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Original Article

FreshTrack: Enhancing Household Food Safety with RFID-Enabled Food Expiry Monitoring System

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Abstract

Background: *Food labels provide essential information such as nutritional content and expiration dates, which are critical for ensuring food safety. However, studies reveal that many consumers neglect to check use-by dates, contributing to foodborne illnesses linked to expired products. Expired food, along with microbial and chemical contamination, adulteration, and mislabeling, remains a major public health concern. This study presents FreshTrack, an RFID-enabled food expiry monitoring system designed for household use.*

Methods: *FreshTrack adapts the RFID-based tracking approach used in commercial settings like grocery stores but emphasizes portability and user-friendliness for home environments. The system uses RFID tags affixed to food items and a reader positioned near a refrigerator to detect and alert users when an item is approaching its expiration. Thirty RFID tags were used to evaluate the system's performance.*

Results: *FreshTrack demonstrated 100% accuracy in identifying food status, with an average response time of 160 milliseconds. It consistently provided timely alerts, offering a practical and reliable solution for household food monitoring.*

Conclusion: *Planned enhancements include mobile integration for real-time alerts, barcode scanning, and synchronization with digital shopping lists. FreshTrack supports food safety at home and contributes to reducing unnecessary food waste.*

Keywords

Arduino Nano, electronic food labels, food expiry monitoring, food waste reduction, household food safety, IoT-based monitoring, perishable inventory management, real-time food tracking, RFID technology, smart packaging, zero hunger

INTRODUCTION

Checking and monitoring food labels and other food-related information on food products are not standard practices. A study conducted in Slovakia on 478 local respondents shows that only more than a quarter of the respondents read the food information on product labels (Nagyová et al., 2019), which raises concern because food labels contain nutritional facts, other product information, and details about the product's use-by date. Many foodborne illnesses occur due to people ingesting products past their use-by dates. Outdated foods or foods past their use-by dates are among the seven most common public health risks identified after analyzing 81 full-text articles (Gizaw, 2019). These health risks include microbial contamination of foods, chemical contamination, adulteration, misuse of food additives, mislabeling, and genetically modified foods (GM foods).

The problem with food label awareness needs to be addressed to improve household food safety and reduce the risks of food-related illnesses due to outdated food. Food products with a "best before" date often have a longer shelf life than the date suggests. Laboratory tests of milk, pasta, mayonnaise, and jam confirm the microbiological safety of the products even six months after the "best before" date (Kavanaugh & Quinlan, 2020). The product's use-by date indicates its freshness and how long it has been on the market. Knowing how to distinguish when a product is already unfit for consumption dramatically reduces food waste at home.

This device reduces the risks of ingesting outdated food products. It significantly impacts food waste management, preventing many households from immediately throwing away food products that have reached their best-before date. It is a common misconception that foods and other products that have reached or surpassed their "best before" date are already unfit for human consumption. This study focuses on developing a device that monitors the use-by dates of food products and alerts the user when the product is near its expiration date. The device is portable and can be used anywhere in the house. Scanning the tags lets the user view the product's use-by date, which is achieved through RFID tags attached to the products and a reader device, allowing the user to quickly determine whether the food is still edible or past its expiration date.

Many RFID-based systems already track the freshness of food products. Most of these applications are found in industrial settings such as restaurants, groceries, and other facilities where food safety is a top priority. Some smart refrigerators also have built-in RFID systems for recognizing food freshness, but these are typically found in high-end industrial settings. The system developed in this study prioritizes accessibility for home users. Thus, portability and ease of use are key considerations for this system. In this way, FreshTrack becomes available to home users whenever they need to check the expiry dates of their food products.

Scalability and Practicality

The widespread use of RFID for food safety in homes is becoming more feasible due to developments in accessible and reasonably priced technology. Previously, RFID was primarily employed in supply chains and retail because of its high cost and complicated setup. However, it becomes feasible for regular consumers to buy low-cost components like Arduino Nano and MFRC522 RFID scanners. These components are inexpensive and straightforward to integrate into smart home systems, enhancing the automation and effectiveness of food safety. As more food manufacturers and retailers adopt RFID tags for inventory tracking, their use for personal food monitoring expands in households. RFID integrates with smart refrigerators, kitchen appliances, and smartphone apps to reduce food waste, increase convenience, and improve safety. Consumers track expiration dates, detect signs of spoilage, and receive recipe recommendations based on available items.

The demand for innovative approaches increases as people become more conscious about food safety and waste reduction. As technology develops, RFID systems will likely become standard in modern kitchens, providing families with greater confidence in storing, preparing, and consuming food. This advancement marks a significant shift from industrial-grade tracking to personal household management. Although RFID begins as an industrial tool, its versatility makes it crucial in security, retail, healthcare, and smart home applications. Households and organizations achieve automated tracking, enhanced safety, and greater efficiency in inventory management, pharmaceutical storage, clothing maintenance, and pet tracking by implementing affordable RFID components. With ongoing advancements in reasonably priced RFID technology, its integration into daily life continues to increase, making everyday tasks safer and more convenient.

Beyond household food safety, RFID technology is also utilized in medical facilities for various purposes. One labor-intensive task in hospitals that RFID streamlines is the tracking and monitoring of medications. Many hospitals implement RFID technology to accurately manage and maintain medications used in kits, trays, and crash carts. By leveraging RFID's ability to read numerous medications in a single scan, these solutions enhance and improve traditionally barcode-driven workflows in real-time and remotely. This approach simplifies and accelerates processes such as determining whether medications need to be refilled or removed due to expiration, expediting recalls, and eliminating the need for manual entry of lot and expiration dates, thereby saving hours of laborious work.

The growing adoption of RFID for medication inventory management is noteworthy. For instance, automated dispensing cabinets (ADCs) typically require pharmacy and nursing staff to ensure accurate narcotic counts. RFID reduces errors and rework by eliminating time-consuming and repetitive processes prone to mistakes. RFID streamlines manual or time-consuming tracking, documentation, and verification processes in existing medication technology systems.

RFID Technology

RFID (Radio Frequency Identification) is a wireless technology that lies beneath most current goods, allowing businesses and consumers worldwide to interact, find, and confirm objects. It appeared a few years back and has received an overwhelming response, significantly advancing the RFID market. Low-maintenance RFID sensors are useful in several industries, such as manufacturing, logistics, health, and agriculture, leading to more development and exploration. This study used RFID tags to store and scan relevant food product data.

RFID sensor tags are classified into two types: active and battery-assisted. Passive tags, which have no power supply and rely on the reader for energy, are used in access control applications, file tracking systems, race timing, inventory tracking and control systems, smart labels, etc. Since disposable tags cost approximately $0.09 each, they can be printed using an RFID printer and are simple to apply. Intelligent RFID tags are self-powered by internal batteries and can transmit signals continuously. They are ideal for asset tracking and high-volume activities such as tolling. Users must replace their batteries every 3-4 years (Cui et al., 2019).

RFID tag research focuses on size, cost, reliability, and data protection in response to increased demand. The agrifood industry benefits significantly from RFID since traceability ensures food quality and safety. RFID technology monitors items across the supply chain, increasing productivity and safety. New sensors combined with RFID tags monitor food quality indicators such as milk freshness and fish rotting, thereby reducing food waste, which accounts for roughly one-third of total food production (Bibi et al., 2017). The quantity of FLW is enough to help 12.5% of the global population escape hunger and tackle the global problem of meeting the growing food needs, which are projected to double by 2050 (Ishangulyyev et al., 2019).

According to the FAO, post-harvest losses account for around one-third of overall food output. It also claims that over half of the energy, or around 3 billion tons, is squandered. Given the global population, it becomes challenging to meet future food demands. Today, 821 million people are hungry, yet food waste could feed four times as many people. In underdeveloped countries, there are early phases of trash, including supply channel waste, but in rich countries, the majority of garbage is generated at the consumer level, primarily in households (Özbük & Coşkun, 2020).

It is used in food packaging and contains a considerable quantity of information on the product. For example, Arnoldo Caprai's SmartCorq wine stoppers include information on the type of wine in the bottle, its origin, further processing, and suggested preservation methods. Unfortunately,. developed an e-control and quality management system for traditional Italian cheese that beacons clients via RFID (Papetti et al., 2012). Rahman linked this supply chain by using an RFID-controlled sensor network for wine ingredients, resulting in outstanding performance and real-time tracking (Osmólska et al., 2022).

TTIs aid in detecting temperature abuse during distribution and provide adjustable expiration dates. They can utilize color indicators instead of "use by" dates, such as red for dangerous food and yellow for diminishing quality. Freshness indicators detect organic acids, pH, biogenic amines, ammonia, and carbon dioxide. Calibration is required for each food type, as leafy green indications may not be appropriate for fish. RFID tags track food goods and provide real-time information on their identity and supply chain trip. They also help to investigate food waste and combat food fraud (Vågsholm et al., 2020).

It is worth noting that identifying equipment has helped food sector management by ensuring product quality and freshness. RFID outperforms it in long-distance identification, with no need for a line of sight, numerous readings, and little human intervention. RFID improves the supply chain, controls temperatures, and protects food safety by tracking things from distribution to storage, automating deliveries, and keeping track of available inventories (Inventag, 2023). Traceability ensures beef products satisfy quality and halal standards along the cold chain. RFID technology monitors beef quality and halal status throughout the distribution process, giving farmers and consumers real-time information (Syahputri & Sucipto, 2021).

Smart refrigerators monitor ingredient levels and inform users, decreasing food waste due to expired dates. RFID inlays give unique identifiers (UIDs) for individual item tracking, which helps retailers manage products that are about to expire and improves supply chain transparency. Consumers using NFC-enabled smartphones can immediately get storage instructions, ingredients, recipes, and recycling information from the packaging. RFID technology in retail and residences allows for effective inventory management and individualized food management recommendations depending on refrigerator contents (Pragmatic Semiconductor, 2021). RFID tagging in grocery shops allows for exact item-level sales monitoring, resulting in greater supply-demand alignment, faster markdowns, and timely food donations. It also improves inventory accuracy and allows for proactive management of expired supplies. Combined with temperature sensors, RFID helps prevent food deterioration and maintains appropriate storage conditions. During recalls, RFID traceability enables quick identification of tainted products, considerably lowering retrieval time. When used with blockchain, RFID improves customer safety and reduces food waste (Vargas, 2019).

Numerous studies have explored the application of RFID technology in enhancing food packaging and safety by integrating sensing, detection, and communication features. Innovative packaging systems now incorporate these elements to assess food quality and determine the need for disposal (Wu et al., 2020). Building on this, RFID has evolved beyond simple identification functions, progressing into systems capable of sensing and computational processing, supported by wireless networks with embedded sensing tags (Landaluce et al., 2020). Within Internet-of-Things (IoT) applications, RFID has emerged as a pivotal tool, particularly in food logistics and supply chain management (Mostaccio et al., 2023).

Advanced developments include passive RFID chips capable of self-tuning in response to environmental changes, enabling real-time monitoring of substrate permittivity—an important parameter for assessing food quality (Piccinno et al., 2023). Additional progress has been made in integrating sensors into RFID tags to monitor key environmental indicators such as humidity, temperature, gas concentration, pH, and structural integrity, which are essential for intelligent packaging. This ensures future scalability, researchers emphasize the need for cost-effective, resilient, and energy-efficient RFID sensor networks (Zuo et al., 2022).

Efforts to optimize RFID performance for specific food products have also been proposed through predictive models based on food composition (Claucherty et al., 2024). Complementary approaches, such as using biopolymer layers with UHF RFID sensors to detect deterioration, provide novel mechanisms for quality monitoring (Saggin et al., 2019). Moreover, chipless RFID sensors are gaining attention for their potential in monitoring multiple environmental factors, with calls for further research on their applications in food packaging (Fathi et al., 2020).

Regarding supply chain integration, RFID-based traceability systems are superior to barcodes for managing perishable food inventories due to their enhanced efficiency and real-time data capabilities Alfian et al., 2020). From an economic standpoint, RFID implementation across retail, manufacturing, and supplier tiers has improved profitability by optimizing control and delegation strategies (Fu et al., 2019).

Compared to traditional barcodes, RFID systems offer substantial logistical advantages, including faster read times—up to 1,500 operations per second—and the ability to detect multiple tags simultaneously without requiring line-of-sight or manual alignment. Furthermore, RFID readers can operate over longer distances and penetrate various materials depending on frequency, making them well-suited for dynamic and large-scale food monitoring applications (Smith-Ditizio & Smith, 2019).

A hybrid model combining the Technology-Organization-Environment (TOE) framework and the 3-S (Substitution, Scale, Structural) model analyzed RFID technology's slow yet evolving adoption in the retail industry. Interviews with retail executives in the US and Europe point out motivators and barriers to adoption, such as cost, complexity, and lack of standards, which have historically slowed progress (Mukhopadhyay, 2015). RFID technology is fast becoming the potential successor to the barcode and finds expanding applications in the agrifood and industrial sectors for product identification, traceability, and environmental monitoring (Mehannaoui et al., 2024). Alwadi et al. (2017) emphasized the potential of RFID technology to enhance inventory management efficiency and minimize material loss.

Most barcode scanners require line-of-sight; hence, an individual has to scan items manually. It is thus not as effective in real-time and non-contact monitoring as other technologies, such as RFID (Qin et al., 2024). Operational performance—even on something as simple as cooling and management of "best before" dates for a smart fridge—may be affected by parts of the IT ecosystem beyond the user's control (Mattsson & Williams, 2022). RFID helps avoid health implications, food allergies, or dietary issues by providing accurate information about the food, such as manufacturing dates and freshness duration (Alam et al., 2025).

METHODS

This research follows a Research and Development design, incorporating an innovative approach to solving household food safety problems by developing an RFID scanner that reads data in the tags attached to food packaging, including the expiration date and other pertinent information. After the data is scanned, the gadget will evaluate it and display a clear status indication, alerting people whether the product is safe to consume or has expired. The development approach will include rigorous testing and incremental enhancements to assure reliability and efficacy.

Materials

Several key components were integrated into the device to enable its intended functionality. At the core of the system is the Arduino Nano, a compact, breadboard-friendly microcontroller based on the ATmega328 (Arduino Nano 3.x). The Arduino Nano, the central processing unit, orchestrates all the device's operations. It is powered by four AA 1.5V batteries, providing a portable and energy-efficient power source.

To enable the identification of tagged items, particularly food products, the device employs RFID technology. Specifically, an RC522 RFID reader module is utilized. Operating at a frequency of 13.56 MHz, this module complies with ISO 14443A standard tags and can generate the required electromagnetic field to read RFID tags. These tags, functioning as electronic food labels, are affixed to individual food items and contain stored information ranging from serial numbers to descriptive data. When an RFID tag is brought into proximity with the scanner, the reader retrieves the encoded information and relays it to the Arduino Nano.

For user interaction and feedback, the device incorporates an SSD1306 OLED display. This single-chip CMOS display driver supports dot-matrix graphic display systems and is known for its low power consumption and lightweight design, which are attributes that align with the portability requirements of the device. After an RFID tag is successfully scanned, the retrieved data is presented to the user via this display module, ensuring clear and immediate feedback.

Integrating these components—the Arduino Nano, RC522 RFID reader, RFID tags, and SSD1306 display—the device effectively functions as a compact, user-friendly food product monitoring and identification tool.

Block Diagram

Figure 1 visually represents how the device functions through a block diagram. The system operates straightforwardly yet efficiently, ensuring that users can easily monitor the freshness of their food products. The process begins when the user scans an RFID tag attached to a food item using the RFID scanner. This scanner is crucial as it reads the encoded information stored within the tag. Once scanned, the data—typically bytes—is transmitted to the Arduino Nano, the device's central processing unit. The system integrates a clock module to ensure accuracy, continuously maintaining real-time synchronization of the current date and time. This module acts as a reference point, allowing the device to compare the recorded expiration date from the RFID tag against the actual date. After receiving the scanned data, Arduino processes it by cross-checking the expiration date stored in the tag with the real-time data retrieved from the clock module. Based on this comparison, the system determines whether the food item is safe to consume or has passed its use-by date. Finally, the result of this analysis is displayed on an OLED screen, providing a clear and immediate visual alert to the user. If the product is still within its safe consumption period, the screen may display a message confirming its freshness. However, if the product has expired, the display will notify the user accordingly, prompting them to take appropriate action.

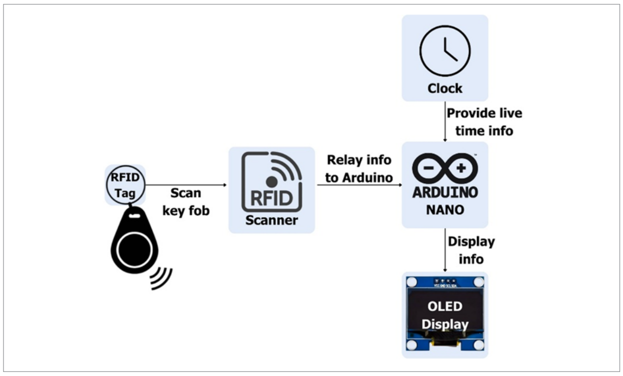

Figure 1. *Block Diagram*

Data Analysis

In this research study, the researchers applied experimental and developmental research methods. The development method used in attaining the objectives of this project is to develop an RFID-based food expiry monitoring system that uses RFID technology to scan the shelf life of canned goods. The experimental method is used to test and evaluate the functionality and accuracy of the device. The statistical tools used in this project are standard analysis parameters, which include the confusion matrix, accuracy, and precision. The confusion matrix presents a table layout of the different outcomes of the results of a classification problem.

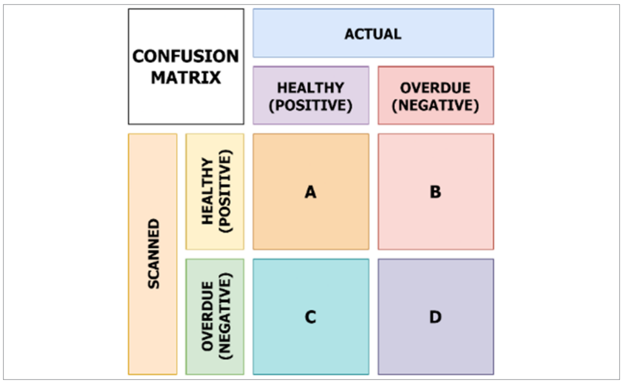

Figure 2. *Confusion Matrix*

Where:

A: True Positives (Correctly scanned HEALTHY)
B: False Positives (Incorrectly scanned HEALTHY)
C: False Negatives (Incorrectly scanned OVERDUE)
D: True Negatives (Correctly scanned OVERDUE)

These are also the analysis metrics used for analyzing the data obtained after testing:

$$Accuracy = \left(\frac{A+D}{A+B+C+D}\right)(100\%) \quad (1)$$

$$Precision = \left(\frac{A}{A+B}\right)(100\%) \quad (2)$$

Final Prototype

Figure 3 shows the exploded views of the device prototype. The figure shows that the device contains an Arduino Nano as the central microprocessor unit, which controls the other components. A clock module was also connected to the Nano since it has no internal clock. The clock was already set up to have real-time date and time updates. On top of the device are the OLED display and the RFID scanner. The scanner was covered to protect the board from outside risks such as moisture. The casing was 3D printed using Polylactic Acid (PLA) as filament.

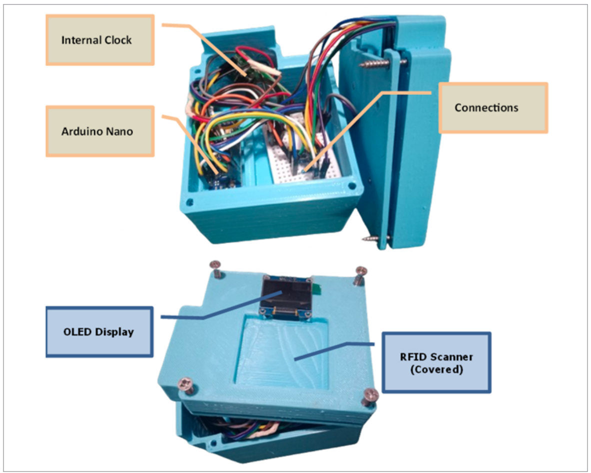

Figure 3. *Exploded Views*

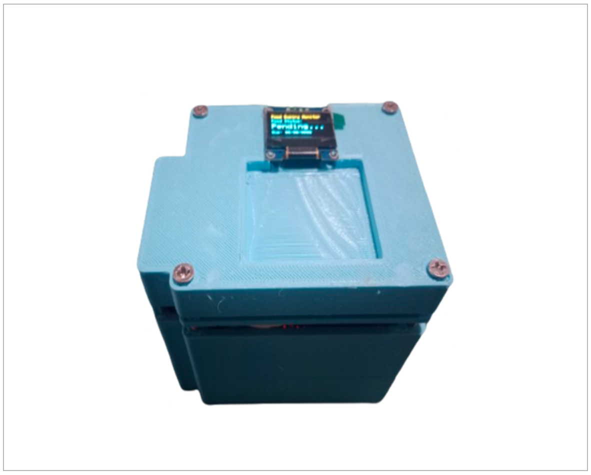

Figure 4. *Perspective View*

RESULTS

The study investigated the reliability and effectiveness of a food expiry monitoring system that uses RFID technology to signal the shelf state of goods as "OVERDUE" or "HEALTHY." To guarantee that the device operates optimally, its readiness was tested by placing 30 RFID tags. The findings above suggested that the proposed device was highly efficient in status classification, and this part clarifies them further with the use of a confusion matrix, as well as other analysis metrics such as accuracy, precision, recall, and mean analysis for the response time. The response time is shown in the plot in Figure 5. The comparison of the scanned feedback results is shown in Figure 6, while the confusion matrix is in Table 1.

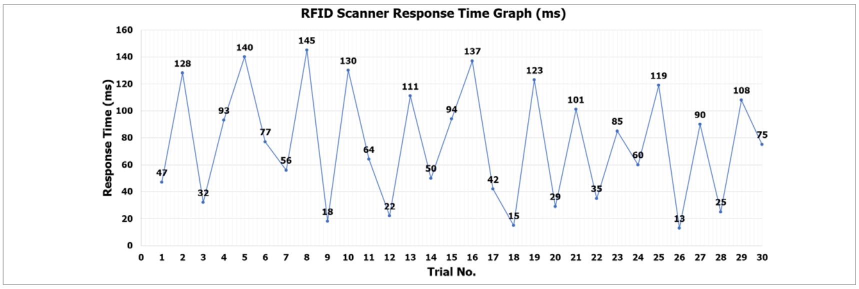

Figure 5. *RFID Scanner Response Time Graph*

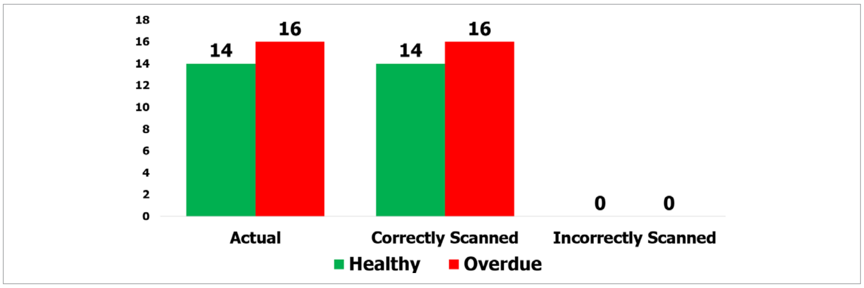

Figure 6. *Actual vs. Scanned Feedback Comparison Graph*

Table 1. *Confusion Matrix*

	Actual Healthy (Positive)	Actual Overdue (Negative)
Scanned Healthy (Positive)	0.47	0
Scanned Overdue (Negative)	0	0.53

These values are normalized over 30 samples.

According to the results of the confusion matrix and the analyzed metrics, the RFID system for monitoring food expiry is exceptionally accurate. The accuracy and precision were 100%, indicating that the gadget identified all 30 tested RFID tags without failure. The rate is a very high level of accuracy, which may demonstrate that the device's utility in tracking and guaranteeing the safety of food items within houses is correct. Also, this supports the efficient working of the device from the response time analysis. The average response time was recorded at 160.03 milliseconds, a reasonable standard deviation; the device works fast and efficiently. The low response time means that the device gives a quick response, which is very useful when using the device in the monitoring process. Thus, by applying the confusion matrix to the device assessment, the author demonstrated the tool's ability to capture precise and reliable data. The perfect accuracy metrics above show that the refrigerator monitoring system using RFID technology effectively improves the accuracy of the status identification of goods and thus has significant potential in improving food safety in a household. Above all, the short response times also guarantee the device's usefulness in day-to-day operations.

DISCUSSION

The RFID-enabled food expiry monitoring system significantly improved the accuracy and efficiency of identifying expired products in household settings. Compared to manual inspection of expiration dates—which is often overlooked by over 70% of consumers (Nagyová et al., 2019)—this system offers a rapid, automated alternative for determining product viability. The system enables informed decision-making by continuously monitoring items inside the refrigerator, thereby reducing the risk of consuming expired products, which contribute to widespread foodborne illnesses globally (Gizaw, 2019).

In the testing phase involving 30 RFID-tagged food items, the system demonstrated 100% accuracy and 100% precision, correctly identifying all products as either "HEALTHY" or "OVERDUE" with no false classifications confirmed through a confusion matrix, where true positives (healthy items correctly identified) and true negatives (overdue items correctly flagged) both yielded perfect results. The average system response time was 160.03 milliseconds, with a standard deviation of 84 milliseconds, making the system responsive enough for daily household use.

Compared to previous innovative systems with average response times of around 62 milliseconds (Wu et al., 2020), the slight delay in FreshTrack's processing is offset by its portability, ease of use, and affordability for the household market. Unlike high-end smart refrigerators limited to industrial settings (Bibi et al., 2017), FreshTrack is designed with accessibility in mind, using low-cost microcontrollers and off-the-shelf components, making the system scalable and practical for the average consumer.

The system's integration into daily routines directly addresses food label neglect, as highlighted in studies showing low consumer engagement with expiration dates (Kavanaugh & Quinlan, 2020; Nagyová et al., 2019). Furthermore, it supports broader efforts in food waste mitigation. Approximately one-third of all food produced globally is wasted, a problem FreshTrack addresses by preventing premature disposal of still-edible items and ensuring timely consumption of perishable goods (Ishangulyyev et al., 2019; Özbük & Coşkun, 2020).

Despite its demonstrated efficiency, the system has limitations. The initial investment cost—including RFID scanners, tag deployment, and system development—may hinder adoption in low-income households, a concern echoed in RFID adoption literature (Mehannaoui et al., 2024). Moreover, the system relies on accurate barcode or RFID-tag encoding at the point of manufacture; incorrect or missing expiration data could compromise performance (Wu et al., 2020). Nevertheless, FreshTrack presents a scientifically validated, numerically supported solution for enhancing household food safety and minimizing waste. Its perfect classification accuracy and sub-200 ms response time position it as a promising candidate for future integration with mobile applications, real-time shopping lists, and IoT-enabled innovative kitchen environments (Inventag, 2023; Pragmatic Semiconductor, 2021).

CONCLUSION

An RFID-based system for monitoring food shelf life in refrigerators offers a practical solution for proper storage and consumption. This approach helps track which items have been in the fridge the longest, reducing food waste and preventing spoiled food from being consumed. By making it easy to check expiration dates, the system minimizes the risk of eating expired food and the potential health issues that come with it. One of the key benefits of this system is improved food safety. By ensuring that only fresh and unexpired food is available, it reduces the chances of foodborne illnesses and builds consumer trust in the quality of stored products. Future variations of this system can improve many of its features. Although the RFID-based food expiry monitoring system has already presented great accuracy and efficiency, much more innovation is necessary to become more sustainable and valuable. Testing under actual conditions within specific circumstances should focus on a more extensive study to guarantee that the system works dependably within daily usage under different house setups, climate settings, and food storage in the commercial sphere. A mobile application that provides real-time alerts about food item expiry could be included. Features like barcode scanning for manually entered products, push alerts, and synchronization with digital shopping lists can be added to the program to increase user involvement and convenience.

Author Contributions

M. C. Muit: Conceptualization, Investigation, Software, Data Curation, Formal Analysis, Validation, Resources, Writing – Review & Editing; **A. Manaog:** Conceptualization, Data Curation, Resources, Writing – Original Draft, Formal Analysis; **J. L. Masagca:** Methodology, Visualization, Formal Analysis, Writing – Original Draft, Data Curation, Validation; **J. J. Montañez:** Conceptualization, Supervision, Formal Analysis, Project Administration, Methodology, Writing – Review & Editing.

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Ethical Approval

Not applicable.

Competing interest

The authors declare no conflicts of interest.

Data Availability

Data will be made available by the corresponding author on request.

Declaration of Artificial Intelligence Use

The authors did not use generative AI or AI-assisted technologies in the preparation, analysis, or writing process.

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