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NATURE ENVIRONMENT AND POLLUTION TECHNOLOGY

Article In Press

PEER-REVIEWED PREPUBLISHED MANUSCRIPT

This is a peer-reviewed prepublished version of the paper to be published in **Vol. 26, No. 1, March 2027.**

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Trivedi, C., Upadhyay, A., Shukla, A., Singh, S. and Yashasvi, V., 2027. Odor-Free Rapid Composting System for Household Organic Waste Using Smart Monitoring Technologies. Nature Environment and Pollution Technology, 26(1), B4454.

https://doi.org/10.46488/NEPT.2027.v26i01.B4454

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**PUBLICATION STATUS**

| PEER REVIEW | ONLINE VERSION | FINAL ISSUE |
|---|---|---|
| **Completed** | **Prepublished** | **March 2027** |

*Original Research*

# Odor-Free Rapid Composting System for Household Organic Waste Using Smart Monitoring Technologies

**Chetan Trivedi †, Arun Upadhyay, Ankita Shukla, Sarita Singh and Vaishnavi Yashasvi**

Amity Institute of Advanced Legal Studies, Amity University, Noida, India
† Corresponding author: Dr. Chetan Trivedi; chetantrivediupkc@gmail.com

**Abstract;**

The rate of waste generation is also increasing exponentially as the volume of waste in landfills, greenhouse gas (GHG) emissions, and public health consequences grow in urban areas. Because of poor segregation, monitoring, and inefficient breakdown in conventional waste disposal systems, the management of biodegradable waste is less effective than that of other waste types. The objective of this study is to propose an intelligent biodegradable waste management framework integrating a conceptual AI-assisted waste segregation module with IoT-based environmental monitoring, rapid composting, and odor-control mechanisms for sustainable household organic waste management. The proposed framework incorporates a conceptual AI-assisted waste segregation module, while the present prototype experimentally evaluates IoT-enabled environmental monitoring, controlled aeration, odor-control mechanisms, and composting performance.

The framework incorporates sensor-based monitoring of the composting process to continuously assess decomposition efficiency and optimize environmental conditions throughout composting. Additionally, the proposed model generates two valuable products: solid compost and liquid organic fertilizer, contributing to sustainable waste management and resource recovery. The prototype was analyzed and compared with the traditional composting and other smart systems using the empirical method. The study focused primarily on issues such as reducing food waste, composting time, odor control, and the system's implementation feasibility in urban households with limited space.

The findings indicate that the proposed intelligent composting framework reduced composting duration from 45 days to 15 days (approximately 66%) while achieving an observed waste reduction efficiency of 89% under controlled experimental conditions compared with the conventional composting system. The prototype demonstrated improved odor control, enhanced compost maturity, and greater user acceptance through IoT-enabled environmental monitoring and controlled composting conditions. The AI-assisted waste segregation module is presented as a conceptual component of the framework and remains a subject for future implementation and validation.

**Keywords:** Smart Composting, Biodegradable Waste Management, Household Organic Waste, Rapid Composting, Sustainable Waste Management, AI-Assisted Waste Segregation, IoT Monitoring, Circular Economy.

## 1. INTRODUCTION

Rapid urbanization, population growth, and changing consumption patterns have significantly increased household solid waste generation worldwide. A major portion of this waste consists of biodegradable organic materials such as food residues, vegetable peels, fruit waste, paper products, and garden waste. Improper disposal of such biodegradable waste contributes to landfill overflow, methane emissions, environmental pollution, unpleasant odors, and public health concerns. Previous studies have further highlighted that the accumulation of domestic organic waste in urban areas contributes to unpleasant odors, disease proliferation, and toxic leachate formation, thereby negatively affecting environmental quality and public health. (Darshani et al., 2023). Existing studies have further highlighted that improper food waste disposal practices significantly contribute to methane emissions from landfills and environmental degradation, thereby increasing the need for efficient household-level organic waste treatment technologies (Wu et al., 2024). In developing countries such as India, inadequate waste segregation practices and the absence of efficient household-level waste treatment mechanisms further aggravate municipal solid waste management challenges.

Traditional waste disposal methods, including open dumping and landfill accumulation, are increasingly becoming environmentally unsustainable due to their contribution to greenhouse gas emissions and soil contamination. Existing studies further indicate that the natural decomposition of municipal solid waste is often time-consuming and often generates unpleasant odors, thereby reducing the effectiveness of household organic waste recycling practices. Previous studies underscore the importance of more effective waste-recycling technologies to facilitate the decomposition of organic waste more quickly and enhance compost quality under controlled environmental conditions (Darshani et al., 2023). It has been believed that composting is an effective way to handle biodegradable waste; however, the composting process still poses many challenges. It tends to be time-consuming, generate odors, and often requires inadequate monitoring and maintenance. These techniques may not be feasible in urban settings where space and time are scarce. Due to these challenges, it is necessary to develop a smarter, more automated waste management system that enables composting at homes in an easier, faster, and more modern way. In response to these operational and environmental challenges, researchers and environmental technologists have increasingly explored technology-driven waste management approaches to improve composting efficiency, monitoring capabilities, and environmental sustainability.

This has led to the emergence of new opportunities for smarter, more environmentally friendly waste management systems, driven by advancements in Artificial Intelligence (AI), the Internet of Things (IoT), and sensor-based monitoring technologies. The technologies assist in more efficient waste collection, reduce environmental pollution, and continuously monitor and automate the composting process. It has also been found that implementing IoT in waste management can significantly improve waste management in urban residential areas (Swarnakantha et al., 2022). Building on these technological advancements, intelligent monitoring and automation systems are increasingly integrated into household composting systems to enhance operational performance and reduce environmental impacts.

AI-driven waste sorting, sensor-based compost tracking, odor management techniques, and automated decomposition processes can streamline the overall process and promote environmental sustainability. These smart systems continuously monitor conditions such as temperature, moisture and microbial activity to ensure the conditions are ideal for decomposition, thereby accelerating compost creation and increasing efficiency. Despite the growing importance of smart composting technologies, limited research has focused on integrating AI, IoT monitoring, rapid composting, and odor-control mechanisms within a unified household waste management framework. In the present study, the AI-assisted waste segregation component is presented as a conceptual extension of the proposed framework. The experimental validation focused primarily on IoT-enabled environmental monitoring, rapid composting, controlled aeration, and odor-control mechanisms.

The main aim of the present study is to propose an Intelligent AI and IoT-supported Biodegradable Waste Management Framework for Sustainable Urban Households. The proposed system will be designed to facilitate automated waste segregation, rapid biodegradation, odor abatement, and real-time environmental monitoring to extract organic fertilizer (liquid or organic) and compost (organic) from domestic waste containing organics. The objective of the study is to assess the efficiency of the proposed composting framework, its sustainability relative to current disposal methods, and its environmental impact.

In addition, the study employs an empirical approach, with the prototype-based assessment and user perception analysis conducted to assess the feasibility of the proposed smart waste management model for application in urban households. The research advances the field of sustainable environmental technologies by proposing a scalable, low-cost, and environmentally friendly option for treating domestic organic waste and promoting circular sustainability.

### 1.1 Research Objective

The study is based on the following objectives:

1. To explore environmental issues related to the generation and disposal of biodegradable wastes in households.
2. Design and develop an intelligent IoT-enabled composting framework incorporating a conceptual AI-assisted waste segregation module.
3. To assess the effectiveness of the proposed smart composting system when compared to the conventional composting system.
4. To study the importance of sensor-based monitoring for enhancing decomposition efficiency and reducing odour emission.
5. To measure the perception and adaptability of users to a smart biodegradable waste management system.
6. Explain the environmental sustainability potential of intelligent composting systems in the reduction of landfill waste and pollution.

### 1.2 Research Questions

The study seeks to answer the following research questions:

1. What are the major challenges associated with conventional household biodegradable waste management systems?
2. How can AI and IoT technologies improve the efficiency of biodegradable waste processing?
3. Does the proposed intelligent composting framework reduce composting time and odor generation?
4. What is the effectiveness of real-time monitoring in optimizing composting conditions?
5. How does the proposed system contribute to environmental sustainability and waste reduction?
6. What is the level of public acceptance and adaptability toward smart household waste management technologies?

### 1.3 Hypotheses of the Study

H 0 : The proposed AI and IoT-enabled biodegradable waste management system does not significantly improve composting efficiency and environmental sustainability compared to conventional waste management methods. H 1 : The proposed AI and IoT-enabled biodegradable waste management system significantly improves composting efficiency and environmental sustainability compared to conventional waste management methods.

## 2. LITERATURE REVIEW

### 2.1 Household biodegradable waste management

Biodegradable waste accounts for a substantial share of municipal solid waste globally. Several studies have emphasized that improper disposal of organic waste leads to environmental degradation, greenhouse gas emissions, and increasing pressure on landfill systems. Traditional waste management practices in developing countries continue to rely heavily on landfilling and open dumping, resulting in severe environmental and public health concerns. Researchers have identified composting as a sustainable solution for organic waste treatment because it converts waste into nutrient-rich organic fertilizer. However, conventional composting systems are often associated with operational limitations, such as slow degradation, unpleasant odors, and a lack of process monitoring. Due to operational limitations of conventional composting methods, recent environmental research has increasingly focused on developing smart, automated waste management technologies.

### 2.2 Smart Waste Management Systems

Over the last couple of years, smart environmental technologies have played a significant part in altering the waste management landscape. Waste management is enhanced by IoT systems that connect devices, leverage wireless technology, and automate processes to streamline waste collection, segregation, and processing. Researchers have also found that implementing IoT and sensor-based automation technologies in composting facilities can help improve the practical and effective management of food waste. Parameters that must be controlled in real time during the composting process are temperature, gas emissions, and pH, with the aim of optimizing the process and increasing its stability (Turvani et al., 2023). There have been studies demonstrating that moisture, aeration, and temperature can be successfully regulated through sensor-controlled monitoring systems during composting, increasing decomposition efficiency and reducing operational inefficiencies. Sustainable urban waste management can also be facilitated by smart composting systems that offer real-time monitoring and predictive maintenance. Recent research has emphasized the shift towards data-driven “smart” composting technologies to improve organic waste management efficiency. There are promising applications for intelligent composting systems that combine artificial intelligence, the Internet of Things (IoT), and automated environmental monitoring, which have shown great potential to optimize composting processes and make them more sustainable for waste treatment (Liu et al., 2025). Previous studies have also highlighted the need to integrate sensors into composting systems to ensure continuous environmental monitoring and process verification. Existing research shows that sensor-based composting systems can accurately monitor environmental conditions and maintain the parameters needed for successful decomposition (Blau & Franko, 2020). Among the various emerging technologies applied to waste management systems, Artificial Intelligence has attracted considerable attention for improving waste segregation accuracy and automating processes.

### 2.3 Artificial Intelligence in Waste Segregation

Artificial Intelligence has proven to be a key technological enabler for waste classification and segregation. Waste materials have been classified using image recognition and machine learning algorithms powered by AI. It has also been noted that the accuracy of waste classification and the efficiency of sustainable waste management using a smart waste segregation system are improved by the IoT technology in previous research (Sowndharya et al., 2021). Previous studies have also investigated the use of machine learning models, such as linear regression, for forecasting compost maturity stages and optimizing the compost process through intelligent environmental analysis. (Turvani et al., 2023). Previous studies have shown that AI-based segregation systems can improve waste processing accuracy and reduce manual labor. Most current systems focus on industrial-scale waste treatment plants rather than domestic applications, creating a research gap for affordable, scalable domestic smart waste management systems. Although AI-assisted segregation improves waste classification efficiency, effective composting additionally requires environmental regulation and odor-control mechanisms to maintain sustainable decomposition conditions.

### 2.4 Odor Control and Rapid Composting Technologies

One of the key challenges of household composting is odor production, especially in urban residential settings. Various methods for reducing odor emissions during composting, such as biofilters, activated charcoal, microbial inoculants, and aeration techniques, have been studied. Moreover, improvements in breakdown time can be achieved through rapid composting techniques such as controlled temperatures, moisture optimization, and mechanical mixing. The importance of insufficient monitoring of environmental conditions on the quality of compost and decomposition efficiency in household organic waste management has been emphasized in previous studies. The use of a smart composting system with IoT has been shown to have significant potential for maintaining optimal temperature and moisture levels to support an efficient composting process. (Rais & Rokhmah, 2025). Previous studies have reported that conventional composting processes often require 2–3 months for complete decomposition, thereby discouraging effective household organic waste conversion practices. Recent research further indicates that IoT-based smart composting systems can significantly reduce composting duration while maintaining high-quality compost standards through automated environmental monitoring and process optimization (Rahman et al., 2024). Nevertheless, the integration of odor-control mechanisms with intelligent monitoring systems at the household level remains relatively underexplored. While previous studies have independently explored smart monitoring systems, AI-assisted segregation, and rapid composting technologies, their integrated application within household-level biodegradable waste management systems remains limited.

### 2.5 Research Gap

The review of existing literature indicates that substantial research has been conducted on composting technologies, smart waste monitoring systems, and AI-based waste segregation mechanisms. However, few studies have focused on integrating AI, IoT, rapid composting, odor control, and household-level sustainability within a unified biodegradable waste management framework. Previous monitoring approaches primarily focused on observational compost analysis and lacked robust environmental controls to maintain stable composting conditions. Recent smart composter prototypes integrating multi-sensor technologies and advanced environmental monitoring systems demonstrate promising potential for improving compost management efficiency and optimizing composting processes (Turvani et al., 2023). Furthermore, there exists a lack of empirical research evaluating the effectiveness of intelligent biodegradable waste systems in urban domestic environments. The present study seeks to bridge this gap by proposing and empirically evaluating an integrated smart biodegradable waste management framework for sustainable urban households.

## 3. METHODOLOGY

To evaluate the practical applicability and environmental effectiveness of the proposed intelligent composting framework, the present study adopted a mixed-method research approach integrating experimental analysis with empirical assessment. The study includes an experimental approach, which will be closely analyzed alongside the empirical evaluation of the adaptability and sustainability of the proposed smart composting system by users, as well as its operational efficiency. Data was gathered by both primary and secondary sources. Secondary data was gathered from research articles, Scopus journal articles, conference proceedings, environmental reports, and literature on composting technology, IoT (Internet of Things) monitoring, AI (Artificial Intelligence) waste management, and sustainable waste processing technology. **Prototype-based composting observations and empirical surveys of urban households using structured questionnaires were the primary methods of data collection.** Three composting units were designed in a controlled environment for experimental evaluation. Unit A is a conventional composting system with no technological intervention. Unit B is a composting system with a sensor monitoring system where the temperature and moisture are monitored in the composting process, and Unit C represented the proposed intelligent composting framework incorporating a conceptual AI-assisted waste segregation module together with IoT-enabled monitoring, controlled aeration, and odor-control mechanisms. The experimental evaluation focused on the environmental monitoring and composting performance of the prototype, while the AI-assisted segregation module is proposed for future implementation and validation. To ensure comparability across all experimental units, each composting unit received an identical quantity and composition of biodegradable waste under the same environmental conditions. The composting experiments were conducted simultaneously over a complete composting cycle, with all units exposed to similar ambient conditions. The experimental protocol was designed to ensure procedural consistency across all three composting units. Moisture monitoring, controlled aeration, and routine observations were carried out using the same operational procedure throughout the experimental period to facilitate a reliable comparative assessment of the conventional, smart-monitored, and proposed intelligent composting systems. Moisture levels and aeration schedules were monitored regularly to minimize external variations and ensure a fair comparison between the conventional, sensor-monitored, and proposed intelligent composting systems. The proposed framework comprises an Arduino UNO, a DHT11 temperature sensor, a soil moisture sensor, an MQ135 gas sensor, an ESP8266 WiFi module, a DC aeration fan, and an activated charcoal filtration system. These elements were combined to track temperature, moisture, gas emissions, odor intensity, and the efficiency of the decomposition process during composting. A total of 150 respondents, including apartment residents, students, and urban households familiar with household waste management practices, participated in the empirical survey. A structured questionnaire, using a Likert scale, was developed to assess awareness of biodegradable waste management, problems with conventional composting practices, adoption of smart composting technology, and perceptions of environmental sustainability. The collected data were analyzed using percentage analysis, mean score analysis, standard deviation, comparative analysis, and the chi-square statistical method. The study mainly tested composting time, waste reduction effectiveness, odor suppression, moisture control, compost quality, and user satisfaction to assess the effectiveness of the proposed intelligent waste management framework.

| **Parameter** | **Experimental condition** |
|---|---|
| Experimental units | Three (traditional, smart-monitored, proposed intelligent system) |
| Input waste quantity | 5 kg biodegradable waste per unit |
| Waste composition | Vegetable waste (50%), fruit waste (30%), cooked food waste (20%) |
| Composter capacity | 20 l |
| Experimental duration | 45 days |
| Number of replicates | Three independent trials |
| Moisture content | Maintained at 55–60% throughout composting |
| Aeration schedule | Controlled aeration every 12 hours |
| Ambient conditions | All units operated under identical environmental conditions |
| Waste mixture | Same biodegradable waste mixture used for all three units |
| Monitoring parameters | Temperature, moisture, odor intensity, waste reduction efficiency, compost maturity |

The experimental conditions were standardized across all composting units to ensure a fair comparison of system performance. Each unit received the same quantity and composition of biodegradable waste and was operated under identical environmental conditions. Moisture content and aeration schedules were maintained consistently throughout the experimental period, while temperature, odor intensity, and decomposition progress were continuously monitored using the designated sensor configuration.

### 3.1 Data collection and validation procedure

The data for the present study were gathered from composting observations on the prototype R.C., sensor-based environmental monitoring, and empirical assessment via questionnaires. Environmental sensors with IoT capabilities have been embedded in the composting chamber to monitor temperature and moisture. The efficiency of waste reduction was determined as the ratio of the weight of the initial biodegradable waste input to the weight of the compost output at the end of the process. Composting duration was determined as the number of days required to obtain visibly stabilized compost under the defined experimental conditions. Waste reduction efficiency was calculated based on the percentage reduction between the initial biodegradable waste input and the final stabilized compost output for each experimental unit. A qualitative rating scale was used for observational analysis and for the respondent's perception of odor intensity. Data for the empirical study were collected from urban households using a five-point Likert scale through structured interviews. Statistical analysis was conducted to validate the relationship between environmental awareness, smart monitoring technologies, and composting efficiency.

### 3.2 Hardware and Sensor Components

The proposed intelligent biodegradable waste management framework utilized several hardware and monitoring components including Arduino UNO, DHT11 temperature sensor, soil moisture sensor, MQ135 gas sensor, ESP8266 WiFi module, DC aeration fan, and activated charcoal filtration system. These components were integrated to facilitate environmental monitoring, odor detection, moisture regulation, and real-time composting analysis. Existing smart compost monitoring systems further indicate that real-time sensor-assisted alert mechanisms improve operational supervision and enable rapid identification of abnormal composting conditions through automated environmental monitoring frameworks (Rajamuneeswaran et al., 2025). Prior research has also demonstrated that the integration of automated airflow systems, mixing mechanisms, and electronically controlled composting units significantly improves aeration efficiency, temperature regulation, and uniform decomposition within smart composting frameworks (Cohn, 2006).

Prior to experimentation, the sensors were tested according to the manufacturer's operating specifications to ensure consistent measurements throughout the composting process. The DHT11 sensor was used for monitoring temperature, the soil moisture sensor for assessing moisture conditions, and the MQ135 sensor for qualitative monitoring of gaseous emissions associated with odor generation. Sensor readings were periodically verified during the experimental period to maintain data consistency.

Following the development of the proposed intelligent composting framework, experimental analysis was conducted to evaluate the operational efficiency, environmental performance, and adaptability of the system under controlled composting conditions.

## 4. System Architecture

### 4.1 System Architecture

The proposed intelligent biodegradable waste management framework is to identify an efficient, sustainable and technology-based solution to the problem of processing the household organic waste. The framework combines Artificial Intelligence (AI), the Internet of Things (IoT), environmental monitoring using sensors, fast compost-ing systems and odor-control technologies within a single waste management model. The main objective of the proposed system is to produce high quality nutrient-rich compost and liquid organic fertilizer from the biodegradable domestic waste and to reduce the use of landfills, generation of odors and environmental pollution.

The system design involves several interconnected components, such as waste input units, segregation units, sensor monitoring systems, composting chambers, aeration systems, odor control systems, data processing units, and output collection units. The waste input chamber receives household biodegradable waste, such as vegetable skins, fruit residues, food remnants, tea leaves, and garden waste. This AI-backed segregation system helps separate biodegradable and non-biodegradable waste, improving waste management efficiency and minimizing contamination during decomposition.

The IoT-based sensor network continuously collects critical environmental data, including temperature, moisture status, humidity, decomposition, and gas emissions. Data collected during the process is used to adjust the composting conditions to optimize the process and increase decomposition efficiency. The system also includes automatic aeration and mixing systems to ensure the correct amount of oxygen is provided and to increase microbial decomposition activity. Further, the activated charcoal filters and controlled ventilation features reduce the generation of odors during composting.

The proposed system is a dual-output system that transforms the processed biodegradable waste into solid compost and liquid organic fertilizer. The compost thus produced can be used for gardening and agricultural purposes, supporting sustainable circularity of waste and the conservation of the environment.

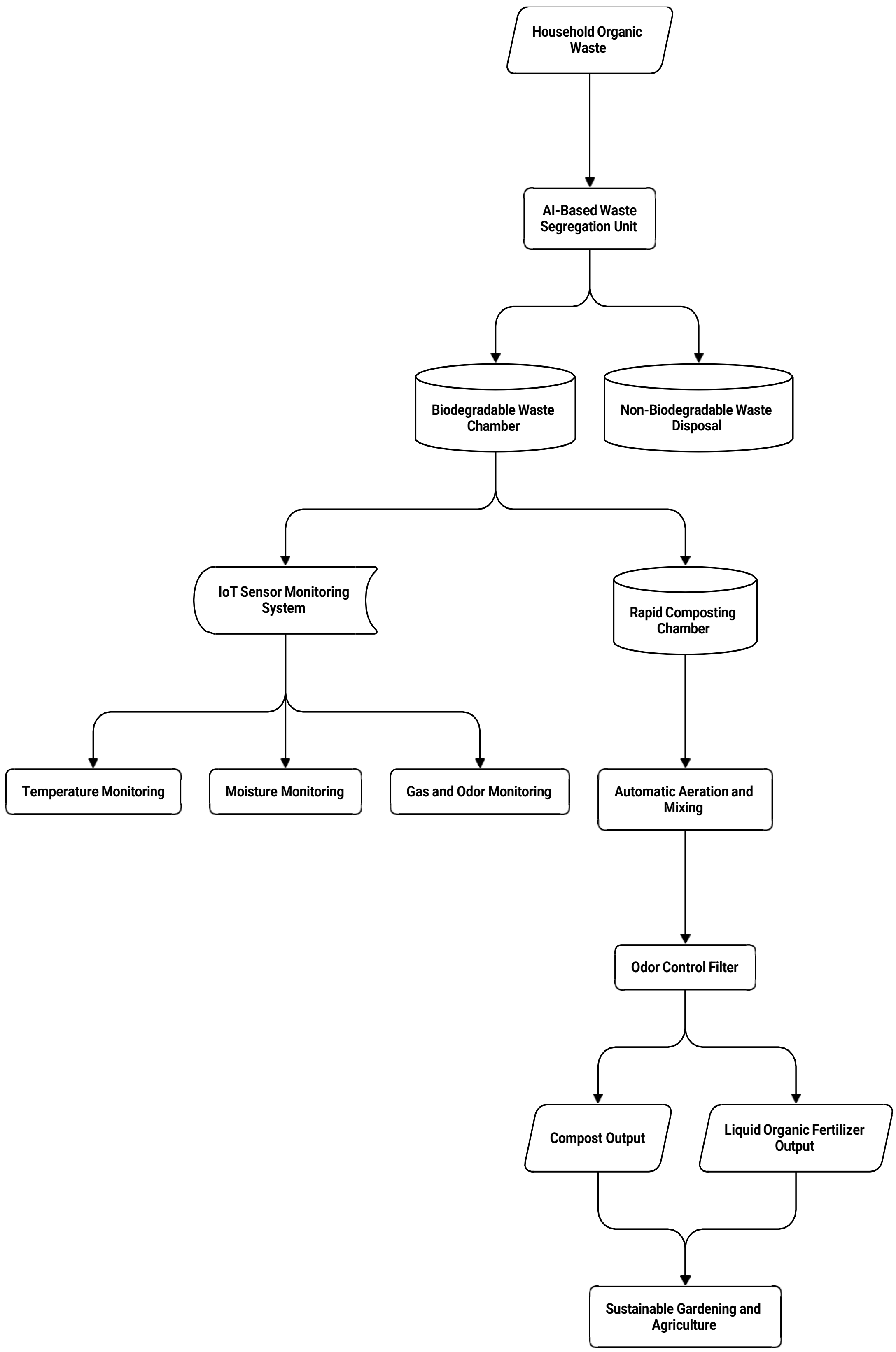


**Fig. 1: System Architecture of the Proposed Intelligent Biodegradable Waste Management Framework**

Figure 1 illustrates the architecture of the proposed AI and IoT-enabled intelligent biodegradable waste management framework, integrating waste segregation, sensor-based monitoring, rapid composting, odor control, and sustainable compost generation mechanisms. Among the illustrated components, the AI-assisted waste segregation module is presented as a conceptual component of the proposed framework, whereas the IoT monitoring, aeration, and odor-control mechanisms constitute the experimentally evaluated prototype.

### 4.2 AI-Based Waste Segregation Mechanism

The proposed framework conceptually incorporates an AI-assisted waste segregation module intended to distinguish biodegradable and non-biodegradable waste before composting. The present prototype primarily evaluated the IoT-enabled environmental monitoring system, controlled aeration, odor-control mechanism, and composting performance. The AI-assisted segregation module represents a proposed extension of the framework and will be implemented and experimentally validated in future studies.

### 4.3 IoT-Based Real-Time Monitoring System

The proposed framework integrates IoT-enabled sensors for continuous environmental monitoring during the composting process. Sensors are installed within the composting chamber to measure critical parameters,, including temperature, moisture content, humidity, and gas generation. Previous research has demonstrated that IoT-enabled compost monitoring systems significantly enhance environmental regulation within composting chambers by continuously monitoring temperature, moisture, and gas emissions, thereby improving compost quality and operational efficiency (Kameswari et al., 2025). Prior studies have emphasized that continuous real-time monitoring of environmental variables, including temperature, gas emissions, and pH levels, significantly improves composting efficiency and operational stability in smart composting systems (Turvani et al., 2023). The existing literature suggests that continuous processing of sensor measurements is crucial for verifying the continuity and efficiency of the composting process. Predefined threshold values for temperature, moisture, and gas emissions help identify abnormal composting conditions and improve process optimization. (Blau & Franko, 2020). The sensor data is transmitted to a centralized monitoring module for real-time analysis and process optimization. Prior studies have also highlighted that remote data processing and automated alert mechanisms significantly enhance compost monitoring efficiency by enabling real-time notifications regarding unfavorable environmental conditions within composting systems (Blau & Franko, 2020). The monitoring system helps maintain favorable environmental conditions necessary for microbial decomposition and rapid compost formation. Moisture regulation and temperature control significantly improve compost quality and reduce decomposition time. The IoT monitoring framework also enables users to track composting progress and system performance through digital interfaces or mobile applications.

### 4.4 Rapid Composting and Odor-Control Mechanism

The proposed smart composting framework leverages controlled aeration, optimized moisture management, enhanced microbial decomposition, and temperature regulation to accelerate the composting process. The rapid composting mechanism significantly reduces decomposition time compared to traditional composting systems. Previous automated composting models have demonstrated that controlled aeration systems, enclosed composting chambers, and automated mixing mechanisms significantly improve decomposition speed while minimizing odor generation during household organic waste treatment processes (RSI International, 2026).

An odor-control mechanism has also been designed into the system to help reduce odor generation during waste decomposition. The framework incorporates activated charcoal filtration, controlled ventilation, and natural bio-enzyme treatment methods to minimize odor emissions and enhance user adaptability, especially in urban residential settings. Existing smart composting models further highlight the effectiveness of chamber-based composting systems, including components such as hoppers, reactors, and curing trays, for improving compost stability and reducing exposure to odorous materials during waste processing. (Cohn, 2006) The odor-control system enhances the feasibility of household-level composting in apartments and compact urban spaces.

### 4.5 Workflow of the Proposed System

The operational workflow of the proposed biodegradable waste management framework involves the following stages:

1. Collection of household biodegradable waste.
2. AI-assisted segregation of biodegradable and non-biodegradable materials.
3. Introduction of segregated organic waste into the composting chamber.
4. Sensor-based monitoring of moisture, temperature, and decomposition conditions.
5. Controlled aeration and microbial decomposition process.
6. Odor reduction through filtration and ventilation mechanisms.
7. Conversion of waste into solid compost and liquid organic fertilizer.
8. Collection and utilization of compost products for sustainable applications.

The proposed workflow demonstrates how intelligent technologies are integrated with sustainable composting processes to achieve environmentally responsible household waste management..

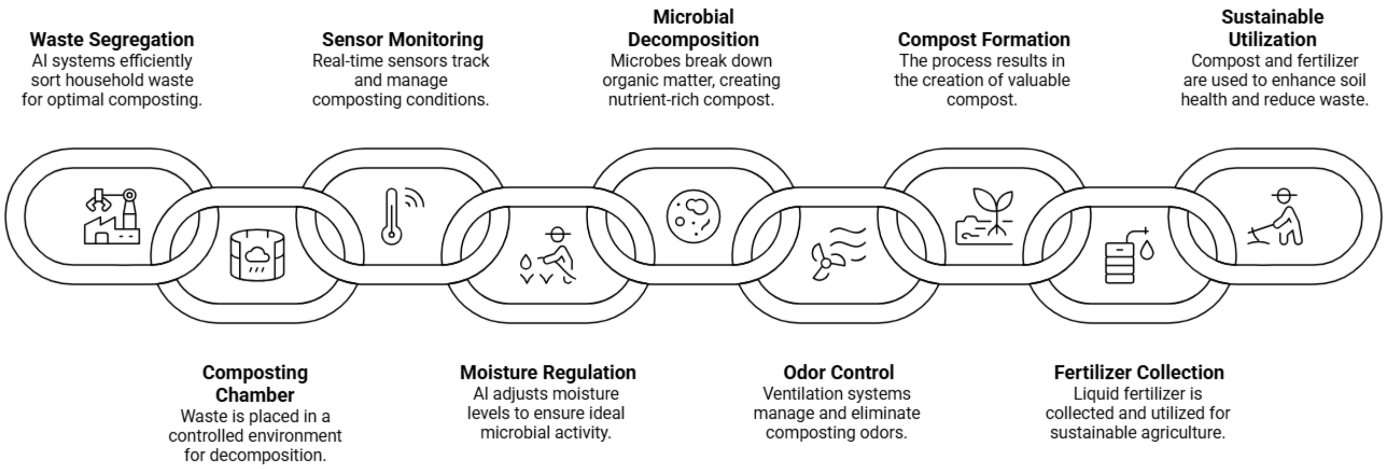


**Fig.2: Workflow of the Proposed Smart Composting System**

The operational workflow of the proposed smart biodegradable waste management system, from household waste collection to compost and liquid fertilizer generation, is shown in Figure 2. Following the development of the proposed intelligent composting framework, experimental analysis was conducted to evaluate the operational efficiency, environmental performance, and adaptability of the system under controlled composting conditions.

## 5. Experimental Analysis and Results

The efficiency and operational performance of the proposed biodegradable waste management system, which uses AI and IoT, were evaluated during the experimental analysis. The performance of the traditional composting process was compared with the intelligent composting process during the same experimental period. The main parameters analyzed were decomposition efficiency, composting time, odor reduction, moisture management, waste reduction % and adaptability to users.
The effectiveness of the proposed intelligent biodegradable waste management framework was investigated through experimental observations and comparative analyses of three composting units under controlled environmental conditions. The empirical data collected encompassed moisture control, odor-reduction efficiency, user adaptability, waste-reduction performance, and temperature variation.

**Table 1. Daily Temperature Monitoring During the Composting Process**

| Day | Traditional Composting (°C) | Smart Monitored Composting (°C) | Proposed Intelligent System (°C) |
|---|---|---|---|
| 1 | 28 | 30 | 31 |
| 3 | 30 | 34 | 36 |
| 5 | 32 | 38 | 41 |
| 7 | 33 | 40 | 44 |
| 10 | 34 | 42 | 46 |
| 15 | 35 | 43 | 48 |
| 20 | 34 | 41 | 46 |
| 25 | 33 | 39 | 43 |
| 30 | 31 | 36 | 39 |

The proposed intelligent composting system consistently attained temperatures approaching the lower thermophilic range (approximately 45–48°C). Although the maximum temperature remained below the upper thermophilic range commonly reported in large-scale composting systems, sustained exposure to temperatures above 45°C for several days promoted enhanced microbial activity, accelerated organic matter decomposition, and improved compost stabilization compared with the conventional composting system. These findings indicate that controlled temperature

regulation, together with moisture management and aeration, contributed to the shorter composting duration observed in the proposed intelligent framework.
In addition to temperature regulation, odor intensity and user adaptability were also comparatively analyzed to evaluate the environmental feasibility of the proposed smart composting system.

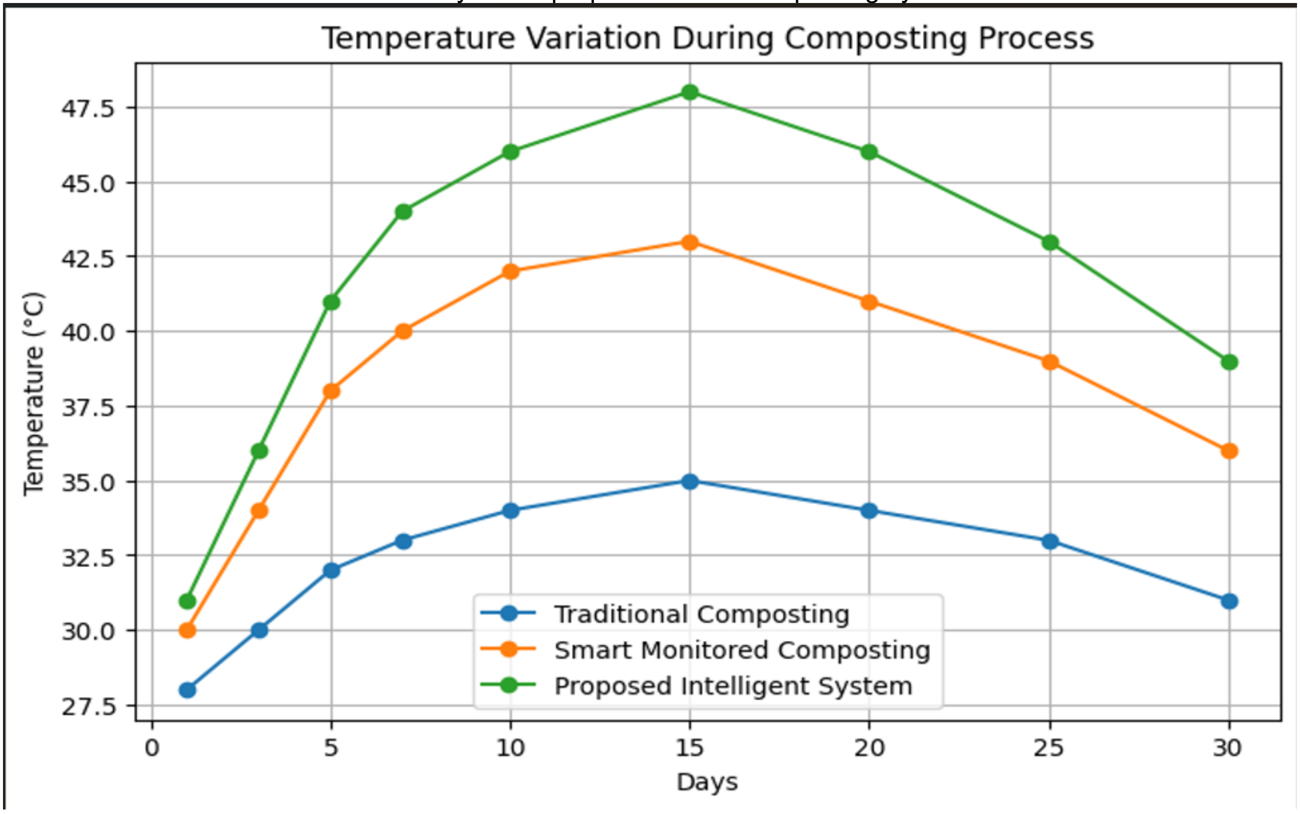


**Fig. 3: Temperature Variation During Composting Process**

The comparative temperature changes in traditional composting, smart-monitored composting, and the suggested intelligent composting system during the experimental period are shown in Figure 3.

**Table 2. Odor Intensity Comparison**

| **Parameter** | **Traditional Composting** | **Smart Monitored Composting** | **Proposed Intelligent System** |
|---|---|---|---|
| Initial Odor Level | High | Moderate | Low |
| Mid-Process Odor | High | Moderate | Very Low |
| Final Stage Odor | Moderate | Low | Negligible |
| User Comfort Level | Low | Moderate | High |

The use of activated charcoal filtration and controlled aeration mechanisms greatly reduced odor production during composting, thereby enhancing user adaptability in urban residential environments. In addition to odor reduction efficiency, a comparative operational performance analysis was conducted to assess composting duration, automation capability, and waste reduction efficiency across all experimental units.

**Table 3. Comparative Composting Performance**

| Parameters | Traditional Composting | Smart Monitored Composting | Proposed Intelligent System |
|---|---|---|---|
| Composting Duration | 45 Days | 25 Days | 15 Days |
| Waste Reduction Efficiency | 58% | 74% | 89% |
| Observed Compost Maturity | Moderate | Good | High |
| Monitoring Capability | Not Available | Available | Real-Time Monitoring |
| Automation Level | Manual | Semi-Automatic | Fully Automated |
| User Adaptability | Low | Moderate | High |

The intelligent biodegradable waste management system proposed in the article demonstrated high operating efficiency, rapid decomposition, and high compost quality, which are superior to those of the ordinary composting method. To further understand public awareness and acceptance of intelligent composting technologies, an empirical survey analysis was conducted among urban households. Observed compost maturity was evaluated qualitatively based on visual stabilization, texture, color, and odor characteristics. Laboratory physicochemical analyses (e.g., pH, EC, C/N ratio, organic carbon, NPK, or germination index) were beyond the scope of the present prototype evaluation.

**Table 3A. Waste Reduction Analysis**

| Composting System | Initial Waste (kg) | Final Compost (kg) | Waste Reduction (%) |
|---|---|---|---|
| Traditional Composting | 5.00 | 2.10 | 58 |
| Smart-Monitored Composting | 5.00 | 1.30 | 74 |
| Proposed Intelligent System | 5.00 | 0.55 | 89 |

Waste reduction efficiency was calculated as the percentage decrease between the initial biodegradable waste input and the final stabilized compost obtained at the end of the composting period. The proposed intelligent composting framework achieved the highest waste reduction efficiency owing to improved environmental regulation, controlled aeration, and continuous monitoring of composting conditions.

**Table 4. Awareness Regarding Household Waste Segregation**

| Response | Frequency | Percentage |
|---|---|---|
| Highly Aware | 52 | 34.7% |
| Aware | 61 | 40.7% |
| Neutral | 21 | 14.0% |
| Unaware | 16 | 10.6% |

The empirical results showed that most respondents knew about household waste segregation and sustainable waste management.

**Table 5. Acceptance of Smart Composting Technologies**

| Response | Frequency | Percentage |
|---|---|---|
| Strongly Agree | 63 | 42.0% |

| Response | Frequency | Percentage |
|---|---|---|
| Agree | 54 | 36.0% |
| Neutral | 18 | 12.0% |
| Disagree | 10 | 6.7% |
| Strongly Disagree | 5 | 3.3% |

The survey findings demonstrate strong public acceptance of AI and IoT-enabled smart composting technologies for sustainable household waste management. In addition to the public acceptance analysis, a statistical evaluation was conducted to assess user satisfaction and environmental perceptions toward smart composting technologies.

**Table 6. Mean Score Analysis**

| Variable | Mean Score | Standard Deviation |
|---|---|---|
| Odor Reduction Satisfaction | 4.32 | 0.74 |
| Ease of Use | 4.11 | 0.81 |
| Environmental Awareness | 4.45 | 0.69 |
| Acceptance of Smart Monitoring | 4.38 | 0.77 |
| Overall User Satisfaction | 4.41 | 0.71 |

The mean score analysis indicates a high level of user satisfaction and positive perception toward intelligent biodegradable waste management systems.

**Table 7. Cross-tabulation of Environmental Awareness and Smart Composting Adoption (N = 150)**

| Environmental Awareness | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Total |
|---|---|---|---|---|---|---|
| Highly Aware | 29 | 17 | 4 | 1 | 1 | 52 |
| Aware | 24 | 27 | 6 | 3 | 1 | 61 |
| Neutral | 7 | 8 | 3 | 2 | 1 | 21 |
| Unaware | 3 | 2 | 5 | 4 | 2 | 16 |
| **Total** | **63** | **54** | **18** | **10** | **5** | **150** |

The cross-tabulation indicates that respondents with higher environmental awareness exhibited greater acceptance of smart composting technologies, whereas respondents with lower awareness were comparatively less likely to support the adoption of smart composting systems.

**Table 8. Chi-Square Test of Association**

| Variables Tested | Categories | Sample Size (N) | $\chi^2$ | df | p-value | Decision |
|---|---|---|---|---|---|---|
| Environmental Awareness × Smart Composting Adoption | 4 × 5 | 150 | 30.96 | 12 | 0.002 | Significant |

A Chi-square test of independence was conducted to examine the association between environmental awareness and the adoption of smart composting technologies. The analysis revealed a statistically significant association between the two variables ($\chi^2 = 30.96$, df = 12, $p = 0.002$), indicating that respondents with higher environmental awareness demonstrated greater willingness to adopt AI- and IoT-enabled smart

composting technologies. These findings provide additional evidence regarding user acceptance of the proposed system but were not used as the primary basis for testing the main study hypothesis.
The primary hypothesis of this study was evaluated through the experimental comparison of the conventional, smart-monitored, and proposed intelligent composting systems (Tables 1–3). The experimental results demonstrated substantial improvements in composting duration, waste reduction efficiency, odor suppression, monitoring capability, and overall operational performance of the proposed intelligent composting framework compared with the conventional composting method. These experimental findings provide the principal evidence supporting the study hypothesis, while the chi-square analysis offers supplementary evidence regarding user acceptance and adoption of smart composting technologies.

The statistical findings indicate a significant relationship between environmental awareness and willingness to adopt intelligent waste management technologies.
The sensor-based intelligent monitoring system effectively maintained optimal moisture conditions required for rapid microbial activity and efficient composting performance.
Three experimental units were utilized during the study. Unit A represented the traditional composting system without technological intervention; Unit B represented a smart, monitored composting system integrated with environmental sensors; and Unit C represented the proposed odor-controlled, rapid composting framework incorporating intelligent monitoring and aeration mechanisms.
The experimental findings revealed that the proposed intelligent composting framework demonstrated significant improvements in decomposition efficiency and environmental sustainability compared to conventional composting methods. The implementation of IoT-enabled monitoring systems improved moisture and temperature regulation, thereby accelerating microbial decomposition activity and reducing composting duration.

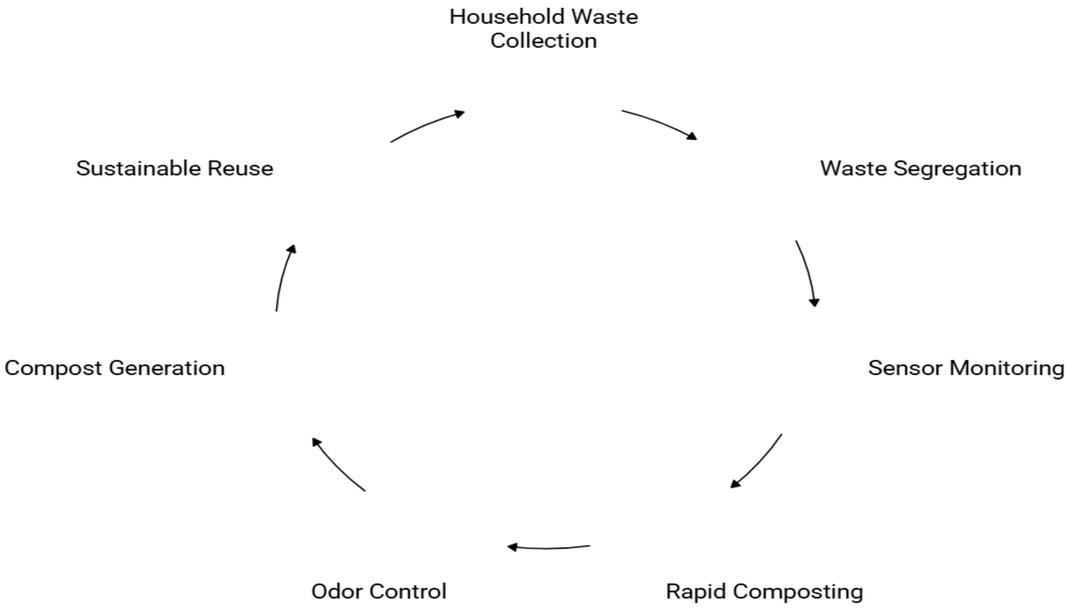


**Fig. 4: Smart Composting Process Cycle**

Figure 4 illustrates the circular smart composting process, emphasizing sustainable waste reuse, environmental conservation, and principles of the circular economy
The results showed that the proposed intelligent system reduced odor generation during composting, improved compost quality, shortened decomposition time, and increased waste reduction efficiency. The automatic environmental monitoring mechanism also improved operational efficiency and reduced manual monitoring during composting.
The empirical survey results also revealed a positive perception among users of smart biodegradable waste management technologies. Among the various responses, the majority of respondents noted that odor reduction, shorter composting duration, and real-time monitoring made them more willing to accept the use of intelligent composting systems for household waste. The experimental and empirical findings obtained from the proposed framework provide important insights regarding the practical feasibility, environmental sustainability, and operational effectiveness of intelligent household composting systems.

## 6. DISCUSSION

The results of the current study have shown the great potential of combining technologies such as artificial intelligence (AI), Internet of Things (IoT), and rapid composting—an accelerated process for biologically decomposing organic matter—to enhance the efficiency and sustainability of residential biosolid waste systems, which manage organic waste from households. The proposed intelligent framework addresses some drawbacks of conventional composting methods, such as slow decomposition, odor production, and a lack of environmental monitoring. The experimental comparison between the conventional composting system and the proposed intelligent composting framework supports the study hypothesis by demonstrating improved composting efficiency, reduced composting duration, enhanced waste reduction efficiency, and improved environmental performance. Furthermore, the chi-square analysis demonstrated that respondents with greater environmental awareness were significantly more willing to adopt smart composting technologies, indicating positive public acceptance of the proposed framework.

It was observed that the proposed system significantly shortened composting time (duration) and enhanced the efficiency of the waste conversion by optimizing the environment during composting and by automating the aeration process with sensors. Using IoT-enabled real-time monitoring systems—where networked devices transmit data to track and regulate compost parameters—helped ensure optimal composting conditions, thereby increasing microbial degradation activity and compost quality. Studies also suggest that suitable interfaces and user dashboards, which are digital panels allowing remote access to system data, for remote monitoring increase adaptability and user supervision while carrying out smart composting operations and provide real-time environmental data in an accessible format (Blau & Franko, 2020). However, previous research has also reported that smart waste segregation systems with IoT, meaning systems that automatically sort waste using networked sensors, can boost waste classification accuracy and make sustainable waste management more efficient by incorporating automated monitoring and intelligent waste processing (Sowndharya et al., 2021).

The embedded smell-control system effectively reduces foul-odor generation during waste decomposition. This function is especially important in urban areas, where odor makes household composting unappealing. The results show that odor-control smart composting systems can help increase public acceptance and adaptability to sustainable waste management technologies.

This study also emphasizes the importance of smart waste management systems in advancing environmental sustainability and circular economy goals. The proposed framework helps reduce reliance on landfills, reduce greenhouse gas emissions, and promote sustainable resource use by converting biodegradable waste into compost and liquid organic fertilizer.

The empirical survey results show that urban households increasingly choose technology-based waste management systems that are user-friendly, odor-free, and efficient. Intelligent technologies for home composting systems, therefore, hold great importance for developing sustainable waste management in developing economies. Based on the experimental observations, statistical analysis, and environmental assessment discussed above, several important conclusions can be drawn regarding the effectiveness of the proposed intelligent composting framework.

## 7. CONCLUSIONS

The experimental evaluation provided the primary evidence supporting the effectiveness of the proposed intelligent composting framework, while the survey-based statistical analysis demonstrated favorable user acceptance of smart composting technologies. This research proposed an intelligent biodegradable waste management framework integrating a conceptual AI-assisted waste segregation module with an experimentally evaluated IoT-enabled compost monitoring system. The prototype evaluation focused on environmental monitoring, rapid composting performance, and odor-control mechanisms, while AI-assisted waste segregation remains a future enhancement of the framework. The study revealed significant problems with the conventional compost system, including slow decomposition, offensive odors, limited environmental monitoring, and limited adaptability to urban residential applications. The proposed framework aimed to address these challenges by incorporating elements such as smart waste sorting, sensor-based waste tracking, rapid composting systems, and odor-control solutions into a holistic, sustainable waste management system. The prototype evaluation demonstrated that the proposed intelligent composting framework reduced composting duration by approximately 66% and achieved an observed waste reduction efficiency of 89% under controlled experimental conditions. These improvements were associated with optimized environmental monitoring, controlled aeration, and enhanced compost stabilization rather than the implementation of an experimentally validated AI-based waste segregation mode.

The experimental results indicated that the proposed intelligent composting system significantly enhanced composting efficiency, including decomposition rate, composting period, odor reduction, and waste reduction, compared to the conventional composting system. The use of Iot-enabled environmental monitoring systems helped to optimize composting conditions and overall operational performance.

The empirical survey also revealed positive user perceptions and adaptability to intelligent, biodegradable waste management technologies, particularly regarding odor control and automatic monitoring in the proposed system. Based on these findings, it is concluded that intelligent biodegradable waste management systems have significant potential to encourage sustainable waste processing in urban areas and to support environmental conservation.

The proposed framework is part of the ongoing research on smart environmental technologies and provides an environmentally friendly, scalable, and practical approach to addressing household organic waste management. The research also contributes to achieving sustainable development and circular economy goals with technology-based solutions for biodegradable waste processing systems**.** Although the proposed framework demonstrated promising results under controlled experimental conditions, further technological advancements and large-scale validation studies remain necessary for broader practical implementation.

## 8. FUTURE SCOPE

The current research offers great possibilities for future research and development in the field of intelligent waste management systems. Future research may incorporate advanced machine learning algorithms to enhance waste segregation accuracy and predictive compost monitoring. To further improve smart waste management infrastructure, adopting blockchain-based waste-tracking systems could enhance transparency and accountability.

Mobile Application interfaces for remote monitoring and automatic control of the system could also be developed, and further research is underway. In the future, intelligent composting technology will be further developed to improve the recycling efficiency of food waste resources through more advanced microbial treatment mechanisms and an automated food waste classification system in urban residential areas (Wu et al., 2024). Additional studies may investigate the use of renewable energy technologies, such as solar-powered composting systems, to enhance energy efficiency and sustainability.

The proposed framework can also be scaled up for other applications such as smart residential so-cities, education, municipal waste processing systems, and smart city infrastructures. Larger datasets, long-term environmental assessment, and industrial-scale validation will be conducted in future experimental studies, providing better insight into the effectiveness and scalability of intelligent biodegradable waste management technologies.

Future studies should implement and experimentally validate the proposed AI-assisted waste segregation module using machine learning algorithms trained on labeled waste image datasets. Subsequent investigations should report waste classification accuracy, precision, recall, F1-score, and validation procedures, together with comprehensive physicochemical analyses of compost quality, including pH, electrical conductivity, C/N ratio, nutrient composition, and maturity indicators

## 9. ACKNOWLEDGMENTS

The authors express their sincere gratitude to Amity Institute of Advanced Legal Studies, Amity University Noida, for providing the academic support and research environment necessary for the completion of this study. The authors also acknowledge the valuable contributions of the respondents who participated in the empirical survey and prototype evaluation. Their responses and observations significantly contributed to the successful completion of the research.

The authors further appreciate the support received during the development and analysis of the proposed intelligent composting framework and acknowledge the importance of interdisciplinary research in promoting sustainable environmental management practices.

**Author Contributions:** Conceptualization, methodology, formal analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, and project administration were carried out by the authors. All authors have read and agreed to the published version of the manuscript.

**Funding:** The research received no external funding”

**Conflicts of Interest:** The authors declare no conflicts of interest.

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