NutriCycle: An IoT-Based Waste-to-Value Machine for Converting Vegetable Waste into Poultry Feed Meal and Compost

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CHAPTER 1

This chapter presents the introduction of the research study and its problem. It includes the dependent and independent variables that are used in the study as well as the significance and limitations.

Introduction

Vegetable waste is a major contributor to the global food wastage problem, affecting economic growth, environmental sustainability, and resource efficiency. Due to their perishable nature, vegetables are highly prone to spoilage and wastage during production, post-harvest handling, transportation, and consumption. Both developed and developing countries face this challenge, with inefficiencies in handling, limited storage facilities, and fluctuating market demand leading to significant losses. Beyond the financial setbacks, the improper disposal of vegetable waste results in environmental degradation and resource depletion. Cultivating vegetables requires large inputs of water, fertilizer, and energy, all of which are wasted when surplus produce is discarded (Food and Agriculture Organization [FAO], 2021). Hence, addressing vegetable waste is an urgent global concern that requires innovative, sustainable, and technology-driven solutions.

One emerging approach to sustainable food waste management is the conversion of vegetable waste into value-added products. Many industries, particularly the livestock and agricultural sectors, are exploring ways to utilize organic waste as an alternative raw material. Vegetables that are often rejected for commercial sale due to overproduction or physical imperfections still contain high nutritional value and can be repurposed into poultry feed and organic compost. Integrating these materials into animal feed formulations not only minimizes waste generation but also provides a sustainable and cost-effective alternative to conventional feed ingredients, such as maize and soybeans (Palada, 2017; Martinez et al., 2021).

In the Philippines, food wastage continues to be a pressing issue, especially in vegetable-producing provinces such as Benguet and the Cordillera region, where market surplus and post-harvest inefficiencies lead to large amounts of unused produce (Philippine Statistics Authority [PSA], 2022). On the other hand, the poultry industry faces persistently high production costs, with feed accounting for nearly 70% of total expenses (Department of Agriculture [DA], 2023). These parallel challenges present an opportunity to establish a value-added process that benefits both vegetable growers and poultry producers.

The purpose of this study is to design and develop NutriCycle: An IoT-Based Waste-to-Value Machine for Converting Vegetable Waste into Poultry Feed Meal and Compost. The main objectives are to reduce food waste through a sustainable conversion process, provide an affordable feed alternative to lower poultry production costs, enhance poultry nutrition by utilizing the natural vitamins and minerals present in vegetables, and promote environmental sustainability through efficient waste management practices. The incorporation of Internet of Things (IoT) technology allows real-time monitoring and automation of the sorting, drying, and conversion processes, ensuring efficiency, consistency, and quality output

The proposed NutriCycle system holds significant economic, environmental, and technological value. Farmers can generate additional income from excess vegetables, poultry producers can access nutrient-rich feed at a reduced cost, and the organic compost produced can be used to improve soil fertility and support sustainable agriculture. This project also aligns with the Philippine Development Plan 2023–2028, which emphasizes environmental protection, innovation, and sustainability (National Economic and Development Authority [NEDA], 2023).

Through IoT integration, the system enables intelligent monitoring, predictive control, and optimized processing, making waste conversion more efficient and data-driven. Ultimately, NutriCycle presents an innovative solution to the global problem of food waste while promoting agricultural sustainability and resource circularity. As food security challenges continue to grow, such technologies play a vital role in creating a resilient and sustainable food ecosystem (FAO, 2021).

1.1 Project Context

Vegetable waste, particularly green leafy vegetable residues generated from wet markets, remains a significant environmental and economic concern. In the Philippines, substantial amounts of these perishable materials are discarded due to oversupply, spoilage, and inefficient post-harvest handling. These wastes are commonly left to decay, resulting in the loss of valuable resources and contributing to environmental degradation. This situation reflects a missed opportunity to repurpose biodegradable waste into useful products. At the same time, both farmers and poultry producers continue to experience high production costs, especially in terms of feed and fertilizer, emphasizing the need for innovative and sustainable waste-to-value solutions.

The NutriCycle addresses this challenge by developing an IoT- and Machine learning device that transforms specific vegetable wastes into either animal feed or compost, depending on their freshness and quality. Equipped with computer vision and weight sensors, the system automatically identifies, classifies, and sorts vegetable residues before directing them into a dual-chamber processing system: one chamber optimized for feed production and the other for composting.

Unlike conventional methods such as sun-drying, manual composting, or uncontrolled disposal, the NutriCycle ensures a faster, automated, and quality-monitored process that maximizes nutrient recovery and minimizes losses.

By upcycling vegetable waste into value-added feed and organic compost, the project not only reduces food waste but also provides sustainable solutions that benefit smallholder farmers, backyard livestock raisers, and the broader agricultural sector, while contributing to environmental protection and circular economy practices.

1.2 Purpose and Description

Contribution to Knowledge

NutriCycle presents an innovative approach to addressing food waste and agricultural sustainability through the conversion of green leafy vegetable waste into valuable poultry feed meal and compost. By integrating IoT technology with sustainable waste management, the project contributes new knowledge on how automation and intelligent sensing can transform organic waste into usable agricultural resources. This initiative not only lessens the environmental burden caused by decaying vegetable matter but also promotes a circular economy, where waste materials are reintegrated into the production cycle instead of being discarded.

The study explores the intersection of technology, sustainability, and agriculture, emphasizing how IoT-driven systems can support environmentally Animal Feed production. It will examine the processes of automated waste detection, sorting, and conversion while evaluating their efficiency, scalability, and potential for adoption in rural and urban settings. Through this research, NutriCycle aims to demonstrate that waste can serve as a valuable input for new forms of production, contributing to reduced feed costs, enhanced resource utilization, and improved food security.

Ultimately, this study advances knowledge in IoT applications for waste-to-value systems, serving as a reference for future innovations in sustainable agriculture and smart environmental management. By merging technology with ecological awareness, NutriCycle illustrates how data-driven solutions can lead to more resilient and resource-efficient communities.

- **Beneficiaries of the Study**

1. **Farmers and Poultry Producers**

   Farmers will benefit from the opportunity to earn additional income by selling surplus or discarded green leafy vegetables that would otherwise go to waste. Poultry producers, on the other hand, can utilize the processed feed meal as a low-cost and nutrient-rich alternative to commercial feeds, thereby reducing production expenses and promoting sustainable farming practices.

2. **Environmental Sector**

   The project contributes to environmental preservation by reducing the volume of organic waste sent to landfills, which in turn minimizes methane emissions and soil contamination. By implementing IoT-based monitoring systems, NutriCycle promotes responsible waste management and supports efforts aligned with climate change mitigation and sustainability goals.

3. **Agricultural Researchers and Innovators**

Researchers and innovators in agriculture and environmental technology can use NutriCycle as a reference model for studying IoT applications in waste-to-value systems. The project's data and framework can serve as a foundation for further development of intelligent waste conversion, feed optimization, and composting technologies.

4. **Local Communities and Policy Makers**

Communities benefit from improved waste management practices and access to sustainable livelihood opportunities through the adoption of NutriCycle systems. Policy makers can also use the study's findings as a basis for creating or enhancing programs that support eco-friendly waste conversion, agricultural innovation, and circular economy initiatives in alignment with the Philippine Development Plan (2023–2028).

5. **Educational Institutions**

The study provides valuable learning material for students and educators in the fields of computer studies, agriculture, and environmental science. It fosters awareness of sustainable technologies and encourages academic engagement in developing solutions for real-world environmental challenges.

1.3 Objectives of the Study

General Objective

To develop an IoT- and Machine learning processing station that automatically converts green leafy vegetable waste from wet markets into ready-to-use animal feed or compost products, reducing food waste while creating value-added agricultural resources for local communities.

Specific Objectives

1. To collect green leafy vegetable waste from wet markets and analyze it using Machine learning computer vision and weight sensors for reliable waste identification in a controlled environment.

2. To sort and convert the collected vegetable waste into either animal feed or compost based on Machine learning quality assessment and freshness classification through a dual-chamber processing system.

3. To grind the collected Green leafy vegetable waste into smaller, uniform particles to enhance processing efficiency, facilitate dehydration, and produce animal feed.

4. To dehydrate the ground vegetable waste by removing excess moisture in a controlled manner, ensuring longer shelf life, preservation of nutrients, and suitability for either feed production or composting.

5. To provide a reliable nutritional fact for animal feed.

6. To produce feed meal or vermicast organic fertilizeras ready-to-use products while providing real-time operation feedback and status notifications to trained personnel through a supervised processing station that ensures consistent product quality.

1.4 Scope and Delimitations

Scope

- **Automated Recognition and Quality Control:** The system employs computer vision combined with weight sensors to accurately identify and assess various types of green leafy vegetable waste, ensuring proper classification and processing integrity through dual verification methods.
- **Integrated Processing**: The system includes an Machine learning driven classification that determines optimal processing path (usable vegetable waste for animal feed, spoiled vegetables for compost).

- **Dual-Chamber Processing System:** The system features separate processing chambers - one for animal feed production (dehydration and grinding) and another for vermicast composting.
- **End-to-End Product Creation:** The system provides complete waste-to-product conversion including automated sorting, grinding, and dehydration ready for poultry consumption.
- **Controlled Environment Operation:** The system operates under personnel supervision with trained operators managing non-biodegradable sorting, managing setup, monitoring processing status, and ensuring quality control through a user-friendly interface displaying real-time processing notifications.
- **Real-Time Processing Workflow:** The system delivers a real-time workflow from waste input to product output, including preparation, recognition, classification, sorting, grinding, dehydration and completion notifications.
- **Environmental Sensitivity:** The system's Machine learning image recognition and mechanical components may be affected by extreme humidity, temperature variations, or harsh wet market conditions, potentially impacting processing accuracy and reliability.

Delimitation

- Multi-Vegetable Waste Processing (Green leafy vegetable Focused): The system is primarily optimized for green leafy vegetable waste processing, reliable and efficiency for this vegetable type. The system still requires manual pre-sorting to prevent contamination and ensure product quality.

- Processing Capacity Constraints: The system is designed for single-stream processing with limited throughput capacity, unable to handle simultaneous inputs from multiple sources or large-scale market operations.
- Technical Maintenance Dependency: The system relies on mechanical components (grinding and sorting mechanisms) that require regular maintenance, calibration, and potential repairs, making it dependent on technical support availability.

CHAPTER 2

This chapter provides a comprehensive review of existing literature related to (research topic), establishing the theoretical foundation for the current study and highlighting key research gaps that the present investigation aims to address.

Review of Related Literature and Study

2.1 Review of Related Literature

- **Foreign Literature**

Control systems are among the most essential components of modern engineering, serving as the foundation for optimizing operations across diverse sectors. These systems consist of interconnected devices or algorithms that manage the behavior of dynamic processes by regulating inputs to achieve desired outputs. They ensure stability, efficiency, and safety across applications such as industrial manufacturing and transportation networks. Generally, control systems are divided into two main types: open-loop systems, which operate solely based on preset instructions without feedback, and closed-loop systems, which continuously adjust actions based on system feedback. The latter has become more prevalent in modern applications due to its accuracy and stability in responding to disturbances or system variability (IEEE Xplore, 2024).

Recent advances in control system technology have introduced adaptive and predictive control methods that further improve system performance. Notably, Model Predictive Control (MPC) has gained widespread use for its ability to anticipate system behavior and optimize control operations over time. This predictive approach is highly beneficial in complex fields such as chemical processing, energy management, and aerospace engineering. MPC enhances efficiency by reducing energy consumption, improving performance, and lowering operational costs (Ali et al., 2023). Additionally, the integration of fault-tolerant control mechanisms allows systems to detect and respond to faults in real time, reducing downtime and accident risks. Continuous progress in sensor and actuator technology has made modern control systems more reliable and flexible, ensuring that engineering operations remain efficient, environmentally responsible, and dependable (Kondratenko et al., 2022).

According to Martins et al. (2021), the demand for sustainable animal feed has driven the exploration of innovative feed ingredients, particularly microalgae. Traditional feed components such as cereal grains and soybean meal present environmental challenges, including high transportation costs and competition with human food sources. Microalgae, however, contain high levels of protein, energy, and essential fatty acids, making them a valuable nutritional source for animal diets. Research has shown that incorporating microalgae into poultry and swine feed improves meat quality by enhancing the fatty acid profile, even at lower inclusion levels, without negatively affecting growth performance.

Beyond their nutritional value, microalgae offer a natural alternative to synthetic feed additives, supporting the shift toward eco-friendly and health-conscious feed formulations. Nonetheless, the widespread use of microalgae is limited by high production costs and uncertainty in nutrient delivery. These barriers may be overcome through technological advancements, such as bioreactor systems and the use of agricultural waste streams for cultivation. Determining the balance between cost efficiency and nutrient consistency remains crucial for large-scale adoption. Although significant investments are needed, microalgae hold strong potential to make animal feed production more sustainable and economically feasible.

Recent studies have shown that green leafy vegetables (GLVs) and their by-products serve as sustainable and nutrient-rich alternatives for animal feed. Goenaga et al. (2023) and Omoruyi et al. (2023) reported that vegetable residues have high digestibility and substantial protein content suitable for livestock diets. Similarly, Yavuz et al. (2023) noted that green biomass contains 10.8–35.7% crude protein, while Rahman et al. (2024) found that *Moringa oleifera* leaves with about 26% protein improved cattle milk production. These findings highlight the potential of GLVs to enhance feed quality and support sustainable livestock production.

In a related study, Swick et al. (2019) focused on the potential of food waste as an alternative protein source for animal feed. Since feed constitutes the most expensive component of poultry production, repurposing waste food offers both economic and environmental advantages. Experiments demonstrated that waste food collected from service establishments contained approximately 404 g/kg of protein, comparable to conventional feed ingredients. Feeding food waste mixtures, such as bakery by-products and restaurant waste, to finishing pigs reduced overall feed expenses by 32.9%, lowering the cost per kilogram of weight gain from \$0.85 to \$0.57.

However, further studies are needed to assess the digestible amino acid content and the economic feasibility of using food waste-based feeds, especially in countries like Australia. Nutrient variability among waste streams remains a concern, as different sources can lead to imbalanced nutrient profiles. Combining multiple food waste types is recommended to reduce this variability, while supplementation with amino acids, minerals, vitamins, and antioxidants can help achieve balanced nutrition. Although certain countries, such as China, have successfully developed food waste-based feeds with high hygiene and safety standards, issues like high salt concentration and low metabolizable energy persist in some waste types. Nevertheless, food waste remains a promising, low-cost, and sustainable feed alternative, provided that further research refines processing methods and ensures nutrient uniformity and safety.

Comparative Analysis of Three (3) Control Systems

Automation plays a vital role in the performance and precision of NutriCycle: An IoT-Based Waste-to-Value Machine for Converting Vegetable Waste into Poultry Feed Meal and Compost. The system relies on accurate control of parameters such as temperature, moisture, and motor speed during waste processing and feed production. To ensure efficiency, stability, and sustainability, it is essential to identify the most appropriate control mechanism. Among the most relevant systems in this context are the Proportional-Integral-Derivative (PID) Control, Adaptive Control, and Model Predictive Control (MPC). Each system offers distinct operational strategies suitable for IoT-integrated agricultural automation.

Proportional-Integral-Derivative (PID) Control

The Proportional-Integral-Derivative (PID) controller is one of the most widely used control systems in industrial and agricultural automation due to its simplicity and reliability. It continuously computes the error between a desired setpoint and the actual process variable, then applies corrective actions to minimize this error using proportional, integral, and derivative terms (Åström & Hägglund, 2006).

In the NutriCycle system, PID control can regulate critical processes such as motor speed in the shredding unit, temperature control in the drying chamber, and moisture consistency during composting. Studies show that properly tuned PID controllers can deliver fast and stable responses, making them ideal for simple, repetitive tasks (Li et al., 2020). However, their performance may degrade under varying system dynamics such as fluctuating moisture levels or load variations common in organic waste processing (Zhang et al., 2019).

Adaptive Control

Adaptive control systems automatically adjust their parameters based on real-time feedback and system behavior. Unlike PID controllers, adaptive controllers can learn from environmental changes, making them effective in handling nonlinear processes such as organic waste conversion and composting (Ioannou & Sun, 2012).

For NutriCycle, adaptive control could enhance performance by dynamically adjusting operational settings based on the waste's composition, moisture level, and environmental temperature. This ensures consistent drying, uniform feed meal texture, and improved compost quality. According to Patel et al. (2021), adaptive control strategies significantly improve process stability and energy efficiency in IoT-based agricultural automation. However, the increased computational demand and implementation complexity make adaptive systems more suitable for advanced IoT architectures with sufficient processing capabilities.

Model Predictive Control (MPC)

Model Predictive Control (MPC) represents a more sophisticated control approach that predicts future system behavior using a mathematical model and optimizes control actions over a defined time horizon (Camacho & Bordons, 2013).

In the NutriCycle system, MPC can optimize multiple interrelated parameters such as temperature, humidity, and drying time by predicting how each variable affects the overall process. This predictive capability allows for proactive adjustments, minimizing energy waste and ensuring consistent product quality. Singh et al. (2022) emphasized that MPC integrated with IoT data analytics enables predictive decision-making and resource optimization in agricultural processes. Nevertheless, MPC's high computational cost and the need for accurate process modeling make it more practical for large-scale or research-based implementations rather than small, low-cost systems.

Control System	Characteristics	Advantages	Limitations	Application in Smart Poultry Feed Monitoring
PID Control	Simple feedback-based mechanism	Easy to implement, reliable, low cost	Less effective under nonlinear and varying conditions	Motor speed regulation, drying temperature control
Adaptive Control	Self-tuning and learning-based system	Handles environmental variations, maintains consistency	Requires more computational power	Adjusts feed drying or composting parameters in real time
Model Predictive Control	Predictive and optimization-bas ed	High accuracy, energy-efficient, multi-variable optimization	Complex setup, high cost	Predictive control for optimizing drying and composting efficiency

Table 1. Comparison Between 3 control Algorithm

In summary, each control system presents distinct advantages depending on the application complexity and resource availability. For NutriCycle, PID control provides a cost-effective and dependable solution for basic automation tasks. Adaptive control offers enhanced flexibility and responsiveness, making it ideal for dynamic processes like waste drying and feed homogenization. Model Predictive Control delivers the highest precision and energy optimization but demands greater computational resources and technical expertise. Ultimately, a hybrid approach integrating adaptive and predictive control could enhance the system's responsiveness, efficiency, and sustainability in converting vegetable waste into valuable poultry feed and compost.

Comparative Analysis between SQL and NoSQL Database Security Measures

SQL and NoSQL databases differ significantly in managing, storing, and securing data, particularly in Internet of Things (IoT)-based systems like NutriCycle, which requires real-time monitoring and data synchronization across devices. SQL databases are known for their structured, relational design, ideal for applications that prioritize consistency, data normalization, and strict security compliance. They rely heavily on schema-based organization, which enforces data integrity through constraints and relationships. SQL systems such as MySQL and PostgreSQL often employ Role-Based Access Control (RBAC), password hashing, and encryption standards such as AES-256 for data at rest and SSL/TLS for data in transit. These ensure high levels of confidentiality and protection against unauthorized access (Scarfone et al., 2021).

However, IoT systems like NutriCycle require flexibility, scalability, and real-time communication areas where NoSQL databases such as Firebase excel. Firebase, as a cloud-based NoSQL database, allows asynchronous data synchronization across multiple IoT devices, enabling real-time data updates from sensors monitoring temperature, humidity, and waste processing. It integrates Firebase Authentication, which supports multi-factor authentication and OAuth providers such as Google and Facebook for secure user access. Firebase Security Rules also allow developers to control data access dynamically, based on user identity or device context, providing more adaptable protection compared to traditional SQL permissions (Firebase Documentation, 2024).

While SQL databases offer stronger transactional consistency and are better suited for systems requiring strict data structure, Firebase's NoSQL model provides scalability and efficient handling of unstructured sensor data crucial for IoT applications. Furthermore, Firebase encrypts all data in transit using TLS and at rest using AES-256 encryption, minimizing the risks of eavesdropping or breaches. Its serverless and distributed architecture also reduces the vulnerability to SQL injection attacks common in traditional systems.

Overall, while SQL databases maintain a robust framework for regulated industries, NoSQL databases like Firebase align better with the needs of NutriCycle, offering flexibility, scalability, and real-time security mechanisms essential for managing continuous IoT data streams securely and efficiently.

Key Comparative Figures

1. **Data Structure and Security Flexibility:**
    - SQL databases enforce a rigid schema structure, ensuring data consistency and relational integrity, but require complex planning and maintenance during the design stage.
    - Firebase, being schema-less, allows NutriCycle to store unstructured sensor data such as temperature, humidity, and feed moisture in real time. This flexibility supports rapid development but requires carefully implemented Firebase Security Rules to prevent data inconsistencies and unauthorized access.

2. **Real-Time vs. Traditional Applications:**
    - SQL databases are highly effective in applications that demand strict ACID (Atomicity, Consistency, Isolation, Durability) compliance, such as inventory management or financial systems. However, their synchronous operation makes them less suitable for continuously streaming IoT data.
    - Firebase provides real-time synchronization between IoT sensors and the central database, allowing NutriCycle to instantly reflect feed processing status, compost

levels, and sensor readings. This capability ensures continuous monitoring and immediate feedback, crucial for maintaining efficiency in automated systems.

3. **Injection Attack Vulnerability:**

• SQL databases mitigate SQL injection risks using prepared statements and parameterized queries; however, manual implementation is required to maintain ongoing security.

• Firebase inherently avoids traditional SQL injection threats since it uses a document-based query system rather than SQL commands. Its built-in authentication and real-time security validation minimize the risk of data breaches, making it suitable for IoT-based applications like NutriCycle.

4. **Scalability and Maintenance:**

• SQL systems often face limitations in horizontal scalability, as expanding storage or performance usually involves complex replication and load-balancing configurations.

• Firebase automatically scales based on user demand and data volume, which suits NutriCycle's IoT environment that continuously generates data from multiple sensors. Its serverless architecture reduces maintenance overhead while ensuring consistent system performance.

Technology Framework

Python for machine learning

- Python has become the de-facto programming language for machine learning and computer vision, particularly in image recognition tasks, due to its rich ecosystem, readability, and widespread adoption in both research and industry. For instance, the graduate course CS231n: Convolutional Neural Networks for Visual Recognition at Stanford University explicitly lists “Proficiency in Python” as a prerequisite and states that *“all class assignments will be in Python (and use NumPy)”*. (vision.stanford.edu+2cs231n.stanford.edu+2) Surveys of AI/ML practitioners further support this predominance: according to the 2024–25 “Developer Nation” report, approximately 75.5 % of AI/ML developers favour Python as their primary language for artificial intelligence and machine learning applications.(developernation.net)Moreover, an article in *The New Stack* noted that Python’s “undisputed” leadership in the AI/ML developer ecosystem is driven by frameworks such as TensorFlow and PyTorch, along with developer-friendly libraries for computer vision and image recognition.(thenewstack.io) Collectively, these pieces of evidence from leading academic curricula to industry surveys and ecosystem analyses underline that Python is not only more accessible but also more appropriate for developing, training, and deploying machine-learning and computer-vision models, including image-recognition systems, than many alternative languages.

Arduino IDE for Internet of Things (IoT)

- The Arduino IDE has emerged as a highly appropriate development environment for IoT systems because of its user-friendly interface, broad hardware support and extensive ecosystem of libraries, which greatly ease the prototyping and deployment of connected sensor/actuator nodes. For example, a study on hobbyist IoT projects notes that "Arduino is an open-source electronics platform based on cheap hardware and the easy-to-use software Integrated Development Environment (IDE)… used among hobbyist and novice programmers for Do It Yourself (DIY) projects, especially in the Internet of Things (IoT) domain." (MDPI+1) Similarly, the IDE's cross-platform compatibility (Windows, Mac, Linux) and the massive library and board support reduce barriers to deployment of IoT nodes. (irjet.net+1) In practical deployment, for instance, an air-quality monitoring system used Arduino IDE programmed boards and IoT connectivity to deliver real-time data that were statistically equivalent in accuracy to standard monitoring systems. (mecs-press.org) Thus, the Arduino IDE supports rapid development, cost-effective sensor integration and broad hardware compatibility features particularly important in IoT applications.

Flutter for mobile app

- Flutter has emerged as a highly appropriate framework for mobile-app development due to its ability to support **cross-platform deployment**, deliver near-native performance, and accelerate time to market all of which align with modern business and engineering requirements. For example, Flutter allows developers to write a **single codebase** for both iOS and Android platforms, thereby reducing duplication of effort and enabling faster launches (e.g., “write once, deploy anywhere”). (nuom.health+1) Its compilation of Dart into native ARM code and use of a custom rendering engine enable high performance and smooth UI transitions comparable to native apps. (Cyber Infrastructure, CIS,+1) Flutter also offers development-friendly features such as “hot reload” for rapid iteration, a rich widget library for customizable and consistent UIs, and strong community support backed by Google. (HackMD+1) These factors demonstrate that Flutter is especially suited not just for prototyping or Minimum Viable Product, but for full scale mobile application projects in both startup and enterprise contexts.

React+Vite for web application

- Vite is considered more appropriate for developing modern web applications compared to traditional React setups using Webpack because it offers significantly faster build times, hot module replacement, and optimized performance. Its use of native ES modules allows instant server startup and efficient code updates, improving developer productivity. Moreover, Vite’s lightweight bundling process results in smaller and faster web apps, making it ideal for rapid development. Overall, while React remains a strong UI library, combining it with Vite provides a faster, more flexible, and modern approach to web app development (Zaid, 2024; LogRocket, 2024; JavaScript in Plain English, 2024).

Relevant Statistics and Policies

In recent years, the growing demand for real-time data processing and cloud-based storage has significantly influenced the adoption of NoSQL databases such as Firebase in IoT and smart automation systems. According to Statista (2024), global cloud database usage has increased by over 52% since 2020, with Firebase and MongoDB among the leading platforms supporting mobile and IoT applications. This trend underscores the movement toward schema-less, flexible, and scalable data management, which is essential for systems like NutriCycle that continuously process sensor data and user interactions.

In the Philippines, the Department of Information and Communications Technology (DICT) promotes the integration of cloud and IoT technologies under the Philippine Digital Transformation Strategy 2022–2028, encouraging industries to adopt secure and interoperable platforms for data management (DICT, 2023). Such initiatives highlight the growing recognition of data-driven sustainability projects, particularly those aligned with smart agriculture and waste management.

From a global perspective, data security remains a top priority in database deployment. A report by Cybersecurity Ventures (2023) projects that cybercrime costs will reach USD 10.5 trillion annually by 2025, emphasizing the importance of robust security mechanisms such as encryption, access control, and compliance frameworks. SQL databases, with their rigid schema and ACID compliance, provide strong transactional integrity ideal for critical data systems. However, Firebase's real-time database model and Firebase Security Rules enable scalable, cloud-based applications to maintain flexibility while reducing risks of SQL injection attacks—a vulnerability common in traditional relational databases (Google, 2023).

In terms of policy, the Data Privacy Act of 2012 (Republic Act No. 10173) governs the collection, storage, and processing of personal and sensitive data in the Philippines. The act mandates organizations to implement appropriate security measures, aligning well with Firebase's role-based authentication and encryption protocols. Globally, frameworks like the General Data Protection Regulation (GDPR) and ISO/IEC 27001 continue to set standards for ensuring database security, data integrity, and transparency in cloud infrastructures (European Union Agency for Cybersecurity [ENISA], 2023).

These statistics and policy frameworks collectively emphasize that secure, flexible, and scalable database architectures such as Firebase are vital for the successful deployment of IoT-based systems. For NutriCycle, adopting Firebase aligns with these standards, ensuring real-time data synchronization, resilience against injection attacks, and compliance with privacy laws, while supporting the efficiency and reliability of its waste-to-value automation process.

- **Local Literature**

The growing demand for cost-effective and sustainable poultry feed in the Philippines has driven researchers and farmers to explore locally available alternatives such as cabbage (Brassica oleracea). As feed expenses account for over 60% of poultry production costs, utilizing vegetable-based feed ingredients has become an important economic strategy. According to the Philippine Statistics Authority (PSA, 2022), agricultural costs have continued to rise due to inflation, reaching 6.4% in mid-2022. In response, the Department of Agriculture (2023) has implemented initiatives under the Enhanced Livestock and Poultry Productivity Program, encouraging smallholder farmers to incorporate vegetable by-products and surplus crops into animal feed production.

Cabbage, one of the most widely cultivated leafy vegetables in the Philippines, offers significant nutritional benefits for poultry. It contains essential vitamins such as A, C, and K, as well as minerals including calcium, potassium, and iron. Studies conducted locally have shown that cabbage leaf meal can serve as a partial replacement for conventional feed ingredients like soybean meal or corn, helping to reduce feed costs without compromising bird performance. Broilers fed with cabbage-based diets have demonstrated improved digestion, enhanced immune response, and better meat quality compared to those on traditional feed (Bureau of Animal Industry [BAI], 2021).

The increasing demand for cost-effective and sustainable poultry feed in the Philippines has encouraged researchers and farmers to explore locally available green leafy vegetables (GLVs) as alternative feed resources. With feed expenses comprising over 60% of total poultry production costs, the use of vegetable-based feed ingredients has become a vital economic strategy. According to the Philippine Statistics Authority (2022), agricultural costs have continued to rise due to inflation, while the Department of Agriculture (2023), through the Enhanced Livestock and Poultry Productivity Program, has promoted the integration of vegetable by-products and surplus crops into animal feed production. Recent studies highlight the potential of various GLVs such as *Moringa oleifera* (malunggay), water spinach (*Ipomoea aquatica*), sweet potato leaves (*Ipomoea batatas*), and banana leaves as nutrient-dense, locally accessible feed alternatives. Research by Goenaga et al. (2023) and Omoruyi et al. (2023) demonstrated that these leafy materials provide high digestibility and crude protein content, while Rahman et al. (2024) reported that dried *Moringa oleifera* leaves, containing approximately 26% crude protein, significantly enhance growth and milk yield in livestock. Similarly, a local survey by Quicoy et al. (2023) revealed that backyard poultry farmers in Mindanao commonly utilize indigenous leafy feeds, including malunggay and ipil-ipil (*Leucaena leucocephala*), to reduce dependence on commercial feeds. These GLVs are also rich in vitamins A, C, and K, minerals such as calcium and iron, and bioactive compounds that improve immunity and feed efficiency. Overall, the utilization of green leafy vegetables as feed ingredients aligns with national efforts to promote sustainable, low-cost, and environmentally responsible poultry production in the Philippines.

A recent study on the vermicomposting process utilizing the epigeic earthworm *Eisenia foetida* revealed that after 60 days, the resulting vermicast exhibited a notably lower carbon-to-nitrogen (C:N) ratio and greater stability than the original substrate, signifying the successful conversion of organic waste into a mature compost product (SpringerLink, 2024). Furthermore, the vermicast demonstrated increased concentrations of plant-available nutrients such as nitrates and phosphates, along with enhanced microbial activity—factors that collectively improve soil fertility, structure, and overall productivity when used as a soil amendment (MDPI, 2024).

2.2 Review of Related Studies

- **Foreign Studies**

The potential of transforming kitchen food waste into valuable poultry feed has been extensively explored in various international studies. According to Shah, P., Patel, D., Patel, B., and Patel, V. M. (2024), food waste can be efficiently processed into poultry feed through proper segregation, nutrient balancing, and anaerobic digestion. This method allows organic waste to break down without oxygen, producing nutrient-rich digestate and biogas that can be used for fertilizers and renewable energy. Such systems not only minimize waste generation but also reduce reliance on conventional feeds, enhancing both environmental and economic sustainability.

Similarly, Mechkirrou, L., Arabi, M., Ouhssine, M., & Afilal, M. E. A. (2021) demonstrated that kitchen food waste can effectively substitute commercial poultry feed. Their research revealed that utilizing food waste contributes to cost reduction and sustainable poultry farming while addressing global concerns about waste management. The study emphasized how repurposing food waste transforms a disposal problem into an agricultural solution.

In line with these findings, Torok, V., et al. (2023) found that recycled food waste has a significant impact on laying hens' performance and nutrient digestibility. The study observed improvements in feed conversion ratios, egg production, and egg quality. Moreover, using recycled waste reduces landfill accumulation and conserves natural resources that are typically consumed during feed production. This supports a more circular agricultural economy.

Dao et al. (2023) also confirmed the advantages of incorporating food waste into poultry feed. Their research revealed that feeding hens with such diets enhances feed efficiency and maintains egg quality. The authors highlighted the practice's economic benefits, as it decreases feed costs for poultry farmers while promoting environmental conservation by reducing food waste sent to landfills.

Meanwhile, Jha, R., & Berrocoso, J. D. S. (2019) examined the substitution of maize and soybean with food waste in broiler diets. Their findings confirmed that food waste provides sufficient nutrients for poultry growth, improving feed conversion ratios and maintaining bird health. Apart from the nutritional benefits, they identified reduced environmental footprints and decreased dependence on traditional feed ingredients, resulting in substantial feed cost savings for producers.

Kearney, J., et al. (2021) shared similar insights, explaining how the recycling of food residues into poultry feed can lower feed costs while maintaining high productivity. They also emphasized environmental benefits such as reducing greenhouse gas emissions from decomposing waste and conserving resources used in conventional feed manufacturing. The study highlighted how this approach contributes to more sustainable livestock production and long-term profitability for farmers.

Nascimento et al. (2022) conducted a nutrient profile evaluation of recycled food waste-based diets, revealing their ability to meet poultry nutritional requirements and support optimal growth and health. Their findings showed positive outcomes in feed conversion efficiency and overall bird welfare while promoting the reduction of waste entering landfills. The study also underscored the significant economic savings achievable through this practice.

Adding a technological perspective, Zhang, Y., et al. (2020) explored how the Internet of Things (IoT) can be applied to sustainable agriculture and poultry feeding systems. By using sensors and real-time monitoring, farmers can track feed utilization, animal health, and environmental conditions. This promotes efficient feeding schedules, minimizes waste, and supports more sustainable farming operations.

Furthermore, Agyekum et al. (2020) highlighted how food waste utilization in poultry feed contributes to sustainable production by improving resource efficiency and reducing environmental impacts. The study discussed both nutritional advantages and challenges of food waste inclusion and emphasized proper waste management to maintain feed safety and quality. Their analysis supports the circular economy model, reducing dependency on conventional feed crops while boosting food security.

Lastly, Smith, J., & Lee, R. C. (2023) analyzed international regulatory frameworks governing the use of food waste as animal feed. Their research compared global initiatives and case studies, noting that feeding food waste to livestock enhances nutrient recycling, decreases landfill use, and supports economic stability for farmers. They concluded that harmonized policies and international cooperation are essential to maximizing the global benefits of food waste conversion in agriculture.

- **Local Studies**

In the Philippines, the use of vegetable waste in poultry feed has gained attention due to both nutritional and economic benefits. Reyes, J. (2022) emphasized that vegetable waste is rich in protein, vitamins, and minerals, promoting growth, health, and productivity in broiler chickens. Including vegetable waste improves feed conversion ratios and reduces reliance on conventional feed sources. Moreover, repurposing this waste supports environmental sustainability by minimizing disposal, reflecting circular economy principles.

Santos, M. (2021) similarly highlighted the advantages of vegetable waste supplementation in broiler diets. Such inclusion enhances growth performance, optimizes feed costs, and provides an environmentally friendly alternative to conventional feeds. By diverting vegetable waste from landfills, farmers benefit from both reduced disposal costs and improved poultry health. Proper processing and recommended inclusion rates make vegetable waste an effective feed ingredient for improving productivity.

According to FAO research, converting vegetable waste into livestock feed in developing countries like the Philippines helps alleviate feed shortages, reduce dependency on costly commercial feeds, and lower production costs. This practice increases farmer profitability while promoting sustainable agriculture, repurposing food waste, and reducing contributions to landfills and greenhouse gas emissions.

Cruz, A., & Villanueva, L. (2023) underscored the role of IoT technology in monitoring feed production from vegetable waste. Sensors and real-time analytics ensure optimal treatment, tracking nutrient content, moisture, and temperature. This enhances feed quality and consistency, supports poultry health, reduces waste, and improves resource efficiency. IoT applications also provide traceability, transparency, and cost savings for farmers, encouraging sustainable practices in feed production.

Garcia, R. (2020) reported that vegetable waste is nutrient-dense, providing essential vitamins, minerals, and fiber that contribute to optimal poultry growth. Feeding this waste improves health, productivity, and the overall sustainability of agricultural practices, while being cost-effective due to local availability.

Delos Reyes, P. (2022) highlighted that recycling vegetable waste into poultry feed reduces greenhouse gas emissions by 20–35% relative to conventional feed production. Diverting vegetable waste from landfills prevents methane formation, reduces energy use, and minimizes synthetic fertilizer requirements. This supports a circular economy, lowers feed costs, and promotes environmentally sustainable agricultural practices.

Mendoza, T. (2023) noted that consumer acceptance of vegetable waste-based poultry feed is increasing. Market trends favor eco-friendly innovations that reduce feed costs, maximize resource efficiency, and deliver consistent nutritional value, creating economic opportunities for farmers and supporting sustainable agriculture.

Lim, E., & Tan, J. (2021) described technological innovations, such as sensors and algorithms, that optimize feed production from vegetable waste. Continuous real-time monitoring ensures high standards of nutritional quality, reduces resource wastage, and improves efficiency, contributing to more sustainable and cost-effective poultry feed production.

Alonzo, F., & Dela Cruz, J. (2022) observed that broilers fed diets supplemented with vegetable waste achieved higher weight gain and improved health indicators compared to those on commercial feed. The rich nutritional profile of vegetable waste supports growth and productivity, demonstrating its feasibility as a sustainable alternative feed ingredient. This approach provides economic benefits for farmers while promoting environmental sustainability.

Finally, FAO reports emphasized that government policies supporting the recycling of vegetable waste into livestock feed, such as regulations, safety standards, and incentives, can facilitate sustainable poultry production. Proper policy frameworks encourage the safe, efficient, and scalable use of vegetable waste, enhancing food security and supporting a resilient agricultural sector in the Philippines

Research Gap

Despite numerous studies demonstrating the nutritional, economic, and environmental benefits of using food waste and vegetable waste in poultry feed, several gaps remain that warrant further investigation. Most local and foreign studies broadly examine food or vegetable waste but do not specifically evaluate cabbage or its impact on poultry health, productivity, and feed efficiency.

While IoT applications in feed production for real-time monitoring have been highlighted, there is limited research combining cabbage-based or vegetable waste feed with IoT-enabled quality control, particularly in the Philippines. The effect of IoT on feed nutrient consistency, safety, and optimization in practical farm settings has not been fully assessed.

Additionally, guidance on optimal processing, inclusion rates, and safety protocols for cabbage-based feeds is limited, and variability in nutrient content and potential anti-nutritional factors remain under-investigated. Although many studies report cost reduction benefits, few provide comprehensive cost-benefit analyses for implementing vegetable waste-based feeds on a commercial scale in smallholder poultry farms.

Finally, while reduced waste and lower greenhouse gas emissions are frequently cited, the long-term environmental impact of systematic cabbage or vegetable waste feeding programs, including soil, water, and farm-level sustainability, has not been fully quantified.

Addressing these gaps can provide a practical, cost-effective, and environmentally sustainable solution for poultry production in the Philippines and similar tropical regions.

CHAPTER 3

This chapter describes the research methodology adopted in this research, explaining the design, methods of data collection, and data analysis techniques utilized to obtain the objectives of the study. It gives an elaborate description of the research methodology, including reasons for choosing certain methods. Moreover, this chapter explains the population, sampling method, data sources, and ethics to ensure that the findings are valid and reliable. By methodically describing the methodology, this chapter sets the stage for the credibility and replicability of the study.

Design and Methodology

3.1 Research Design

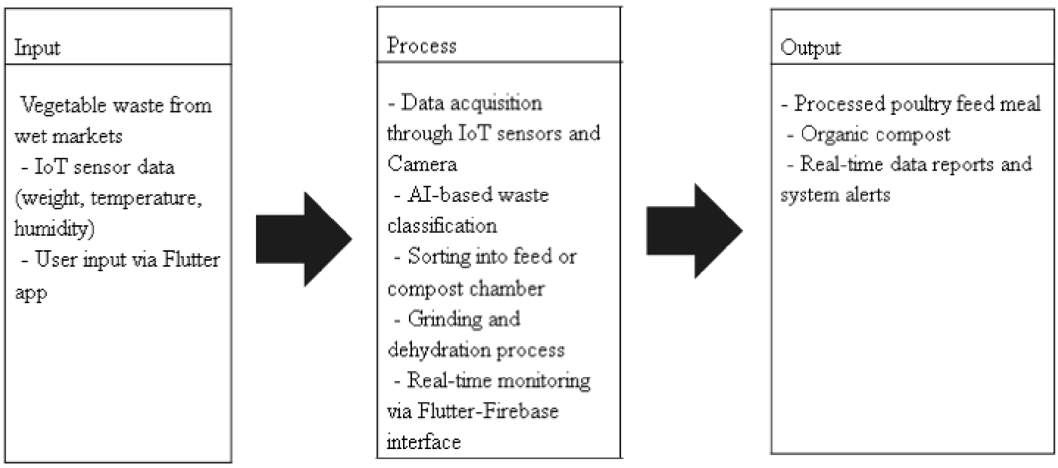
This study utilized a Developmental Research Design, focusing on the design, construction, and evaluation of the NutriCycle prototype. The research combines engineering design principles and software development methodologies to produce an IoT- and AI-powered machine capable of identifying, classifying, and processing vegetable waste into poultry feed or compost.

The study adopted the Agile Software Development Model, which allows iterative development, continuous testing, and stakeholder feedback throughout the project’s lifecycle. Each phase of development involved planning, designing, building, and evaluating components to ensure functional integration and system stability.

3.2 Conceptual Framework

The NutriCycle system is structured based on the Input–Process–Output (IPO) model, serving as the foundation of the research process.

Figure 3.1 IPO Model of NutriCycle System



Input

The system starts by collecting all the necessary inputs to begin the waste-to-value process. It takes in vegetable waste from wet markets, which serve as the main raw materials. IoT sensors also play an important role by collecting data on weight, temperature, and humidity to help regulate and monitor the process. On top of that, users can interact with the system through the Flutter mobile app, where they can adjust settings, check status updates, and input configurations when needed. All these inputs work together to make sure the system runs accurately and efficiently.

Process

The process involves several automated stages that turn vegetable waste into something useful. It begins with data gathering through IoT sensors and a built-in camera that collect real-time information about the waste and its environment. Afterward, the system uses Machine learning to classify the waste and determine whether it should be processed into poultry feed or compost. Once identified, the waste is automatically sorted into the correct chamber, then goes through grinding and dehydration to remove moisture and prepare it for final use. Throughout the process, the Flutter-Firebase interface allows real-time monitoring and control, so users can easily keep track of the system's activity and performance.

Output

At the end of the process, the system produces processed poultry feed meal and organic compost, both made from vegetable waste collected from wet markets. These outputs help promote sustainable agriculture by recycling waste into valuable products instead of letting it go to landfills. Along with these physical results, the system also generates real-time data reports and system alerts through the Flutter-Firebase platform, allowing users to monitor performance, check system status, and ensure that everything runs efficiently. This makes the operation not only effective but also environmentally friendly.

3.3 System Architecture

The system architecture of NutriCycle integrates IoT hardware, Machine learning image processing, and Firebase cloud services. It illustrates how each component interacts through both wired and wireless connections to automate the waste processing and data monitoring functions.

Use Case Diagram:

Actors:

1. **Wet Market Vendor / Supplier** – provides vegetable waste to the system.
2. **System Operator / Personnel** – monitors, manages, and controls system processes.
3. **Machine learning computer vision** – automatically identifies, classifies, and assesses vegetable waste.
4. **Weight Sensor System** – measures weight and sends data to the controller.
5. **Processing Unit (Dual-Chamber)** – handles sorting, grinding, dehydration, and conversion.
6. **Database / Cloud Storage (Firebase)** – stores collected data, analysis results, and notifications.
7. **Mobile / Web Interface (Flutter App)** – displays results, status, and notifications to the user.

Use case:

1. **Collect and Identify Waste** - Collects and detects green leafy vegetable waste using Machine learning and sensors.
2. **Sort Waste** - Classifies waste for feed or compost using Machine learning based quality checks.
3. **Grind waste** - Grinds waste into small, uniform particles for easier processing.

4. **Dehydrate Waste** - Removes excess moisture to extend shelf life and preserve nutrients.
5. **Analyze Nutrition** - Provides accurate nutritional data for processed feed.
6. **Produce Final Product** - Converts processed waste into feed meal or organic fertilizer.
7. **Monitor and Notify** - Displays real-time system status and sends process notifications.

3.4 Requirements Documentation

The project follows the Developmental Research Method, emphasizing prototype creation, system integration, and evaluation. It combines both hardware and software design to achieve the study's objectives.

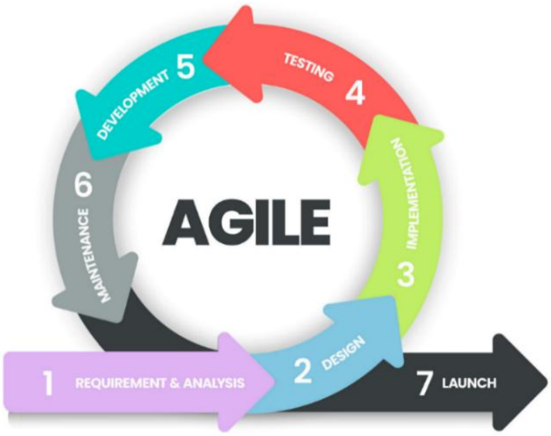
Vegetable waste samples were collected from local wet markets within Caloocan City, including common leafy vegetables such as cabbage, malunggay, and carrot trimmings. Data were gathered during prototype testing to analyze classification accuracy, dehydration efficiency, and processing time.

Collected data were analyzed quantitatively using Firebase logs and sensor data (temperature, humidity, weight, and classification accuracy). Performance metrics were evaluated to determine system reliability and efficiency.

All procedures followed local sanitation and environmental guidelines. Waste materials were handled safely, with no live animals involved. All data collected were used strictly for academic and research purposes.

Design of Software, Systems, Product, and/or Processes

- **Software Methodology**



The **Agile methodology**, an iterative and flexible approach to project development, emphasizes collaboration, adaptability, and continuous improvement through short development cycles called sprints. This makes it well-suited for the NutriCycle project, which integrates IoT hardware, software, and cloud systems. Since NutriCycle involves testing, refining, and enhancing various components—such as the load cell, LCD display, and Firestore integration—Agile allows the team to quickly respond to changes, gather feedback, and improve functionality after each iteration. This ensures the system evolves efficiently and remains aligned with user needs and real-world performance.

3.5 System Design and Development

The system development process followed the Agile methodology, with each iteration focusing on incremental progress, feedback, and testing.

1. **Planning Phase** – Defined project objectives, system scope, and technical specifications. Identified hardware (Raspberry Pi 4, Esp32s3 with cam module, Grinder, etc.) and software (Flutter, Firebase, Python).

User stories

1. **User Authentication & Access**

As a system operator, I want to:

- Log in securely using my account credentials so that I can access NutriCycle's control dashboard safely.
- Stay logged in during operation so that I can continuously monitor the system without frequent re-login.
- Log out anytime so that I can protect the system from unauthorized use.

2. **Waste Collection & Identification**

As a system operator, I want to:

- Collect green leafy vegetable waste and scan it using machine learning computer vision so that the system can identify waste type and freshness accurately.
- Automatically measure the weight of each vegetable waste using load cell sensors so that I can verify the amount of waste being processed.
- View classification and weight results in real time so that I can confirm the waste data before processing.

3. **Machine learning-Based Sorting and Classification**

As a system operator, I want to:

- Allow the machine learning computer vision to assess vegetable quality and freshness so that I can determine whether the waste is suitable for animal feed or compost.
- Automatically direct the waste to the proper chamber based on classification so that I can ensure the correct processing path.

- Manually override machine learning sorting decisions when necessary so that I can adjust in case of misclassification

4. **Dehydration and Moisture Control**

As a system operator, I want to:

- Start the dehydration process to remove excess moisture from the ground waste so that the product lasts longer and retains nutrients.
- Monitor the dehydration temperature and duration so that I can prevent overheating or nutrient loss.
- Automatically stop dehydration once the target dryness is achieved so that energy use is optimized.

5. **Nutritional Analysis and Reporting**

As a system operator, I want to:

- Analyze the nutritional content of the processed feed using chemical analysis data so that I can ensure accurate nutrient composition.
- View and store the nutritional report in the database so that I can track feed quality.
- Export or print nutritional reports for documentation or research purposes.

7. **Product Output and Quality Control**

As a system operator, I want to:

- Produce either animal feed or compost based on the machine learning classification so that waste is converted into usable products.

- Check and verify final product quality before packaging so that only approved outputs are distributed.
- Record each finished batch in the system for traceability and consistency tracking.

8. **Weight Sensor Monitoring (Load Cell)**

As a system operator, I want to:

- Monitor the real-time weight of waste materials in each chamber so that I can ensure proper input and balanced processing.
- Receive alerts if the system detects overloading or unbalanced weight so that I can prevent mechanical issues.
- Maintain accurate weight ratios throughout processing so that product quality remains consistent.

9. **Cloud Storage & Data Management (Firebase)**

As a system operator, I want to:

- Access stored data on waste input, processing logs, and output history so that I can analyze system performance.
- Retrieve previous records through Firebase so that I can review trends and results.
- Automatically back up all collected data to the cloud so that no information is lost

.

10. **Real-Time Monitoring & Notifications (Flutter App)**

As a system operator, I want to:

- Monitor system operations (sorting, grinding, dehydration) from my mobile device so that I can supervise processes remotely.
- Receive real-time alerts for process completion, system errors, or maintenance schedules so that I can respond quickly.
- View overall system performance and operation logs conveniently through the mobile app.

11. **Mobile Platform Compatibility**

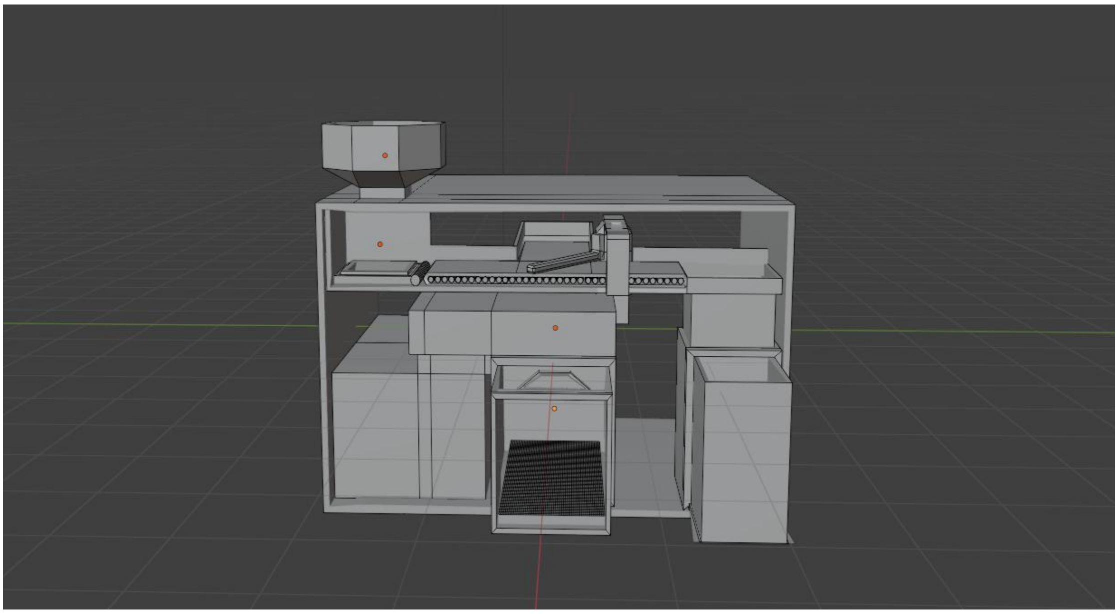
As a system operator, I want to:

- Access the NutriCycle dashboard on both Android and iOS devices so that I can manage the system anytime and anywhere.
- Experience smooth app performance and responsive controls so that I can operate the system efficiently in real time.

2. **Design Phase** – The Design Phase of the NutriCycle system focuses on establishing a clear blueprint that defines how the system components interact, communicate, and store data. During this stage, several diagrams and models were developed to visualize the system's overall structure and operational flow, ensuring that both the software and hardware components work cohesively.

NutriCycle is an Machine learning and IoT-powered waste processing system designed to convert vegetable waste into animal feed or compost. It integrates load cell sensors, computer vision -based classification, and a dual-chamber processing mechanism controlled through a Flutter-based mobile application connected to Firebase for real-time data storage and monitoring. The system emphasizes sustainability by optimizing waste management and producing valuable outputs while maintaining data transparency and operational accuracy.

- **Machine Initial Prototype.**



3. **Prototyping Phase** – The Prototyping Phase focused on constructing the initial working model of the NutriCycle system by integrating key hardware components, including the camera module, load cell sensor, and ESP32 microcontroller, with Firebase connectivity. The ESP32 served as the main controller, enabling real-time data transmission between sensors and the cloud. The prototype was designed to validate the system's core functions, such as vegetable waste identification using machine learning-

powered image capture, accurate weight measurement through the load cell, and stable data communication via Wi-Fi. This phase established the technical feasibility of the system and provided a functional foundation for further software and machine learning development.

4. **Development Phase** – The Development Phase involved implementing the intelligent and interactive features of NutriCycle, transforming the prototype into a fully functional An IoT system. This stage focused on developing the machine learning computer vision-based classification model for analyzing vegetable freshness and quality, enabling automatic sorting for feed or compost processing. Real-time sensor data handling was enhanced through Firebase integration, while a user-friendly mobile dashboard was built using Flutter to display live sensor readings, process status, and notifications. Overall, this phase ensured that both hardware and software components worked cohesively, achieving efficient monitoring, accurate classification, and reliable system control.

- **Logo design**

Dark Green: #0B440E Light Yellow/Cream: #F6F0B3

The NutriCycle logo represents the project's mission of transforming food waste from wet markets into valuable animal feed through innovation and sustainability. The circular design illustrates the continuous cycle of waste conversion, emphasizing the system's eco-friendly process.

Leaf Icon – Symbolizes the vegetables collected from wet markets, highlighting the project's agricultural and organic roots.

Recycle Symbol – Represents the integration of IoT and automation technology in processing and converting waste efficiently.

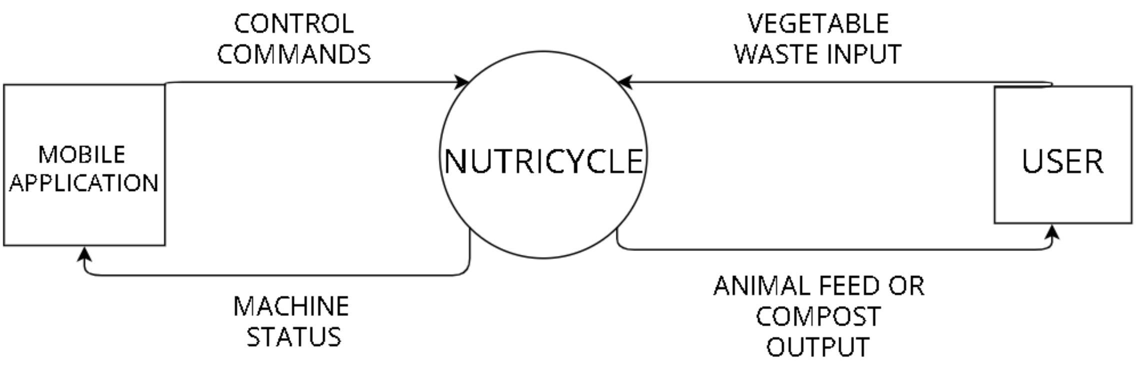
Circular Arrows – Depict the recycling process, showing the transformation of discarded food into nutritious poultry feed and compost.

Green and Yellow Colors – Green signifies sustainability and environmental care, while yellow symbolizes innovation, energy, and productivity.

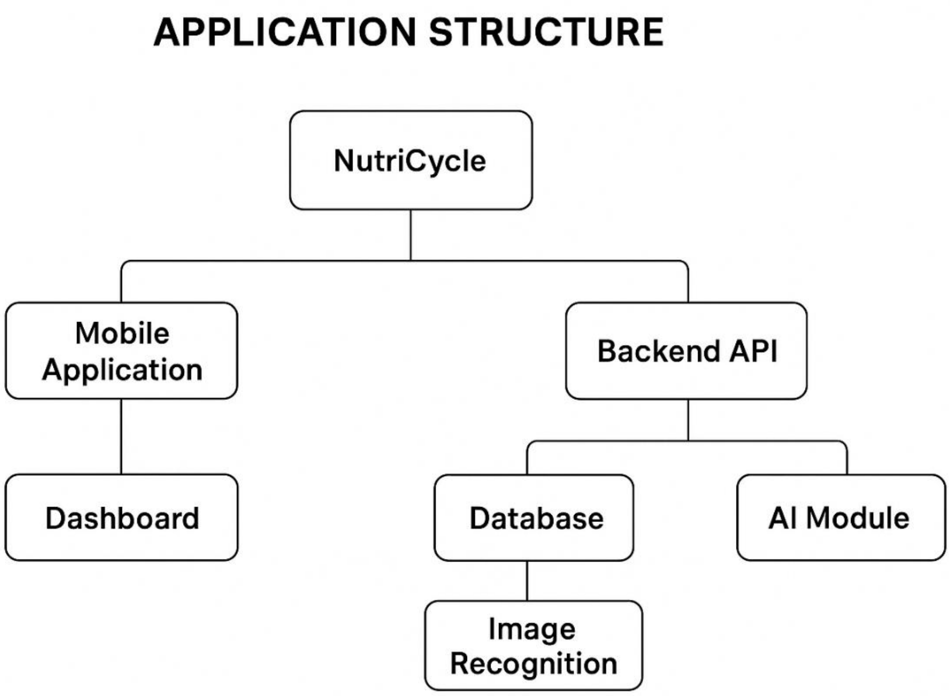
Typography (NutriCycle) – The clean and bold font reflects modernization and technological advancement in sustainable waste management.

Overall, the logo embodies NutriCycle's advocacy for sustainability by turning wet market food waste into resources that support agriculture and reduce environmental impact.

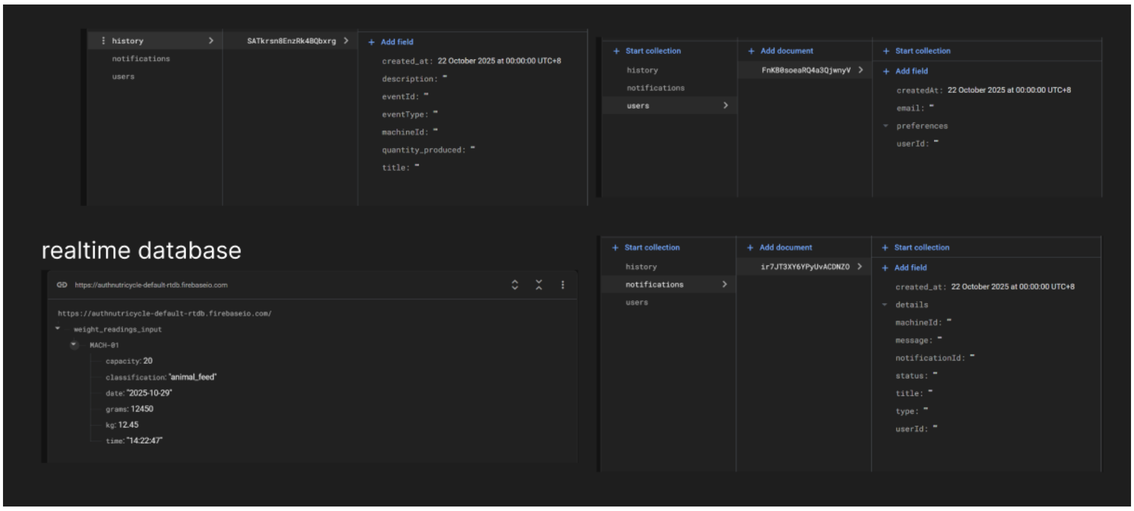
- **System Context Diagram**



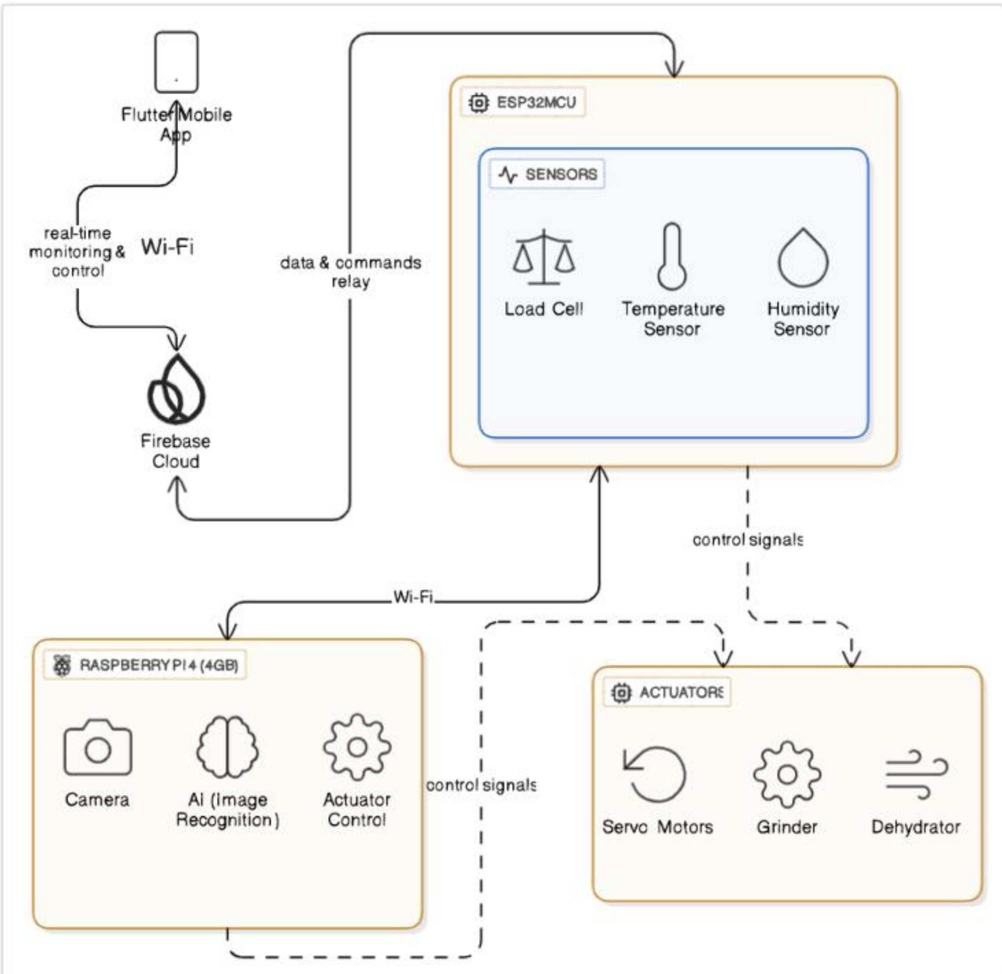
- **Application structure diagram**



- Database Design



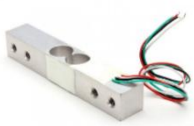
Network Diagram



5. **Testing Phase** –Conducted system functionality and communication tests.
6. **Deployment Phase** – Deployed in a simulated wet market environment.
7. **Review Phase** – Collected expert feedback to refine design and improve reliability.

3.6 Development and Testing

Table 3.1 Hardware Components

Component	Name/ Description Model	Description / Function	Price (original price and/or discounted price) in peso	Availability in the Philippines
	Raspberry Pi 4 (4GB)	Main controller for machine learning image recognition and cloud communication	5,990.00	Online Shop
	ESP32-Cam	Microcontroller managing sensors and actuators	350.00	Online Shop
	Straight bar load cell weight sensor (20KG)	Measures vegetable waste weight	149.00	Online Shop

	Clone Servo MG995 12KG 360 degree	Operate waste sorting mechanism	250.00	Online Shop
	Grinder/Agitator	Breaks down waste into smaller particles		
	Dehydrator	Removes moisture for feed processing		
	Power Supply (5V / 24V)	Provides power to system modules		
	Dual-Chamber Container	Separates feed and compost outputs		

3.2 Software Components

Software Image	Software Name	Purpose in the project	Version Used
	Python	Machine learning-based image recognition and data processing	Version 3.13.9

	Flutter	Mobile application development for real-time monitoring	Version 3.35
Firebase Realtime Database	Firebase Realtime Database	Stores sensor data, logs, and image results	16.0.3
Firebase Authentication	Firebase Authentication	Provides secure user login and management	6.1.1
Firebase Cloud Messaging	Firebase Cloud Messaging	Sends system alerts and notifications	12.0.0
Cloud Storage for Firebase	Firebase Cloud Storage	Stores captured images for analysis	13.0.3

Table 3.2. List of Software Components of the NutriCycle System.

3.7 Testing Procedures

The Testing Procedures were conducted to evaluate the performance, functionality, and reliability of the NutriCycle system. Each testing method was designed to assess specific aspects of both the hardware and software components, ensuring that the system operates accurately and efficiently.

1.**Unit Testing** - This testing focused on verifying the functionality of individual components such as the camera module, load cell sensor, ESP32 microcontroller, and mobile interface. Each module was tested independently to ensure that it performed its intended function—capturing images, measuring weight, processing data, and displaying information—without hardware or software errors.

2. **Integration Testing** - After confirming that each unit worked properly, integration testing was performed to ensure seamless communication between the hardware components and the Firebase database. This process validated that data collected from sensors was successfully transmitted to the cloud and synchronized with the Flutter-based mobile dashboard in real time.

3.**Functional Testing** - Functional testing was conducted to determine whether the system performed its main operations correctly. This included validating the machine learning -based waste classification, automatic sorting process, and conversion of vegetable waste into either animal feed or compost. Each process was observed to ensure that expected outputs were achieved based on specific input data.

4. **Performance Testing** - This testing measured the overall efficiency and stability of the NutriCycle system. Factors such as response time, data transmission rate, and system stability

were evaluated under continuous operation. The results were used to optimize performance, particularly during simultaneous sensor reading, image processing, and data synchronization.

5. **User Acceptance Testing (UAT) -** The final testing phase involved obtaining feedback from selected experts and trained operators who interacted with the system under controlled conditions. They assessed the usability, accuracy, and ease of operation of the NutriCycle interface and functions. Feedback from this testing helped identify minor adjustments for improving user experience and operational reliability.

Test Cases of Nutricycle:

1. Weight Sensor Functionality Test

- **Description:** Tests the accuracy of the load cell sensor in measuring vegetable waste.
- **Preconditions:** The load cell is calibrated and connected to the ESP32 and Firebase.
- **Test Steps:**
    1. Place a known weight sample on the sensor.
    2. Observe the weight reading on the mobile application.
    3. Compare displayed value with actual weight.

2. Camera and Machine learning Classification Test

- **Description:** Verifies that the camera and machine learning model can correctly identify and classify vegetable types and freshness.

- **Preconditions:** The computer vision is trained, and the camera module is properly connected to the ESP32.
- **Test Steps:**
  1. Capture images of various green leafy vegetables.
  2. Let the machine learning system analyzes each image.
  3. Check if the classification matches the actual vegetable type and condition.

3. ESP32–Firebase Communication Test

- **Description:** Ensures reliable real-time data transmission between the ESP32 and Firebase.
- **Preconditions:** Wi-Fi is connected, and Firebase project credentials are properly configured in the ESP32.
- **Test Steps:**
  1. Collect sensor data from the ESP32.
  2. Transmit data to Firebase.
  3. Check Firebase console for real-time data updates.

4. Flutter–Firebase Synchronization Test

- **Description:** Confirms that the mobile dashboard receives and displays live data from Firebase accurately.
- **Preconditions:** The Flutter app is connected to the Firebase database and the user is logged in.
- **Test Steps:**

1. Launch the mobile app and log in.
2. Monitor live sensor readings during operation.
3. Verify if displayed data matches Firebase records.

5. Machine learning-Based Waste Classification Test

- **Description:** Validates the computer vision system's ability to determine whether vegetable waste is suitable for feed or compost.
- **Preconditions:** The machine learning computer vision is deployed and linked with the camera input module.
- **Test Steps:**
  1. Input vegetable waste samples into the classification system.
  2. Let the computer vision analyze and assign classification results.
  3. Check if classification aligns with manual evaluation.

6. Grinding Mechanism Test

- **Description:** Tests if the grinding mechanism activates and processes the waste properly after classification.
- **Preconditions:** System is classified to feed mode and grinding motor is functional.
- **TestSteps:**
  1. Start grinding sequence from the control interface.
  2. Observe grinding operation and consistency of output.
  3. Ensure material is uniformly processed.

7. Dehydration Process Test

- **Description:** Evaluates the dehydration system's ability to remove excess moisture efficiently.
- **Preconditions:** Ground vegetable waste is loaded into the dehydration chamber.
- **Test Steps:**
    1. Initiate dehydration through the mobile app.
    2. Allow process to complete under controlled heat and time.
    3. Check moisture level and output texture.

8. Real-Time Mobile Monitoring Test

- **Description:** Checks if the mobile application displays live data updates during operation.
- **Preconditions:** System is active and all sensors are transmitting data to Firebase.
- **Test Steps:**
    1. Open the mobile dashboard.
    2. Observe real-time weight and classification updates.
    3. Confirm that no delay or data loss occurs.

9. System Response Time Test

- **Description:** Measures the delay between sensor data generation and display on the mobile dashboard.
- **Preconditions:** Internet connection is stable, and sensors are actively transmitting data.

- **Test Steps:**
    1. Trigger a sensor reading event.
    2. Measure the time between the sensor input and app display.
    3. Record average response time.

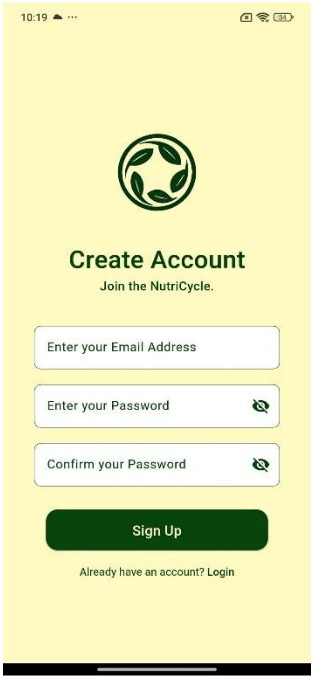
10. Notification and Alert System Test

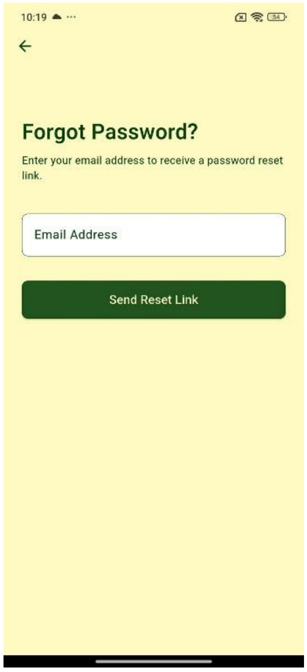
- **Description:** Tests the system's ability to send alerts for completion, errors, or system updates.
- **Preconditions:** Notification feature is enabled and mobile app is connected to Firebase.
- **Test Steps:**
    1. Simulate process completion or error event.
    2. Wait for notification prompt on the mobile app.
    3. Verify accuracy and timeliness of alerts.

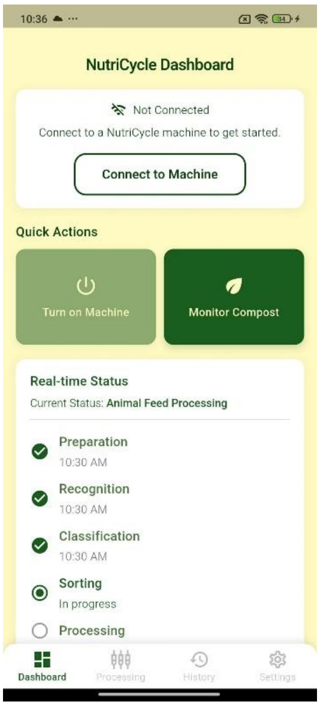
11. User Usability Test

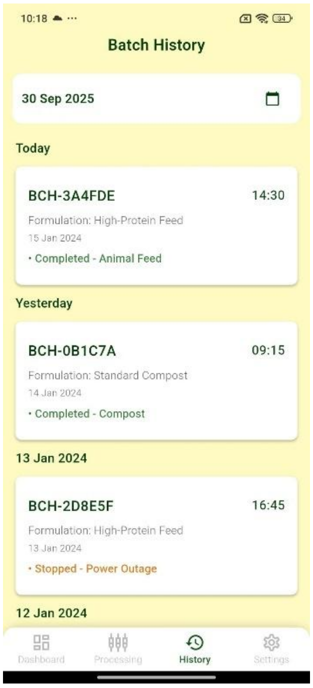
- **Description:** Evaluates the ease of use and clarity of the NutriCycle interface for operators.
- **Preconditions:** System is fully operational, and users are familiarized with its basic functions.
- **Test Steps:**
    1. Allow trained users to operate the system for a full processing cycle.
    2. Observe how they interact with the interface and monitor data.
    3. Collect feedback on usability and clarity of controls.

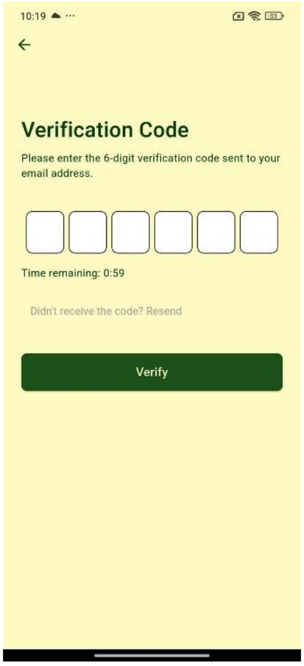

10:19
Welcome to NutriCycle
Log in to manage cabbage waste
Email Address
Password
Forgot password
Login
Don't have an account? Sign up

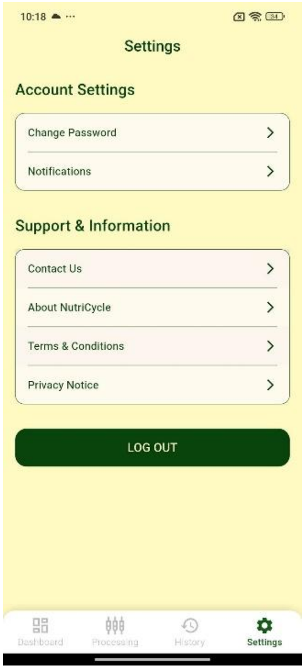

10:19
Create Account
Join the NutriCycle.
Enter your Email Address
Enter your Password
Confirm your Password
Sign Up
Already have an account? Login


10:19
Forgot Password?
Enter your email address to receive a password reset link.
Email Address
Send Reset Link


10:36
NutriCycle Dashboard
Not Connected
Connect to a NutriCycle machine to get started.
Connect to Machine
Quick Actions
Turn on Machine
Monitor Compost
Real-time Status
Current Status: Animal Feed Processing
Preparation
10:30 AM
Recognition
10:30 AM
Classification
10:30 AM
Sorting
In progress
Processing
Dashboard
Processing
History
Settings


10:18
Batch History
30 Sep 2025
Today
BCH-3A4FDE
14:30
Formulation: High-Protein Feed
15 Jan 2024
• Completed - Animal Feed
Yesterday
BCH-0B1C7A
09:15
Formulation: Standard Compost
14 Jan 2024
• Completed - Compost
13 Jan 2024
BCH-2D8E5F
16:45
Formulation: High-Protein Feed
13 Jan 2024
• Stopped - Power Outage
12 Jan 2024
Dashboard
Processing
History
Settings


10:19
Verification Code
Please enter the 6-digit verification code sent to your email address.
Time remaining: 0:59
Didn't receive the code? Resend
Verify


10:18
Settings
Account Settings
Change Password
Notifications
Support & Information
Contact Us
About NutriCycle
Terms & Conditions
Privacy Notice
LOG OUT
Dashboard
Processing
History
Settings

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