International Journal of Sustainability and Advanced Integrated Research
Volume 2, Issue 2 (April-June 2026) | ISSN: 3107-7854
DOI: https://doi.org/10.65339/ijsair.V2.I2.371

Development of Cost-Effective Storage Structure to Prolong Shelf-Life of Red Onion in Isabela

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Publication history: Received: March 18, 2026; Revised: April 30, 2026; Accepted: May 6, 2026
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Abstract

This study aimed to develop and evaluate Naturally Ventilated Onion Storage Structures (NVOSS) using locally available materials to reduce postharvest losses, extend shelf life, and improve the economic outcomes of red onion (*Allium cepa L.*) farmers in Isabela, Philippines. Grounded in postharvest physiology and storage system design principles, the study emphasized the regulation of temperature, humidity, and airflow through passive ventilation. An experimental research design using a Completely Randomized Design (CRD) was employed, comparing four treatments: NVOSS with mud block/bricks, charcoal, sawali walling, and traditional storage (basar). A total of 600 kg of cured red onions were evaluated over a 70-day storage period, with data collected on moisture content, temperature, relative humidity, physiological weight loss, rotting, pest and disease incidence, marketability, and economic performance. Data were analyzed using ANOVA and Least Significant Difference (LSD) tests, alongside return on investment (ROI) analysis. Results revealed that mud block/bricks NVOSS provided the most stable microclimate, resulting in the lowest physiological weight loss, reduced rotting and bacterial incidence, and the highest marketable yield and economic returns. Charcoal walling also performed favorably, while sawali and traditional storage exhibited higher temperature fluctuations, moisture loss, and spoilage. The study concluded that low-cost NVOSS, particularly using mud block/bricks, significantly improves onion storability and farmer profitability. It recommends the adoption of these structures alongside proper postharvest handling practices and continued institutional support. This study supports SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production) by reducing food losses and promoting affordable agricultural innovations. Its sustainability impact lies in enhancing food system efficiency, increasing farmer income, and promoting environmentally sustainable, low-energy storage technologies suitable for rural communities.

Keywords: Bacterial Rot, Marketability, Naturally Ventilated Onion Storage Structures, Physiological Weight Loss, Postharvest Losses, Red Onion, Relative Humidity, Storage Microclimate, Temperature

1. Introduction

Rising inflation and postharvest inefficiencies have intensified challenges in onion *(Allium cepa L.)* production in the Philippines, particularly affecting affordability, farmer income, and supply stability. High storage losses due to inadequate infrastructure highlight the need for cost-effective and sustainable storage solutions. This study focuses on developing and evaluating Naturally Ventilated Onion Storage Structures (NVOSS) using locally available materials to reduce losses, extend shelf life, and improve economic outcomes for onion farmers in Isabela.

1.1 Background on Red Onion Storage Challenges among Farmers in Isabela

The Philippines experienced significant inflation, reaching 8.1% in December 2022, which reduced household purchasing power and increased commodity prices, including onions (Philippine Statistics Authority [PSA], 2022). Onion prices rose to PHP 500–600 per kilogram, limiting consumer access. National production is estimated at 229,539.24 metric tons from 18,391.37 hectares, while Cagayan Valley contributes 8,784.07 metric tons from 717.11 hectares (Arizapa, 2024). Despite favorable yields of approximately 12,000 kg per hectare (Department of Agriculture Regional Field Office 02 [DA RFO 02], 2021), inadequate storage facilities result in substantial postharvest losses. Traditional storage methods expose onions to spoilage, forcing farmers to sell at low prices while traders dominate market control. Imported onions further threaten local production due to lower costs and higher quality (Department of Agriculture-Bureau of Agricultural Research [DA-BAR], 2014). Storage losses reach 30–40%, caused by weight reduction, sprouting, and rotting. Although cold storage can extend shelf life up to ten months, its high cost limits accessibility. Proper curing and controlled storage conditions are essential to maintain quality. The NVOSS offers a low-cost alternative capable of reducing losses and extending storage duration using locally available materials.

1.2 Literature Insights on NVOSS, Postharvest Losses, and Onion Storability

Onion is a globally important crop due to its economic and nutritional value (Fritsch & Friesen, 2002). In the Philippines, it is a major high-value crop cultivated in regions such as Cagayan Valley, where varieties like Red Pinoy and Red Creole are preferred for their adaptability and storage qualities (Department of Agriculture, 2018). However, postharvest losses remain a major constraint. Studies highlight that proper cultural practices such as nutrient management, harvesting at optimal maturity, curing, and pest control significantly influence storability (Mohammad & Khurshid, 2020; Tsegay & Gebretsadik, 2015; Yadav et al., 2021; Girmay et al., 2019; Mahajan et al., 2023). Traditional storage practices lead to losses of up to 30–40% due to sprouting, rotting, and pest infestation (Cruz et al., 2021; Dizon et al., 2019). Improved ventilation and humidity control reduce these losses (Garcia et al., 2023). Pest and disease management is critical, as storage pests and pathogens contribute to deterioration (Lara et al., 2020; Alkharouf et al., 2020; Singh et al., 2021). Research on low-cost storage materials shows that bamboo, mud blocks, charcoal, and sawali improve airflow and reduce spoilage (Pascua et al., 2022; Gupta et al., 2021; Moe, 2021). NVOSS has been proven to maintain optimal storage conditions, reducing losses and improving quality (Gupta et al., 2018; Mahajan et al., 2022; Singh and Singh, 2020).

1.3 Local (Isabela), National (Philippines), and Global Onion Storage Context

Locally, onion production in Isabela and Cagayan Valley is expanding due to favorable conditions and increasing demand, yet storage limitations persist (Department of Agriculture, 2018). Nationally, postharvest losses remain high due to inadequate infrastructure, affecting supply stability and pricing (Cruz et al., 2021; Dizon et al., 2019). Globally, similar challenges have led to the development of ventilated and low-cost storage technologies that reduce losses and improve farmer profitability (Gupta et al., 2021; Ahmed et al., 2022). Innovations such as NVOSS and alternative materials have been successfully implemented in countries like India and Bangladesh, demonstrating improved airflow, reduced microbial growth, and extended storage duration (Gupta et al., 2018; Moe, 2021). These global practices highlight the relevance of adapting similar technologies in the Philippine context.

1.4 Conceptual Basis of NVOSS and Postharvest Storage Performance of Red Onion

This study is grounded in postharvest physiology and storage system design principles, which emphasize the control of temperature, humidity, and airflow to minimize physiological weight loss, sprouting, and decay (Chope, 2006; Milenkovic et al., 2009). The concept of passive ventilation underpins NVOSS, where natural airflow regulates internal conditions without external energy inputs. Material-based cooling mechanisms, such as evaporative cooling in charcoal and thermal insulation in mud blocks, contribute to maintaining a stable microclimate (De Bruin & Holtzhausen, 2020). Ventilated storage structures are designed to reduce moisture accumulation and microbial growth, thereby preserving product quality and extending shelf life.

1.5 Research Gaps in Low-Cost NVOSS Materials for Red Onion Storage in Isabela

Despite existing studies on onion storage, there is limited localized research on the comparative effectiveness of different walling materials within NVOSS under Isabela conditions. While previous studies confirm the benefits of ventilated storage, there remains a need to identify the most cost-efficient and effective materials for smallholder farmers. Additionally, many storage technologies remain inaccessible due to high costs or lack of adaptation to local environments. This study addresses these gaps by evaluating locally available materials such charcoal, bricks, and sawali, and assessing their impact on storage performance, economic feasibility, and loss reduction.

1.6 Alignment with Relevant Sustainable Development Goals (SDGs) for Onion Storage Innovation

This study aligns with several Sustainable Development Goals. It supports SDG 2 (Zero Hunger) by improving food availability through reduced postharvest losses. It contributes to SDG 8 (Decent Work and Economic Growth) by enhancing farmer income and productivity. The development of low-cost, locally sourced storage solutions aligns with SDG 9 (Industry, Innovation and Infrastructure) by promoting appropriate agricultural technologies. Furthermore, it supports SDG 12 (Responsible Consumption and Production) by minimizing food waste and improving resource efficiency.

1.7 Importance of NVOSS-Based Onion Storage to Multidisciplinary Sustainability

The study contributes to socio-economic sustainability by improving farmer profitability and stabilizing market supply. It supports agricultural and food system sustainability by reducing postharvest losses and ensuring year-round availability of onions. The use of locally available materials promotes environmental sustainability by minimizing reliance on energy-intensive cold storage systems. Additionally, the study enhances technological and innovation sustainability through the development of affordable storage solutions adaptable to rural communities. It also contributes to community sustainability by empowering smallholder farmers with practical knowledge and accessible technologies, ultimately strengthening local agricultural systems.

2. Material and methods

2.1 Research Design

The study employed an experimental approach using a Completely Randomized Design (CRD) to evaluate the performance of different storage structures. The treatments consisted of NVOSS with mud block/bricks walling, charcoal walling, sawali walling, and traditional storage (basar). Each treatment used 150 kg of onions, with 10 1-kg samples replicated 3 times and observed throughout the storage period.

2.2 Locale of the Study

The experiment was conducted at the Department of Agriculture - Cagayan Valley Research Center (DA-CVRC) located in San Felipe, City of Ilagan, Isabela.

2.3 Respondents of the Study

The study did not involve human respondents, as it focused on experimental evaluation of onion storage systems. Instead, the primary subjects were red onion bulbs used for assessing storage performance under different treatments.

2.4 Sample and Sampling Procedure

A total of 600 kg of freshly harvested red pinoy onions, with a diameter of 1.5–2 inches, were collected from Mallig, Isabela, during the peak harvest season. The onions were transported in ventilated sacks using a covered vehicle to prevent damage and overheating. They were cured through air drying for eight days to form a protective layer and reduce postharvest losses. Moisture content was determined in the laboratory with assistance from the Department of Agriculture Integrated Laboratory Division (DA-ILD). Equal quantities of onions were distributed across treatments, with 150 kg assigned to each storage structure, and samples were monitored at seven-day intervals.

2.5 Research Instrument

The study utilized NVOSS constructed with an angle bar frame, PVC-coated wire mesh trays reinforced with steel bars, and walling materials consisting of mud blocks or bricks, charcoal, and sawali. The structures featured elevated flooring, kugon grass roofing, and ventilation systems to regulate temperature and humidity. Traditional storage (basar) served as a control. Instruments included digital thermometers and hygrometers with data loggers for environmental monitoring, as well as weighing tools and record books for data collection.

2.6 Data Gathering Procedure

Onions were stored after curing, and data were collected periodically to evaluate storage performance. Temperature and relative humidity were monitored using digital devices with data loggers. Physiological weight loss was measured by recording initial and periodic weights of selected samples and calculating percentage loss using the formula (Soomro et al., 2016). Rotting and sprouting percentages were determined through physical observation and counting of affected bulbs using established formulas (Sohany et al., 2016; Soomro et al., 2016). Pest and disease incidence was assessed by inspecting selected bulbs at regular intervals and computing the percentage of affected samples (Sohany et al., 2016). Marketable and non-marketable bulbs were classified based on quality attributes such as size, firmness, color, and absence of defects.

2.7 Data Analysis Techniques

Data were analyzed using one-way Analysis of Variance (ANOVA) under a Completely Randomized Design to determine the effects of storage treatments on onion quality. Significant differences among treatments were further compared using the Least Significant Difference (LSD) test at a 5% level of significance. Statistical analysis was performed using STAR software. In addition, cost and return analysis was conducted through Return on Investment (ROI) to evaluate the economic viability of NVOSS compared to traditional storage methods, considering construction costs, operational expenses, and marketable yield.

3. Results and Discussion

3.1 Storage Performance and Onion Quality

3.1.1 Moisture Content and Physical Changes of Onion Bulbs

The initial moisture content of onion bulbs was 87.6%, which decreased to a range of 82.9% to 84.9% after storage. Traditional storage (basar) recorded the highest final moisture content. Physical changes observed included fading of red to maroon color, slight browning, reduced firmness, minimal sprouting after 60–70 days, and the development of soft spots in some bulbs. Most bulbs retained their characteristic aroma, although slightly stronger odors were noted in those with early rot. These results indicate that moisture loss and physical deterioration are natural outcomes of prolonged storage, influenced by environmental conditions such as temperature and relative humidity. Higher moisture retention in traditional storage suggests less effective moisture regulation, while observed discoloration, softening, and sprouting reflect physiological responses to dehydration and microbial activity.

3.1.2 Storage Microclimate: Temperature and Relative Humidity

Temperature within the storage structures ranged from 27.31°C to 33.53°C, while relative humidity varied from 60.79% to 90.04%. Bricks-walled storage maintained stable temperatures and high relative humidity, charcoal storage exhibited slightly higher temperatures with moderate humidity, and sawali structures showed wider fluctuations. Traditional basar storage recorded the highest temperatures and humidity levels. Despite rainfall variations from 0.10 mm to 66.8 mm, internal conditions remained within acceptable ranges. These findings demonstrate that walling materials significantly influence the internal microclimate of storage structures. Brick and mud block materials stabilize temperature due to high thermal mass (Kumar et al., 2017), while charcoal promotes evaporative cooling (De Bruin & Holtzhausen, 2020). Sawali allows airflow but lacks insulation, and traditional storage conditions accelerate deterioration due to higher temperature and humidity.

3.1.3 Physiological Weight Loss

Physiological weight loss increased gradually across all treatments, with no significant differences during the first 28 days. Significant differences emerged after 35 days, with the lowest weight loss recorded in mud block/bricks walling and the highest in traditional storage. By 70 days, weight loss ranged from 7.45% in mud block/bricks to 8.73% in traditional storage. The results suggest that storage structures with better insulation and humidity control reduce moisture loss. Stable microclimates in mud block/bricks and charcoal structures minimized transpiration compared to more permeable sawali and basar systems. These findings support previous studies showing that higher temperatures increase respiration and moisture loss (Benkeblia, 2004), while proper humidity control reduces physiological losses (FAO, 2020; Kumar et al., 2017).

3.1.4 Rotting Incidence

Rotting incidence was minimal during early storage but became significantly different after 60 days. Traditional storage recorded the highest rotting levels, followed by sawali, charcoal, and mud block/bricks, which had the lowest incidence. These results indicate that higher temperature and humidity conditions promote microbial growth and decay. Structures with better insulation and ventilation reduced rotting by maintaining favorable storage conditions. This is consistent with findings that warm and humid environments increase susceptibility to rot, while controlled conditions reduce microbial activity (Khan et al., 2018; Singh et al., 2020; FAO, 2020).

3.1.5 Pest and Disease Incidence

3.1.5.1 Bacterial Rot

Bacterial rot remained low during early storage but increased significantly after 60 days. Traditional storage showed the highest incidence, followed by sawali, charcoal, and mud block/bricks, which had the lowest levels. The increase in bacterial rot is associated with elevated temperature and humidity conditions that favor microbial proliferation. Improved storage structures limited bacterial growth by maintaining more stable conditions. These findings align with studies indicating that high temperature and humidity increase bacterial spoilage, while controlled environments reduce rot (Singh et al., 2020; FAO, 2020).

3.1.5.2 Black Mold Incidence

Black mold incidence remained low and did not significantly differ among treatments throughout the storage period. All storage structures showed similar moderate levels of infection. This suggests that black mold development is less sensitive to moderate variations in storage conditions and is more influenced by extreme moisture or condensation. The results are consistent with findings that adequate ventilation limits fungal growth under typical storage conditions (Singh et al., 2020; FAO, 2020).

3.2 Marketability and Economic Performance

3.2.1 Marketable and Non-Marketable Yield

Mud block/bricks storage retained the highest marketable weight (136.14 kg) from an initial 150 kg, followed by charcoal (127.51 kg) and sawali (122.97 kg). Traditional storage (basar) had the lowest marketable weight (116.72 kg) and the highest weight loss. These results indicate that improved storage structures enhance product quality by reducing moisture loss and decay. Stable temperature and relative humidity contributed to higher marketable output, consistent with studies emphasizing the importance of controlled storage environments in maintaining onion quality (Khan et al., 2018; Singh et al., 2020; FAO, 2019).

3.2.2 Economic Analysis of Storage Systems

Mud block/bricks storage produced the highest marketable yield, net income, benefit-cost ratio, and return on investment, followed by charcoal and sawali, while traditional storage recorded the lowest economic returns. The superior economic performance of improved storage systems is attributed to reduced postharvest losses and higher marketable yield. These findings confirm that effective storage technologies not only improve product quality but also enhance profitability for farmers, supporting previous studies on the economic benefits of improved storage systems (Khan et al., 2018; Singh et al., 2020).

4. Conclusion & Recommendations

The study demonstrated that the design of storage structures and the type of walling materials significantly influence the storability, quality, and marketability of red onion bulbs. The developed Naturally Ventilated Onion Storage Structures (NVOSS) effectively created a controlled microclimate that reduced physiological deterioration and postharvest losses. Among the treatments, mud block/bricks NVOSS consistently provided the most stable temperature and relative humidity, resulting in the highest marketable yield and economic returns, followed by charcoal walling, which also showed favorable performance. In contrast, sawali and traditional basar storage were less effective due to their inability to maintain optimal storage conditions, leading to higher losses. Overall, the findings confirm that low-cost, naturally ventilated storage structures can improve onion shelf life and profitability for smallholder farmers in Isabela.

It is recommended that farmers adopt the mud block or bricks NVOSS due to its superior performance in maintaining favorable storage conditions, resulting in higher yield and profitability. Charcoal walling may be considered as an alternative option, while the use of sawali and traditional basar should be minimized because of their higher associated losses. Farmers are also encouraged to implement proper postharvest handling practices, such as sorting and cleaning prior to storage to further reduce losses. In addition, continued technical support from the Department of Agriculture-Cagayan Valley Research Center and the DA-Agricultural Training Institute is recommended to promote wider adoption of the technology among smallholder farmers.

The study was limited to the evaluation of low-cost naturally ventilated storage structures using selected walling materials under the environmental conditions of Isabela over a 70-day storage period. The assessment focused on temperature, relative humidity, physiological weight loss, rot incidence, marketability, and economic returns, without extending to other postharvest practices or long-term storage beyond the specified duration.

Compliance with ethical standards

This study was conducted as an experimental evaluation of naturally ventilated onion storage structures using red onion bulbs under controlled field and laboratory conditions. The procedures involved design, construction, storage, and analysis of postharvest performance, including temperature, relative humidity, physiological weight loss, rot incidence, and economic evaluation. No human participants or animal subjects were involved in the conduct of this study. Proper acknowledgement is given to all individuals and institutions that contributed to the completion of the study, while copyright ownership and authorship responsibility remain with the researchers

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