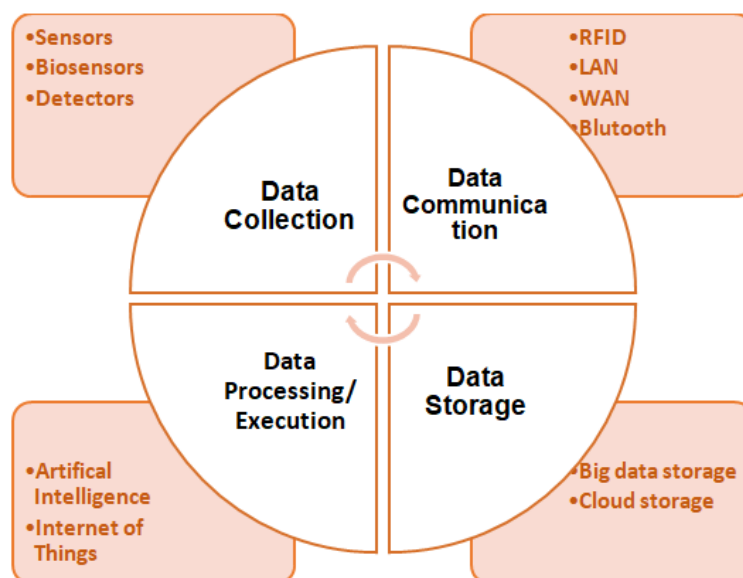
Figure 1: Components of ICT

III. ARTIFICIAL INTELLIGENCE (AI) IN FOOD INDUSTRY

Systems utilizing AI and machine vision make enormous data accessible, which is crucial for the processing and manufacturing of food. The introduction of AI-driven processes and equipment into the agricultural and food business has transformed how crops are grown, produced, and processed. In the coming decades, startups in the food sector that are powered by AI have the potential to enhance both the public and private food systems. Numerous researchers have stressed the need of utilizing AI in robotics, machine learning, computer vision, robotic farming (Sheth et al., 2017), pattern recognition for crop health monitoring (Tian et al., 2020), and demand-driven food supply chains (Griffin et al., 2018). Anselma et al. (2017) created "augmented personalized health," an AI-based program for the food and nutrition industry, to help consumers customize their nutritional consumption. A shift to fewer environmental consequences, improved resilience, and better health might be supported by AI and the food systems (Camarena, 2020). A few applications of AI include supply chain management, food sorting, production development, food quality enhancement, and good industrial hygiene (Garver, 2018; Sharma, 2019; Utermohlen, 2019).

IV. INTERNET OF THINGS (IOT) IN FOOD INDUSTRY

The Internet of Things (IoT) is one of the most significant and recent innovations in the world of IT. IoT in the supply chain can enhance human-to-human connection and object coordination while elevating supply chain communication (Ellis et al., 2015). The Internet of Things is a network of mechanical and digital computer devices that are connected to one another and employ sensors attached to people, animals, and machines to deliver a ton of vital and detailed information about systems that can be used to improve them. By upholding safety requirements, lowering food waste, handling unanticipated changes, and tracking and monitoring food quality, IoT benefits the food industry. Due to the wide range of sensors that are now on the market and the even broader range of software solutions available for data analysis, there are countless IoT uses in the food sector. Deploying IoT enables better overall control over the food supply chain, from raw materials in the plant through product distribution to clients and consumers.

When transporting food, for example, temperature control, hygiene and pest control, traceability, product management (i.e., movement of goods, damage, rejection, and safety), preventative maintenance of the vehicle/container, and staff management, handling, personal hygiene, safety, policies, and training may all be issues that the product needs to address. Temperature control, hygiene and pest control, traceability, product management (i.e., movement of goods, damage, rejection, and safety), preventative maintenance of the vehicle/container, and staff management, handling, personal hygiene, safety, policies, and training may all be issues that the product needs to address. All food-related actions may be tracked with the help of the Internet of Things. One of the most efficient and affordable IoT methods for tracking food goods is RFID technology. RFID tags can readily connect over a wireless network and store precise and significant information about the food goods being sent. Alerts are quickly transmitted across the supply chain in the case of a food recall or food safety issue, and the contaminated product is immediately quarantined. IoT use in the food industry has mostly enhanced food security and control (Balamurugan et al., 2020; Beker et al., 2016), enhanced traceability and transparency in the supply chain (Maksimovic et al., 2015; Grecuccio et al., 2020), strengthening sustainability and minimizing waste (Jagtap et

al., 2019; Cho et al., 2017) and optimizing transportation (Kumat et al., 2020; Reddy et al., 2020).

Table 1: Applications of IoT in Food Industry

Process	Impact	Reference
Food Transportation	More precise delivery dates are made possible by systems that can identify and evaluate events, such as traffic accidents, inside a distribution network.	Chauhan et al. (2021)
Food Logistics	Tools (such as delivery vans) that can find the quickest or most fuel-efficient route	Moudoud et al. (2019)
Food Production	Systems that can be utilized to optimize food production systems without human intervention by automating labor processes and processes	Rejeb et al. (2021)
Resource/waste management	reducing the production of food waste, energy use, and water use	Pal and Kant (2020)
Maintaining food quality	Systems that can continually check the product quality can detect and instantly correct any deviations from the established criteria.	Kayikci et al. (2020); Khan et al. (2020)
Food supply chain	Systems that might result in improved labor management, lower costs, and quicker lead times	Alfian et al. (2020)

1. **Advantages of ICT**

- **The Rise of Globalization :** Travel and hotel expenses are decreased with video conferencing. ICT has increased social interaction between people and across nations. It has also allowed for the integration of the global economy into a single, linked system, which has helped corporations communicate and become tremendously efficient.

- **Cost-Effectiveness :** Unquestionably cheaper and more convenient to send than phone calls are emails. ICT has also greatly reduced the cost of business procedures by automating them.

- **Extended Time :** You may have your items delivered right to your door without lifting a finger by making your selections and making your payment online.

- **Development of New Jobs:** The creation of new, exciting roles has been the major advantage of ICT. Web designers, system, hardware, and software developers, as well as computer programmers, are just a few of the many new jobs that IT has created.

- **Educational Opportunities :** Computers, their programs, and the internet have made it possible for current generations to access educational possibilities that were not possible in the past. Online courses may be taken from home to get a degree. You may work while pursuing your degree.

- **Standardization:** Machines can help to make work more uniform. No one can afford to disregard the benefits of standardization since it ensures consistency uniformity in both the quality and quantity of work.

- **Authenticity and Efficiency:** Proper message delivery is essential for the recipient to comprehend in the same spirit and respond appropriately. Accuracy is promoted by the automated and methodical technologies. Efficiency often improves with new technologies (Sooryanarayana et al. 2000).

2. Applications

- **Monitoring the Food Supply Chain, Product Recalls, and Traceability:** ICT is used to track applications of tracking sensors for location and quality tracing of food commodities at every level of the supply chain, increasing traceability and the potential for product recall in the event of a quality change or degradation. It also enhances the quality and visibility of food components in the supply chain. However, the FSC's disjointed structure requires consistency in the design of its traceability. To do that, traceability support models must be created that may synchronize data from different food supply chain segments and analyses to facilitate effective decision-making (Gallo et al., 2021).

- **Quality Evaluation of Foods Using Non-Destructive Methods:** The analytical technique known as near infrared, or NIR, spectroscopy may be used to quickly and accurately examine foods. Food contamination is a constant issue, and the two things that are most frequently contaminated are meat and alcohol. In the food and beverage business as well as the agriculture sector, food quality is a major problem. Food suppliers, retailers, and their clients must all have complete trust in the readily available food on a national and worldwide basis. NIR measurement assists several elements of food processing, such as: Identifying components and additives, composition analysis for food labeling, and the quality control of a wide variety of foods. Detecting food fraud and improving production and manufacturing methods. Due to the availability and applicability of numerous calibration techniques as well as the advancement of contemporary computer science, potential applications in the field of food analysis have garnered a lot of interest. Detecting food fraud and improving production and manufacturing methods. Due to the availability and applicability of numerous calibration techniques as well as the advancement of contemporary computer science1, potential applications in the field of food analysis have garnered a lot of interest. Off-line, anline, on-line, and in-line measurements can be classified depending on how a process is implemented (FAO, 2017; UNEP, 2018; Spaargaren et al. 2013, for example).

- **Consumer Transparency:** Greater transparency in product-related information is made possible by ICT technologies, giving consumers a clear understanding of all the necessary product data. Thanks to the usage of many scannable tags and labels, such as QR codes, NFC tags, data matrix codes, barcodes, and RFID systems, consumers may scan and identify any food product with just their phone. ICT facilitates easy access to information in the food supply chain, but there is a possibility that it may

exclude farmers and processors who are not tech-savvy. In order to achieve transparency with a range of food qualities, ICT must be modernized with user interfaces that are simpler for complex and dynamic FSC (Manning, 2018).

- **Food Production:** The timely availability and application of important information to address opportunities and challenges is agricultural innovation. In low-income countries, outreach and advisory organizations commonly use ICTs to notify farmers through SMS, online portals, and call centers about market prices for resources, weather forecasts, crop and animal ailments, and other information (Allahyari et al. 2018; FAO, 2017). The FAO's research and dissemination systems (VERCON) are among the innovative application and service models that have been made possible by ICT. Farmers may now affordably obtain financial services (such as savings, credit, insurance, payment methods, and money transfers) because to ICT, notably mobile phones.

- **Enhanced Food Safety and Quality:** In order to maintain and improve product quality during production, storage, and transportation, wireless sensor systems are employed to remotely monitor and communicate the quantitative measurements of temperature, humidity, gas concentrations in storage environments, and other quality characteristics. More research is needed in the areas of food quality assurance in order to create cutting-edge techniques for judging food quality that might be incorporated with ICT technology.

- **Sorting Fresh Produce:** The cataloguing of food may be greatly automated by food processing enterprises using cameras, lasers, machine learning, and artificial intelligence, enabling more efficient food sorting. By merging sensor-based optical sorting technologies with artificial intelligence, for instance, the slow, time-consuming techniques for sorting fresh fruit may be abolished, leading to increased yields of better-quality produce and less waste. AI is utilized to reduce costs and waste, handle a variety of product sizes, and enhance machine calibration (Sebastin, 2018).

- **Improved Inventory Management:** Additionally, ICT-based technologies have been employed to digitally change products using smart or active packaging, which instantly updates the inventory status of every product and offers simple inventory management options. Organization-specific framework optimization needs to be looked into as soon as possible for effective inventory management systems in the food sector.

- **Reduction in Food Wastage:** Product expiry date detection and cloud storage application control aid in reducing food waste at both the industrial and consumer levels. Researchers have lately looked into ways to decrease food waste at consumer points using smart refrigerators with cameras (Liegeard and Manning, 2020), applications for sharing food on mobile devices, information sharing, and advertising-based techniques. The believability of these tactics is, however, only partially supported by measurable data (Reynolds et al., 2019). To significantly reduce food waste, this must be addressed, and additional ICT-based solutions can be investigated.

- **Authenticity Assurance:** The availability of authenticating food goods through the use of scannable digital tags also makes it possible to spot fake food products on the market. Additional information is required about how to integrate technology with genuine food supply chains (such as halal FSC) and the difficulties that may arise due to technical immaturity, end users' resistance, and financial and legal constraints (Rejeb et al., 2021).

- **Automation as a Shield against Pandemic Breakouts:** Due to panic purchasing, hoarding, and slumping food outputs with factory closures and personnel absenteeism during the COVID-19 pandemic, there were tremendous stresses on the food supply chain (Mavridou et al., 2019). Automating manufacturing facilities using "machine vision technologies" would reduce food contamination and aid with pandemic-related concerns. It is necessary to further investigate the techno-economic viability of ICT in assessing the dynamically changing food quality in the supply chain caused by toxins found in food and environmental conditions.

- **Sustainability:** A system of production and consumption that is sustainable ensures food security for all people on the world while having the least possible negative effects on the environment. This is accomplished through minimizing waste, improving food production, and utilizing agri-food techniques that are both ecologically and socially sustainable. A useful instrument for achieving sustainability in the food business is the Internet of Things. Data may be gathered from drones and sensors in farms, silos, and fields thanks to the Internet of Things. This data, once analyzed by the IoT system, provides farmers with the information they need to produce sustainably. It allows farmers to measure the quantity of water used to irrigate their fields, indicating where more water is needed and reducing waste, as well as to determine which plants need fertilizer and which ones need pesticides or how much feed to provide animals (Maroli et al., 2021).

Table 2: Examples of ICT applications in food industries

Area	Application	Reference
Agri-food supply chain	a production, processing, storage, and sales-focused agrifood supply-chain traceability solution that incorporates blockchain and RFID	Tian (2016)
Supply Chain	based on HACCP (Hazard Analysis and Critical Con trol Points), blockchain, and the Internet of Things, built a food supply-chain traceability system for real-time food tracing.	Tian (2017)
Fish supply chain	Internet of Things analysis of the idea of virtual food supply networks and a proposal for an architecture to build enabling information systems	Caro et al. 2018
Virtual food supply chain development	To create a virtual food supply chain, IoT-based systems with cloud storage and data processing will be used to track the location, temperature,	Verdouw et al. 2016

	microbiological information, and other quality criteria of food ingredients.	
Process control for improved process quality	Wireless sensors can be used to collect data on temperature or sulfur dioxide, and fuzzy analysis or other big data analytical techniques can be used to make decisions about process control.	Ranasinghe et al. 2013
Supply chain management of perishable food materials	determining food quality and estimating shelf life by keeping an eye on environmental factors and mobility states	Wang et al. 2015
Fruit quality detection	Using wireless sensors, principal component analysis, and gas sensors to detect the concentration of ethylene gas, one may determine the stages of fruit ripening.	Pang et al. 2010
Meat supply chain	Data gathering on the carbon footprint of the meat supply chain at various points and analysis of the data using big data analytical tools for decision-making on activities to reduce the carbon footprint of the meat supply chain	Alfian et al. 2017
Food waste reduction	Foods are packaged intelligently (using barcodes, QR codes, RFID, gas sensors, time sensors, temperature sensors, pathogen sensors, and biosensors).	Feng et al. 2015
Food waste reduction	Intelligent refrigerators (which monitor and manage temperature and humidity, recognize shopping trends using IoT or AI technology, and inform customers when food is ready to expire)	Qiao et al. 2017 and Shweta (2017)
Quality of Milk	IoT and AI applications for the viscosity and other milk quality parameter profiling utilizing wireless sensors to detect adulteration in food products	Rajakumar et al. 2018
Juice Quality Detection	Using an electronic tongue system linked to an Internet of Things system, support vector machine (SVM)-based purity detection may be used for juices.	Ma et al. 2018
Microbial spoilage detection in food materials	Real-time microbial identification using smart sensors made of nanomaterials and deep learning techniques	Alafeef et al. 2020
Agri supply chain	Agriculture made possible by technology has improved food quality, safety, demand and supply balance, real-time information, trackability, and traceability.	Nayal et al. 2021
Dairy supply chain	The primary findings demonstrated that implementing ICTs (information and communication technologies) has a favorable effect on capacity and, as a consequence, increases the effectiveness of the dairy supply chain.	Mohammad i et al (2012)

V. CONCLUSION

As a promising tool to achieve green and sustainable developments, ICT applications in the food sectors are growing quickly. The advantages of current ICT trends for supply chain, food waste, food quality, and food safety were thoroughly discussed in this study. Through the use of strategic frameworks, digitalization and automation are expected to enhance the mutually beneficial connection between farmers, the food processing sector, and consumers. Although ICT technologies are widely used in many sectors of the economy, the food processing sector has not yet adopted the technology needed for full automation, increased production capacity, cleaner production with little waste, and control measures provided by data. ICT-based technologies' economic, environmental, and social viability must be considered, particularly in the context of food processing businesses and the supply chain.

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