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## IoT-Enabled Solutions for Ensuring Food Safety and Improving Processing Practices



**Abstract:** - Every industry involved in food must uphold food quality standards to protect consumer safety and premium products. Enhancements of government regulations and standards may make it necessary for emerging nations to adopt Industry 4.0 technologies. Industry 4.0 in the food sector is defined by a high degree of interconnection and the application of digital breakthroughs to improve automation and monitoring, such as blockchain, cloud computing, AI, smart sensors, autonomous robotics, 3D food printing, and IoT. IoT facilitates the food industry's transition to industrial 4.0 by establishing strict manufacturing guidelines, resolving bottlenecks in the supply chain, meeting and surpassing food safety regulations, and granting access to their customer base. This literature will mainly focus on the applications of IoT in food safety and processing practices.

**Keywords:** IoT, Food Safety, Supply Chain, Industry 4.0

### 1. INTRODUCTION

Many countries are prioritizing strengthening food control systems through stringent international laws as a result of growing consumer concerns about the safety and quality of food. Right now, fresh vegetables from all over the world are available due to global food enterprises' connectivity. In response, governments are using Codex Alimentarius standards to help them pass new laws and regulations. Traditional, cost-effective methods are rapidly being replaced by standard quality assurance systems. Standards are specified specifications that group similar things and give a uniform term that market participants can use to describe them (Okpala & Korzeniowska, 2023). Companies must adhere to mandatory standards like HACCP for change to occur. Every industry involved in food must uphold food quality standards to protect consumer safety and premium products. The food industry benefits from ISO 22000; however, small businesses cannot afford the adoption and implementation costs.

The next objective will be quality management once improved practices are achieved through HACCP. Quality management is the process of making sure a company is following the appropriate quality standard or system that an enterprise has designed. A safe food supply requires both scientific understanding and law enforcement. To ensure a consistent supply of food products that are both desirable and safe for human consumption, new rules must be implemented as technology advances. There will always be concern about potential contaminants and

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foodborne hazards (Fung et al., 2018).

These technologies are defined by a high degree of interconnection and the application of digital breakthroughs to improve automation and monitoring, such as blockchain, cloud computing, smart sensors, 3D food printing, etc (Hassoun et al., 2023). This literature will focus on IoT-enabled technologies and their application in the food sector. The goal of IoT is the ability to connect objects in an environment and enable them to communicate to generate new data or carry out a desired job without the need for human intervention (Farooq et al., n.d.) & (Shaddad Abdul-Qawy et al., 2015). A physical object with the capacity to transmit data across a network and having an IP address is referred to as a "thing" (Bigliardi et al., 2022). Every day, more and more gadgets are availing for internet access; when these gadgets are all linked, users will have access to an enormous source of information (Farooq et al., n.d.). (Shaddad Abdul-Qawy et al., 2015) describes connectivity as the ability of devices to interact with one another, which enables the collection and exchange of data through applications and management systems residing in data centers or network clouds. Mainly, four words are used to characterize the connectivity of IoT devices: anytime, anywhere, anyone, and anything. IoT and sustainable development goals are closely related since they advance several areas, including infrastructure, agriculture, health care, and the environment, all of which support SDGs 2, 3, 13, 9, and 7, respectively (Dadhaneeya et al., 2023).

The food industry, in particular, is primarily concerned with cutting production costs, getting rid of errors and downtime, quality control waste reduction, customization, and flexibility. Consequently, the food business has countless opportunities for IoT due to the abundance of devices and software solutions to support it (Bigliardi et al., 2022). IoT facilitates the food industry's transition to industrial 4.0 by establishing strict manufacturing guidelines, resolving bottlenecks in the supply chain, meeting and surpassing food safety regulations, and granting access to their customer base. When referring to IoT applications in industry, the term "Industrial Internet of Things (IIoT)" is frequently used (Dadhaneeya et al., 2023).

## 2. SIGNIFICANCE OF FOOD SAFETY AND PROCESSING PRACTICES

Annually, around one billion instances of diarrhea caused by food poisoning occur globally. Less than 10% of foodborne disease cases are reported, and among them, less than 1% of illnesses occur in developing nations, according to WHO estimates, which indicates that most of the cases are not being reported (Fung et al., 2018). (Okpala & Korzeniowska, 2023) defines food safety as a guarantee that food is suitable for human consumption under its intended usage. The purpose of food safety regulations is to eliminate hazardous foods and inform the public about them. These rules are implemented through a risk assessment process. But first, the scientific risk threshold needs to be determined to guarantee public safety. The maximum intake is then determined by assuming that the person would consume the item daily for the rest of their life. For more vulnerable individuals, this threshold is doubled by a factor of 100 or 1000 to add a degree of safety (Fung et al., 2018). Food Safety Management System is defined as the adoption of GMP, GHP, HACCP, and such other practices as may be specified by regulation for the food business (Okpala & Korzeniowska, 2023). Japan experienced multiple outbreaks of Minimata disease, or methyl mercury poisoning, between 1956 and 1965. Methyl mercury was found in seafood, and individuals experienced speech and hearing difficulties. A comparable outbreak from fungicide-containing seeds containing organomercury compounds happened in Iraq in 1972. Similar to this, rice contaminated with high levels of cadmium from the mining industry was causing "ItaieItai" in the people of Japan. When heat-degraded polychlorinated biphenyls (PCBs) contaminated rice oil during processing, there was widespread polychlorinated biphenyl poisoning in Japan in 1968. These patients had chloracne, a rare form of skin disease. The illness was named "Yusho" disease, which means "oil syndrome" in Japanese. Taiwan also reported a comparable outbreak in 1970 (Fung et al., 2018).

The US Centers for Disease Control estimate that foodborne illnesses result in 48 million illnesses annually in the US, 9.4 million of which are attributable to known pathogens. *Bacillus*, *E. Coli*, *Clostridium*, *Vibrio*, *Campylobacter*, *Staphylococcus*, and *Listeria* species account for more than 90% of food poisoning cases. The overuse and misuse of antibiotics in veterinary and human medicine have been associated with the formation of antibiotic-resistant bacteria, which makes treating infectious diseases in people and animals futile (Fung et al., 2018).

**Table 1:** Common pathogen and their medical impact according to WHO (Fung et al., 2018).

Foodborne hazards	Incidence of foodborne illness	Death due to foodborne illness
Bacteria	359,747,420	272,554
Virus	138,513,782	120,814
Protozoa	77,462,734	6242
Worms	26,063,664	90,261
Chemicals	217,632	19,712

### 3. IMPACT OF PROCESSING PRACTICES ON FOOD QUALITY AND SAFETY

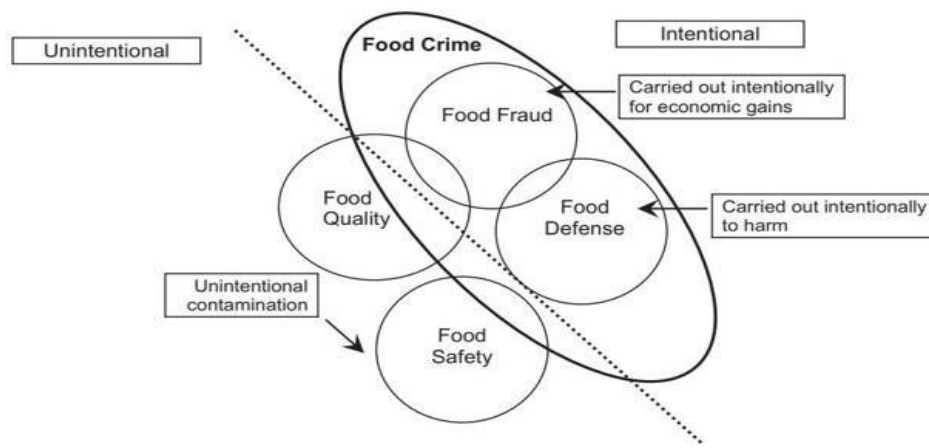
Food crime is on the rise these days, and it's mostly the result of food business owners committing purposeful and unintentional contamination for financial advantage, which compromises food safety and quality. Additionally, some processing procedures are to blame for the unintentional contamination that is detailed below (Nerín et al., 2016).

- Toxic heavy metal contamination is mostly thought to be caused by the uncontrolled usage of pesticides and fertilizers. Toxic heavy metals, including arsenic, mercury, cadmium, and lead, can find their way into food through soil, water, and the air.
- Cross-contamination in trucks or exhaust from gasoline and diesel engines can contaminate food while it's being transported.
- Chemicals used as disinfectants or cleansing agents have to be safe for surfaces that come in contact with food and compliant with laws. Because of safety considerations, glassware and metal cleaners are not allowed. To ensure chemical removal, quantifying the residues of cleaning agents in food is essential.
- Toxic chemicals can be produced in food by high cooking temperatures and external influences, which would compromise food quality and safety. These substances can be created by a variety of processing techniques, with frying being the most prevalent method to produce harmful substances.
- Food packaging extends the shelf life of products by protecting them from external factors. However, plasticizers, stabilizers, and antioxidants added to the packaging material can migrate into food and cause health problems.

This type of contamination is prevented by stringent laws at the FDA. Regulation No. 1935/2004 on materials designed to come in contact with food and laws on good manufacturing practices must be followed by materials used in food packaging.

- Temperature and relative humidity during food storage have a big impact on food safety and quality. Elevated temperatures and high humidity levels can impact the quality of packages, causing materials to seep and absorb into food. Good barrier qualities are necessary for long-term storage materials to avoid organoleptic alterations.

To control the penetration of contaminants into food, temperature, and humidity are important factors to consider. The range of temperatures that works best is 4 to 21 °C.



**Figure 1:** Intentional and unintentional modification of food (Manning & Soon, 2016)

#### 4. ADVANCED SOLUTIONS TO ADDRESS CHALLENGES IN FOOD SAFETY AND PROCESSING

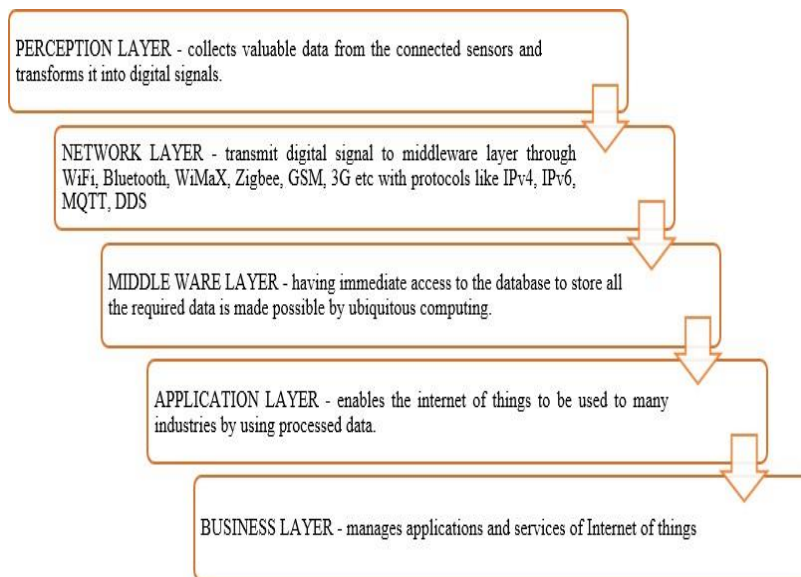
Consumer expectations about shelf life, quality, safety, and sustainability are rising for the food sector. Due to the potential for existing traditional technologies to alter the sensory quality, cutting-edge solutions, and creative approaches are required to satisfy these needs. Existing methods for evaluating food quality have been difficult, time-consuming, and destructive. On the other hand, non-targeted techniques that collect data on several characteristics at once are becoming more and more popular for assessing and tracking food quality. The COVID-19 epidemic and the growing need for fewer human food interactions have increased attention to this trend. When compared to conventional analytical methods, the implementation of Industry 4.0 technology could result in significant time and financial savings. Moving from a traditional to a Quality 4.0 system is financially feasible, even if the initial capital expenditure required for novel technologies may be substantial. Other desirable aspects of smart technologies include reduced machine downtime, fewer errors, and greater product quality (Hassoun et al., 2023).

Instead of replacing conventional quality practices, Quality 4.0 is now integrating with them. The most often used high-throughput analytical methods today for evaluating food safety and quality are capillary electrophoresis, nuclear magnetic resonance (NMR) spectroscopy, liquid or gas chromatography (GC), typically in conjunction with mass spectrometry (MS), and capillary chromatography (CE).

Apart from molecular analysis techniques, other biologically based methodological approaches like PCR and ELISA are also widely employed in food analysis. Rapid and affordable results can be obtained via fingerprinting technologies, like spectroscopic and imaging techniques, which are perfect for assessing complex materials like food products. The COVID-19 pandemic and the food industry's increased use of automation and artificial intelligence have raised the demand for these techniques. Due to their great sensitivity and specificity as well as their potential for real-time data capture during food production, spectroscopic techniques like fluorescence, Raman spectroscopy, and near- and mid- infrared (NIR) spectroscopy have received attention. These techniques can be used for everything from identifying fraud and adulteration to assessing the safety and quality of food. This resulted in further developments in handheld devices, tiny spectrum sensors, and miniaturized instrumentation (Hassoun et al., 2023).

#### 5. IoT TECHNOLOGIES IN FOOD SAFETY

When introducing IoT architecture, a few factors to be considered are functionality, interoperability, data storage reliability, and service quality. IEEE Standard 2413 provides an internationally recognized framework for specifying Internet of Things architecture, which is provided in the international standard ISO/IEC/IEEE 42010:2011. Based on this, (Dadhaneeya et al., 2023) categorized the IoT ecosystem into 4 layers; data generation layer, data transmission layer, data processing layer, and application layer. Several studies have been done on the architecture of IoT, (Farooq et al., n.d.) described the architecture of IoT as 6 layers; coding layer, perception layer, network layer, middleware layer, application layer, and business layer.



**Fig 2:** six-layered architecture of IoT ecosystem

In addition to the above-mentioned, IoT generally consists of IoT core hardware, which is the main entity component. This covers things like transceiver capabilities, power supplies, memory, and processor units (Shaddad Abdul-Qawy et al., 2015). The microcontroller is mentioned as the heart of the IoT ecosystem. The system's microcontroller, which functions as a miniature computer and can send and receive commands to the peripheral devices it is attached to, is its central component. The ESP32 is an inexpensive, low-power on-chip microcontroller. It has built-in dual-mode Bluetooth and Wi-Fi already. Its primary objective is to offer flexibility, robustness, and dependability in a variety of applications (N. Mishra et al., 2023). The majority of sensors used in the food business are linked to this microcontroller.



**Figure 3:** ESP32 microcontroller (N. Mishra et al., 2023)

From the study of (Farooq et al., n.d.) RFID, Wireless Sensor Networks, and cloud computing are some of the common technologies that are being implemented in IoT. WSN is a multi-hop, bi-directional wireless sensor network consisting of several nodes dispersed over a sensor field, each connected to a sensor or sensors with the ability to gather and send object-specific data to processing devices. RFID allows the objects to be uniquely identified. Compared to RFID, WSNs offer a greater range and peer-to-peer communication. Intelligent

computing technology known as "cloud computing" allows for the pooling of resources among multiple computers on a single cloud platform, which can be accessed from anywhere at any time. uID, IPv6 addressing and URN can also be used to differentiate each element besides RFID (Shaddad Abdul-Qawy et al., 2015). Low-lossy networks are one of the main characteristics of the Internet of Things.

These devices usually have predefined limits for nodes and connectivity, resulting in limited power, memory, and computing resources (Shaddad Abdul-Qawy et al., 2015). The IEEE 802.15.4 standard can greatly improve energy efficiency and radio frequency network dependability (Bigliardi et al., 2022). IEEE 802.15.4, 6LoWPAN, RPL, and CoAP are some of the standards or protocols described by (Shaddad Abdul-Qawy et al., 2015).

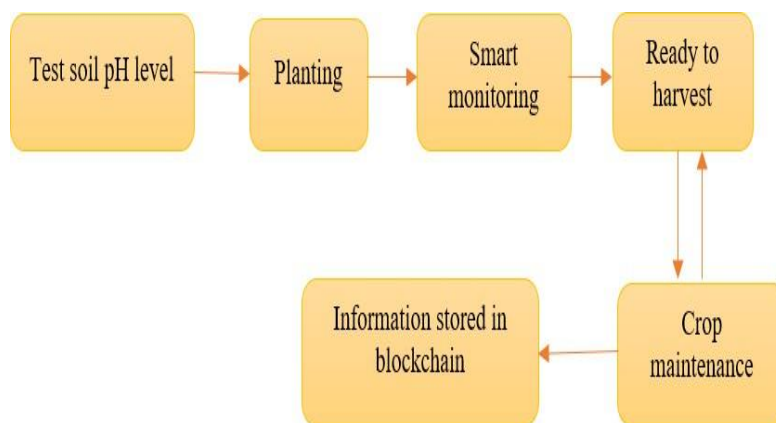
IoT encourages smart farming and real-time tracking techniques guarantee the security and dependability of goods across the whole supply chain by giving farmers the knowledge they need to produce sustainably and by using blockchain technology to monitor data in real-time (Bigliardi et al., 2022). Fast data interchange between sensors, machinery, and farmers' actions in real time is necessary for precise agriculture and smart farming. Low Power Wide Area (LPWA) networks like LoRa and NB-IoT, are especially well-suited for agriculture because of their long range and low power consumption (van Hilten & Wolfert, 2022).

**6. INTEGRATION OF IOT IN SUPPLY CHAIN MANAGEMENT AND QUALITY CONTROL**

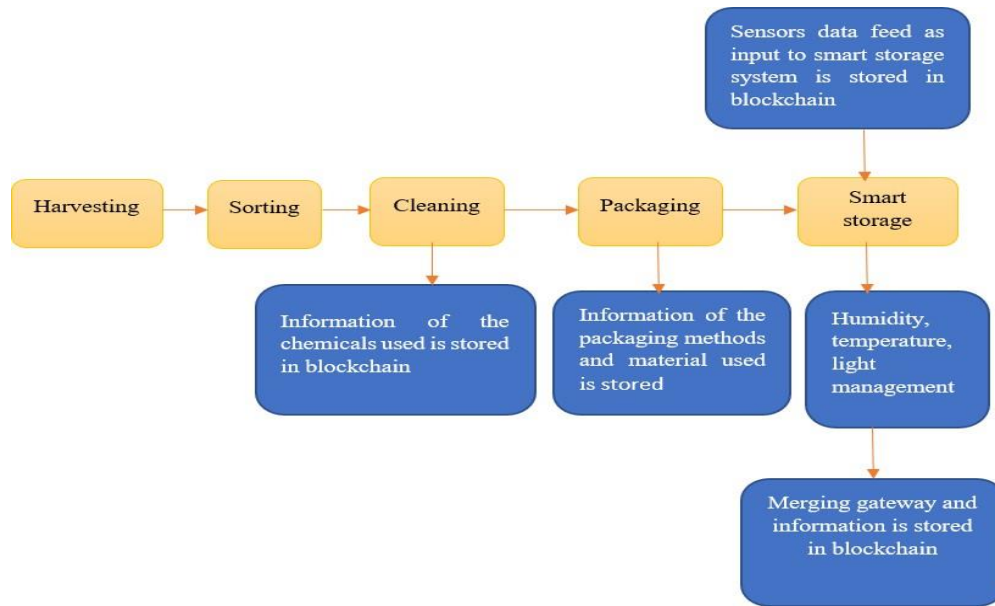
The field of supply chain management is always changing. Complicated regulations and globalization have made supply networks more complex. (Raza et al., n.d.) supply chain management is the process of getting the correct product, in the right amount, to the right consumers at the appropriate time and location. Supply chains employ centralized information management systems, which have one point of failure and are vulnerable to hackers. The presence of numerous carriers, logistics companies, and modes of transportation might impede supply chain visibility. Inadequate tracking, postponed shipping, inadequate storage methods, and communication problems might result in decreased revenue, decreased earnings, and compromised product safety and quality.

The three major components of a smart supply chain system are blockchain, smart contracts, and IoT. Blockchain addresses supply chain issues like information sharing, data tampering, and transparency. It offers a digital currency alternative to traditional money transfers and allows monitoring of product movement across the supply chain using IoT sensors, ensuring transparency and accountability. Programs that run automatically and are kept on the blockchain are called smart contracts.

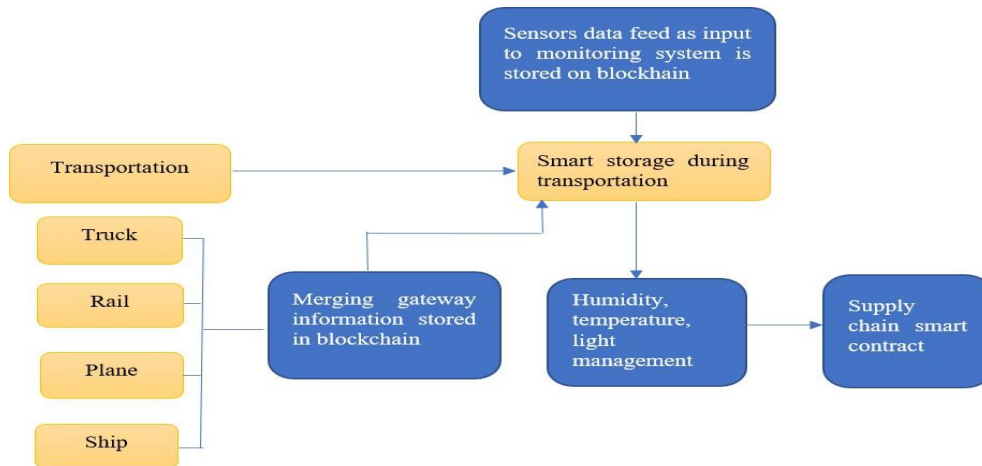
Third parties can no longer be involved through smart contracts. (Raza et al., n.d.) introduces a layered framework for a smart agricultural supply chain known as AGRI-4-ALL. It gathers information from IoT-enabled products. Communication protocols such as ZigBee, LoRaWAN, SIGFOX, Bluetooth, and 5G are used to link IoT devices with the infrastructure.



**Figure 4:** Application of blockchain technology at farming level



**Figure 5:** Application of blockchain technology at the processing level



**Figure 6:** Application of blockchain technology at the transportation level

An Internet of Things (IoT)-based smart monitoring system helps to provide timely information regarding field maintenance and fertilization while keeping an eye on the crops and field until harvest. The ideal harvesting time is also updated by this system according to the product's moisture content. For the benefit of customers, sensor-generated alerts and the decisions made in response to them can be recorded on the blockchain. Similarly, light and temperature are controlled in the warehouses and during transportation. Better transparency could be achieved by storing all pre-processing data on the blockchain.

### 7. ANALYSIS OF IoT ON FOOD SAFETY AND PROCESSING PRACTICES

(Udanor et al., 2022) developed an IoT system using an ESP-32 microcontroller to control water quality sensors in aquaponic fish ponds. The system includes submersible temperature sensors, pH probes, dissolved oxygen sensors, and NH<sub>3</sub> gas sensors. The sensors measure turbidity, nitrate detection, and NO<sub>3</sub> gas levels, enabling accurate monitoring of pond water quality. The study by (N. Mishra et al., 2023) introduced an IoT-based dryer to monitor critical parameters, control its work, and send alerts in emergencies. The dryer's temperature, humidity, and air velocity sensors were calibrated using a controlled atmosphere incubator and anemometer at different temperatures. This technology helps prevent risks and improve the quality of dried food. With the aid of the Internet of Things, the edible membrane of soybean protein isolate fused with polyphenols is created.

This can replace the conventional food film, which has a weak water barrier (Niu & Jiang, 2022). In the study conducted by (Afolaranmi et al., 2023) with the help of pasteurizer, which uses IoT and virtual sensing technologies, the issue of faulty products and equipment malfunctions in the beverage industry is tackled. With the help of a biocompatible impedance sensor, the author (Nagamalla et al., 2022) was able to discern between various forms of contaminated milk and various types of fake milk and also developed an automated sensing technology for the identification of synthetic milk.

The authors (Xu et al., 2022) proposed a flexible humidity sensor with Nano-silver interdigital electrodes and micropores for improved sensitivity. This sensor can be attached in small packages, increasing their utilization compared to conventional sensors that require limited volume. Following a statistical analysis of the gathered data, pertinent rules were extracted from the examination of the cold chain's critical points, microenvironmental factors, and quality indicators. Important pertinent indicators were created to create a knowledge rules database to predict and evaluate quality. The ESP32-S3 microcontroller, temperature and humidity sensors and an electronic nose make up the majority of the IoT system, which was developed to measure the content of volatile organic molecules in food to assess its quality (Damdam et al., 2023). Most of the time, the IEEE 802.15.4 standard is the most widely used and embraced because of its affordability, low power needs, and ease of usage (S. Mishra & Sharma, 2023) study uses this standard for the architecture of IoT in monitoring the health of livestock.

**Table 2:** IoT projects that have been implemented in the agri-food sector

IoT project	Key findings	References
An IoT system was developed to monitor the water quality in aquaponics.	6 water quality parameters have been monitored and transmitted to cloud storage hosted by Thingspeak every 5 s	(Udanor et al., 2022)
For the chilled chicken cold chain, a smart dynamic prediction model with integrated adjustable humidity sensors and knowledge rules	The concentration of humidity, O <sub>2</sub> , CO <sub>2</sub> , and H <sub>2</sub> S were the input of the model. TVB-N and sensory assessment were the two output indications.  The accuracy of the model was higher than 90.5%	(Xu et al., 2022)
IoT-based drying system to monitor microclimate parameters in the drying chamber.	The drying system was operated autonomously by an ESP32 microcontroller that was programmed in the Arduino IDE using data from several sensors.	(N. Mishra et al., 2023)
Identification of different beer typologies using the MOX sensor and S3 device	The responsiveness of the sensors was determined by measuring the variation in resistance over time resulting from their contact with various volatile compounds.	(Liboà et al., 2023)
Soybean protein isolate preparation and preservation using the Internet of Things	Soybean protein isolate was modified, which involved the changes in physical technologies achieved through IoT.	(Niu & Jiang, 2022)
Detecting spoilage in beef with an Internet of Things-enabled E-nose system	It was shown that Pseudomonas species and aerobic bacteria produce the majority of the volatile organic compounds (VOCs) in raw beef.	(Damdam et al., 2023)
Pasteurizer: quality monitoring of beers during tunnel pasteurization.	inexpensive substitute for replacing or improving established equipment and increased shop floor productivity	(Afolaranmi et al., 2023)

## 8. CHALLENGES AND FUTURE DIRECTIONS

The authors (Farooq et al., n.d.) describe some of the threats or security issues that could happen which are Malicious Insider, Data Loss, Accounts Hijacking, Monstrous use of Shared Computers, and unauthorized access to tags.

1) Short-medium distance (up to a few hundred meters) - Technologies like RFID, Bluetooth, WiFi, and ZigBee are used. Examples given are tracking cows and sensors in greenhouses (van Hilten & Wolfert, 2022).

2) Long-distance (up to a few km) - Technologies suited for open-field use like 2G,3G, and 4G cellular networks, which have wide coverage and allow less power/ data transfer. Examples given are soil moisture sensors and GPS guidance for tractors (van Hilten & Wolfert, 2022).

The number of devices that base stations can handle and the restricted medium data transfer capability are the primary issues facing existing technology. 5G is expected to provide benefits like higher speeds, larger data volumes, lower latency, and the ability to connect more devices. This could improve applications in areas like sensors, drones, precision agriculture systems, and supply chain management (van Hilten & Wolfert, 2022).

This could allow IoT applications in agriculture to move beyond just monitoring to actual remote control and automation, allowing robots and drones to take over tasks from manual labor. 5G-enabled IoT has the potential to greatly increase agricultural productivity, but upfront costs may limit its applicability mostly to large-scale farming at first. Costs are expected to decrease over time as the technologies scale up. The development of 5G networks is still ongoing, with many networks in development phases. Six major opportunities for 5G in agriculture are identified related to cyber-physical management systems, increased IoT uptake, higher performance for farming, supply chain management, and fully autonomous farms. For real-time smart farming applications, 5G and edge computing together could better allow the processing of large data volumes from farm machinery in real-time, enabling remote monitoring and use of third-party AI/software (van Hilten & Wolfert, 2022).

Key challenges for applying 5G and IoT in agriculture include developing hardware for harsh environments, ensuring electricity access in rural areas, and technical issues like antenna coverage when using higher 5G frequencies (van Hilten & Wolfert, 2022).

## 9. CONCLUSION

This new paradigm of networking, which integrates intelligence into everything around us, will have an influence on every part of our lives, from automated houses to smart health and environment monitoring. In this paper, we discussed the general architecture of IoT. Next, we discussed a few of the security risks associated with these many enabling technologies. Finally, we spoke about several IoT applications in the food industry. Studies are already being conducted to ensure its widespread acceptance, but it is highly unlikely that technology will become ubiquitous until the problems in its creation are addressed and users are given secrecy, privacy, and security. It will take a lot of work to address and provide answers for the security and privacy risks associated with IoT deployment. The creation of an IoT-based food safety monitoring system is a difficult and drawn-out undertaking. A thorough framework system for food safety supervision based on IoT technology has been suggested, which analyses the introduction of IoT technology to enhance food safety monitoring.

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