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Development of Smart Clay Pottery Integrated with IoT to Extend the Shelf Life of Fruits and Vegetables

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Abstract

Fruits and vegetables have relatively short shelf lives, necessitating storage solutions such as refrigerators to maintain freshness. However, not all types of fruits and vegetables are suitable for refrigeration, and not all vendors have access to refrigerators or space to accommodate them. This study aims to develop an eco-friendly alternative storage medium using clay pottery enhanced with zeolite and activated charcoal to extend the shelf life of fruits and vegetables. The freshness levels were monitored using TGS 2600, MQ3, MQ4, MQ2, and MQ8 sensors connected to smartphones through an Internet of Things (IoT) platform and supported by an artificial intelligence-based chatbot. This quantitative descriptive research employed experimental methods with samples consisting of spinach (Ipomoea aquatica), mangoes (Mangifera indica), and bananas (Musa spp.). Each produce item was stored in treated clay pottery (with zeolite and activated charcoal), untreated clay pottery, and a refrigerator (control). Observations were conducted over five days, evaluating parameters such as texture, color, and aroma. Six expert respondents assessed the samples using a Likert scale. Data were analyzed using ANOVA and Duncan's Multiple Range Test (DMRT). The findings indicate that the treated pottery significantly improved the shelf life of fruits and vegetables compared to untreated pottery and refrigeration. Sensor-based monitoring integrated with solar-powered panels and the Blynk application, supported by cloud storage and AI-driven chatbot communication, enabled real-time assessment and user interaction. This research demonstrates that innovative clay storage systems, enhanced with natural absorbents and digital technologies, offer a sustainable and effective method for preserving perishable produce.

Keywords: *activated charcoal, artificial intelligence, fruits, Internet of Things, pottery, storage, vegetables, zeolite*

Introduction

The growing awareness of the need for environmental preservation has driven the pursuit of sustainable and efficient food processing and storage methods. Fruits and vegetables play a central role in daily dietary patterns and are critical to human health. However, one of the key challenges associated with these commodities is their limited shelf life [1], which often leads to food waste and increased electricity consumption. Compounding the problem is that not everyone has access to or can afford a refrigerator to extend the freshness of fruits and vegetables.

Although refrigerators are a standard solution for maintaining food quality [2], their accessibility remains limited in specific populations, particularly regions with underdeveloped infrastructure. Factors such as cost and unreliable electricity supply further hinder the widespread use of refrigeration technology. Thus, there is a pressing need for alternative methods that are both effective in prolonging the shelf life of fresh produce and adaptable to various environmental conditions.

A promising solution is using clay pottery enriched with zeolite and activated charcoal. As noted by Pérez-Botella et al. [3], zeolite can absorb moisture and gases that accelerate food degradation. It also has potential applications in reducing harmful substances in food, such as toxins and heavy metals [4], and its ion-exchange capacity can be leveraged to create antimicrobial properties [5]. Similarly, activated charcoal has effectively removed compounds contributing to spoilage [6]. Its uses span various industries, including pharmaceuticals, food and beverages, and water purification [7], and it exhibits potent antibacterial activity [8]. The combination of these materials shows potential for preserving the quality and extending the shelf life of fruits and vegetables in an environmentally friendly and accessible manner.

Methods

This study employed a Research and Development (R&D) approach. The clay-based storage containers were produced from June to November 2024 in Karangtengah Village, Sampang Subdistrict, Cilacap Regency. Testing of the developed containers took place from November 2024 to February 2025 in Kuripan Kidul Village, Kesugihan Subdistrict, Cilacap Regency. Nutritional analysis, specifically vitamin C and dietary fiber content, was conducted at the Food Technology Laboratory of Jenderal Soedirman University, Purwokerto.

The materials and tools fabricating the pottery included a rotating base, a hoe, clay, zeolite, activated charcoal, water, and straw. The production process followed traditional manual methods involving shaping, drying, and firing of the pottery [9]. The sensors used in this study included TGS 2600, MQ3, MQ4, MQ2, and MQ8. Additional components for the sensor system included 18650 batteries, power bank casing, jumper wires, pin headers, breadboard, Arduino Mega 2560, ESP32 microcontroller, solar-powered power banks, and double-tape foam. The Internet of Things (IoT) platform utilized was Blynk [10], while the AI-powered chatbot platform was Telegram, integrated with Artificial Intelligence functionalities [11].

Data collection involved comparative shelf-life testing of bananas, mangoes, and water spinach stored in the treated clay containers versus standard (control) clay containers. Sensory evaluations were conducted over five days, assessing parameters such as texture, color, and aroma [12]. A minimum of six panelists were involved in the assessment, following the Indonesian National Standard SNI 01-2346-2006 [13], using a five-point Likert scale [14]. Nutritional analyses focused on determining vitamin C and dietary fiber contents. Additionally, the gaseous emissions inside the containers were monitored using mobile devices. The level of spoilage was determined via a chatbot system linked to an AI-based platform on Telegram.

Data analysis employed comparative descriptive analysis, comparing the quality of fruits and vegetables stored in treated clay containers with those in the control containers. Where applicable, Analysis of Variance (ANOVA) was conducted to assess statistical significance, followed by Duncan's Multiple Range Test (DMRT) for post-hoc comparison.

Results

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Clay pottery was fabricated by incorporating zeolite and activated charcoal, following a compositional ratio of 60% clay, 20% zeolite powder, and 20% activated charcoal powder. This ratio was adapted from the standard composition used in Portland cement [15]. All ingredients were mixed until homogeneous, shaped on a rotating base, sun-dried, and subsequently fired (Fig. 1).

Mixing Shaping Firing Finished pottery product

Fig. 1. The Process of Fabricating Clay Pottery Enhanced With Zeolite and Activated Charcoal

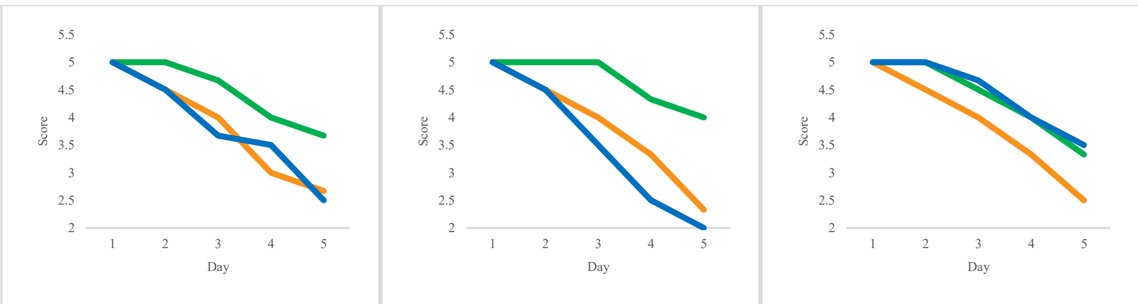
The experimental setup involved storing various types of produce, including bananas, mangoes, and water spinach (Ipomoea aquatica), inside specialized pottery containers called "pane." For comparison, conventional clay pottery and a standard household refrigerator were used. The storage period lasted five days, during which six trained panelists evaluated the freshness of the produce using a 5-point Likert scale, where 1 = very rotten and 5 = very fresh (Fig. 2).

Insertion process Inside view

Fig. 2. Storage of Fruits and Vegetables in Pane Pottery

A. Sensory Evaluation of Bananas

For bananas, sensory evaluations were conducted for texture, color, and aroma. The results of the texture assessment are shown in Fig. 3.



Remark: Green-Experiment Group; Orange-Control Group; Blue-Refrigerator

Fig. 3. Sensory Evaluation: Texture, Color, and Aroma of Bananas

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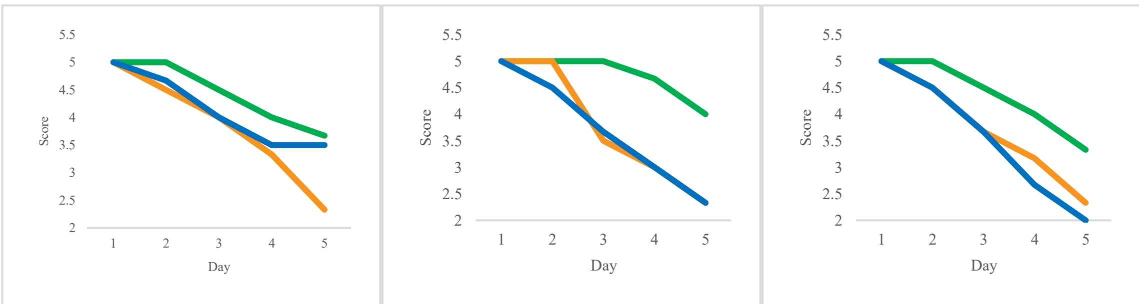
The ANOVA results indicated a statistically significant difference in texture (p = 0.003, α < 0.05), suggesting that the use of treated pottery significantly extended the shelf life of bananas in terms of texture. Further analysis using Duncan's Multiple Range Test (DMRT) showed a significant difference between the treated pottery, the conventional pottery, and the refrigerator. In contrast, no significant difference was observed between the latter two. For color, ANOVA also revealed a highly significant result (p = 0.000, α < 0.05). The DMRT analysis confirmed that bananas stored in treated pottery exhibited significantly better color retention than those stored using the other two methods. Aroma analysis showed a significant ANOVA result (p = 0.012, α < 0.05). DMRT indicated that bananas stored in treated pottery had a significantly better aroma than those kept in conventional pottery, although no significant difference was found when compared with refrigerated samples. See Table 1 for the summary of the DMRT for Banana.

Table 1. DMRT Analysis Results – Bananas

Treatment	Texture	Color	Aroma
Conventional Pottery	2.67 a	2.33 a	2.50 a
Refrigerator	2.50 a	2.00 a	3.50 b
Treated Pottery	3.67 b	4.00 b	3.33 b

B. Sensory Evaluation of Water Spinach

For bananas, sensory evaluations were conducted for texture, color, and aroma. The results of the texture assessment are shown in Fig. 4.



Remark: Green-Experiment Group; Orange-Control Group; Blue-Refrigerator

Fig. 4. Sensory evaluation: Texture, Color, and Aroma of Water Spinach.

The ANOVA analysis revealed a statistically significant improvement in texture for bananas stored in treated pottery (p = 0.001). Further comparison using Duncan's Multiple Range Test (DMRT) indicated an essential difference between treated and conventional pottery, while no significant difference was found between treated pottery and the refrigerator.

In terms of color, the analysis also showed a significant effect (p = 0.000), with bananas stored in treated pottery demonstrating better color retention compared to both the conventional pottery and the refrigerator. Similarly, the ANOVA results for aroma (p = 0.000), supported by DMRT analysis, confirmed that treated pottery significantly preserved the aroma of bananas better than both the conventional pottery and the refrigerator. Table 2 shows the DMRT analysis results for water spinach.

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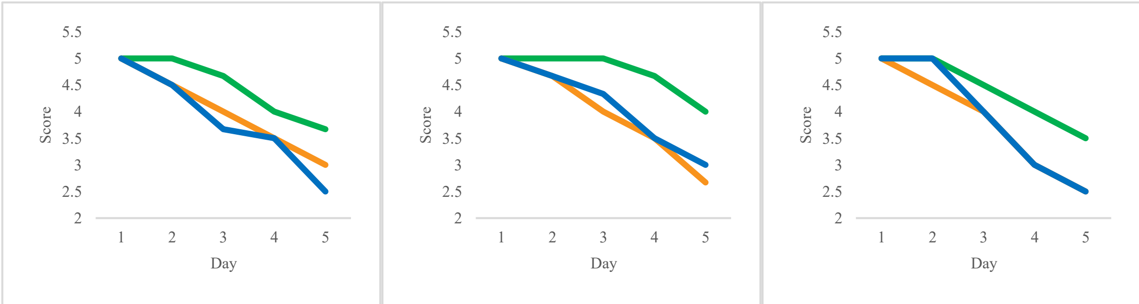
Table 2. DMRT Analysis Results – Water Spinach

Treatment	Texture	Color	Aroma
Conventional Pottery	2.33 a	2.33 a	2.33 a
Refrigerator	3.50 b	2.33 a	2.00 a
Treated Pottery	3.67 b	4.00 b	3.33 b

C. Sensory Evaluation of Mangoes

For mangoes, sensory evaluations were conducted for texture, color, and aroma. The results of the texture assessment are shown in Fig. 5.



Remark: Green-Experiment Group; Orange-Control Group; Blue-Refrigerator

Fig. 5. Sensory Evaluation: Texture, Color, Aroma of Mangoes

The ANOVA results indicated statistically significant differences in mango texture across the storage methods ($p = 0.000$). Subsequent DMRT analysis showed that treated pottery preserved the texture significantly better than conventional pottery and the refrigerator.

The storage method also significantly affected color ($p = 0.000$). DMRT analysis confirmed that treated pottery was more effective in maintaining mango color than other methods.

Aroma analysis revealed significant variation among the storage treatments ($p = 0.008$), with treated pottery demonstrating superior performance over conventional pottery and refrigerator preserving aroma quality. Table 2 shows the DMRT analysis results for mangoes.

Table 3. DMRT Analysis Results – Mangoes

Treatment	Texture	Color	Aroma
Conventional Pottery	3.00 b	2.67 a	2.50 a
Refrigerator	2.50 a	3.00 a	2.50 a
Treated Pottery	3.67 c	4.00 b	3.50 b

D. Vitamin C and Fiber Content

Vitamin C was assessed using the iodometric method [16], and fiber content was analyzed using the oven-drying method [17] (Fig. 6). Samples were taken after 7 days of storage.

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Grinding Weighing Reagent addition Titration process

Fig. 6. Procedures for Vitamin C and Fiber Analysis

Table 4 presents a comparison of vitamin C content (mg/100g) and fiber content (%) in fresh versus control (stored) samples of mango, banana, and water spinach. Results show that all control samples experienced a reduction in both vitamin C and fiber content compared to their fresh counterparts. The most notable decrease in vitamin C was observed in mangoes, while bananas showed the most significant reduction in fiber content.

Table 4. Vitamin C and Fiber Retention

Sample	Vitamin C (mg/100g)	Fiber Content (%)
	Fresh	Control
Mango	73.24	66.41
Banana	9.12	5.10
Water Spinach	45.11	43.26

Results indicate that the treated pottery preserved vitamin C and fiber better than the control pottery and the refrigerator. The smallest reductions occurred in samples stored in treated pottery, supporting its efficacy.

E. IoT-Based Spoilage Monitoring

Spoilage was monitored using gas sensors (TGS 2600, MQ3, MQ4, MQ2, MQ8) capable of detecting ethylene [19] and methane [20], common indicators of fruit and vegetable decomposition. Sensors were installed on the pottery lid and connected to an Arduino Mega 2560 (Fig. 7).

Inner side of the cover Outer view

Fig. 7. Clay Pottery Equipped wth IoT-Based Gas Sensors

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Sensor calibration was performed using clean air baselines. Data were transmitted via the Blynk IoT app and powered by a solar panel-integrated power bank, enabling use in off-grid environments. Machine learning models were employed to analyze gas levels. Notifications were sent to Blynk and Telegram-based AI chatbot systems (Fig. 8).

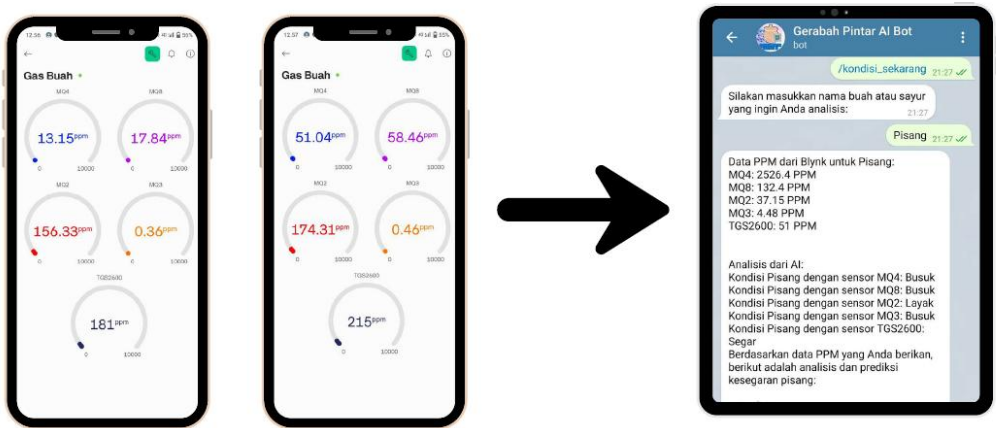


Fig. 8. Blynk and Chatbot Integration for Spoilage Prediction and User Interaction

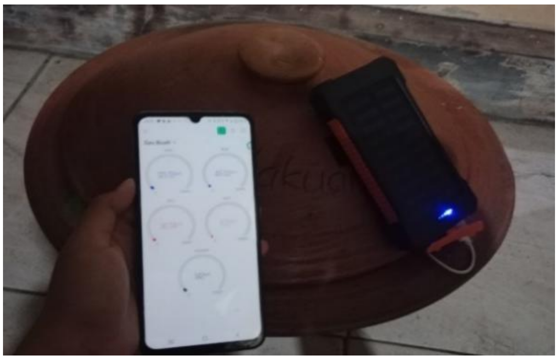
The chatbot (e.g., Gemini AI) used deep learning to provide users with actionable suggestions based on gas concentration, such as spoilage prediction timelines and recommendations for repurposing produce.

Discussion

Fruits and vegetables are perishable commodities with relatively short shelf lives. Typically, households store these items in refrigerators to preserve food, minimize waste, and enhance daily convenience. However, refrigerators require a continuous electricity supply to maintain low internal temperatures. This energy demand is predominantly met by power sources that are still reliant on fossil fuels, such as coal or petroleum. Consequently, electricity consumption contributes to greenhouse gas emissions and exacerbates climate change [25]. Furthermore, many refrigerators still utilize refrigerant gases that pose significant environmental risks. Certain refrigerants, including chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs), are known to deplete the ozone layer and intensify global warming [26].

Historically, people preserved their food using clay pottery. As noted by [27], earthenware pottery has been used since prehistoric times, particularly after the advent of settled agricultural communities. It is believed that pottery first emerged during the Neolithic era in continental Europe and the late Paleolithic period in the Near East. The adoption of pottery subsequently became widespread across various regions of the world. During the food-gathering phase of human civilization, when communities were often nomadic, pottery offered a practical solution due to its light weight, portability, and greater durability compared to materials like wood, bamboo, or animal skins. Clay—the primary raw material used in pottery—was widely available in most areas. However, despite its advantages, the shelf life of food stored in traditional clay containers remains limited.

To address this limitation, innovation is required by incorporating environmentally friendly materials such as zeolite and activated charcoal, which effectively inhibit bacterial activity [28]. A prototype of an innovative pottery storage system integrated with IoT sensors and an AI chatbot is presented in Fig. 9.



Clay pottery integrated with IoT using the Blynk platform

Clay pottery equipped with a solar-powered power bank

Fig. 9. Innovative Pottery System with Solar-powered IoT Integration.

Experimental tests using bananas, mangoes, and water spinach (Ipomoea aquatica) demonstrated that optimized clay pottery—enhanced with a mixture of zeolite and activated charcoal—significantly extended the shelf life of stored produce. Data indicate that adding zeolite and activated charcoal to the clay matrix significantly enhances preservation capacity, particularly for bananas and water spinach. This strategy has proven effective in substantially prolonging freshness while maintaining product safety.

Moreover, clay pottery offers a sustainable, energy-efficient alternative to conventional refrigeration, as it operates without electricity. The material is environmentally friendly, safe for food storage, affordable, and portable—making it especially suitable for rural or off-grid communities seeking practical and low-impact food preservation solutions.

Conclusion

This study demonstrated that clay pottery enhanced with zeolite and activated charcoal significantly improves the shelf life of fruits and vegetables. Combining traditional materials with modern IoT and AI systems offers an innovative, sustainable, and portable storage solution. Not only does this reduce dependence on electricity and refrigerants, but it also enhances food safety and access in remote or underserved areas.

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