**Original Research Article**

**PERFORMANCE EVALUATION OF A LOW-COST COLD STORAGE SYSTEM ON FRUITS AND VEGETABLES IN RURAL AREAS**

**ABSTRACT**

This paper evaluates the performance of a low-cost cold storage system developed to preserve the quality and extend the shelf life of perishable agricultural produce, including fruits and vegetables. The low-cost cold storage system constructed using locally available materials and energy-efficient components, the system aims to offer an affordable and accessible solution for small and medium-scale farmers in the rural areas of Nigeria. Internal temperature control and stability, the performance parameter was assessed under varying load conditions using selected produce. The system effectively maintained optimal storage conditions, significantly reducing post-harvest losses and maintaining the freshness of fruits and vegetables over an extended period compared to ambient storage. This is particularly critical in regions within the Inter-tropical Convergence Zone, where high ambient temperatures contribute heavily to postharvest losses, threatening food security and sustainability. The smart cold storage unit, designed with a capacity of 20kg and a temperature range of -17°C to 55°C, stored fruits (mango and pineapple) at 9°C and vegetables (cabbage and carrot) at 0°C, while control samples were left at ambient temperatures ranging from 31.4°C to 35.2°C. After 5 hours, produce stored in the system exhibited significantly lower weight loss: mango (0.7% vs. 1.9%), pineapple (0.75% vs. 2.75%), cabbage (1% vs. 3.5%), and carrot (2.1% vs. 7.6%). These results demonstrate the system's effectiveness in reducing deterioration caused by high temperatures, slowing respiration rates, and extending shelf life. The cold storage unit's consistent performance and minimal energy consumption make it ideal for rural or off-grid use, especially when powered by renewable energy. Overall, this study underscores the potential of smart, low-cost cold storage technologies as sustainable solutions for reducing food waste and enhancing food security in temperature-sensitive regions.

**Keywords:** cold storage,food security, fruits and vegetables, Performance evaluation, smart storage unit,temperature,

**1.0 INTRODUCTION**

Fruits and vegetables are vital components of the human diet, serving as primary sources of essential vitamins and minerals necessary for proper nutrition. However, they are highly perishable due to microbial activity and natural enzymatic processes, which lead to rapid spoilage. As a result, the proper storage of farm produce is crucial in the food industry to reduce postharvest losses. Effective storage methods play a key role in preserving their quality, extending shelf life, and maintaining their nutritional value (Barry-Ryan et al., 2020).

Storage and preservation of farm produce fruits and vegetables inclusive after harvest is a major challenge encountered by farmers and commodities handlers. Lossing the values farm produce occur across the globe starting from the harvesting to consumers, this depends on how perishable and sensitivity to temperature and relative humidity of the farm produce. Fresh fruits and vegetable deteriorate easily when stored under ambient condition, mainly due to physiological and microbial activities, which are accelerated at high temperature and low relative humidity of the storage environment. Most of the fruits and vegetables produce require a cooling temperature range between 0 °C and 15 °C for safe storage and transit purposes (Akorede et al., 2017; Ogunjirin et al., 2025)

Cold storage is primarily used to extend the shelf life and availability of agricultural produce. It helps preserve the freshness, taste, and nutritional value of fruits and vegetables, preventing spoilage and ensuring their availability throughout the year. Once harvested, the quality of produce cannot be improved; therefore, maintaining proper storage conditions particularly temperature and humidity is essential to prolong storage life and retain quality. Fresh fruits and vegetables typically require low temperatures, ranging from 32°F to 55°F, along with high relative humidity between 80% and 90%. These conditions are necessary to reduce respiration rates and slow down metabolic and transpiration processes, thereby minimizing deterioration (Hardenburg et al., 1986). Cold storage of fruits and vegetables has significantly advanced in recent years, resulting in improved preservation of their organoleptic qualities, reduced spoilage, and extended shelf life. These developments have enhanced the effectiveness of postharvest handling, ensuring that produce retains its freshness, taste, texture, and nutritional value for longer periods (Barry-Ryan, 1996).

All farm produce requires specific temperature and relative humidity conditions for optimal storage. Additionally, the same type of produce grown in different ecological regions may have varying storage needs. Even under ideal storage conditions, each fruit and vegetable have a defined shelf life, typically ranging from 5 days to 6 months. Over time, regardless of how well storage conditions are maintained, the quality of the produce will eventually decline. Therefore, the shelf life in cold storage is inherently limited (Afolabi et al., 2023).

Temperature is the most critical factor influencing the effectiveness of storage. For most agricultural products, the optimal storage temperature is slightly above their freezing point. Maintaining a stable temperature is essential, as significant fluctuations can lead to premature deterioration and loss of quality. Consistent temperature control ensures better preservation and extends the shelf life of stored produce (Tashtoush, 2000; Ajeigbe et al., 2024). In cold storage, the temperature is maintained 10°C to 20°C above the freezing point, ensuring that the produce does not freeze. This distinguishes cold storage from freezing, where fruits and vegetables are kept at temperatures of –20°C or lower, preserving them in a frozen state (Natarajan et al., 2023).

Relative humidity refers to the percentage of water vapor present in the air compared to the maximum amount the air can hold at a given temperature. It can be determined using psychrometric charts, which rely on the wet-bulb and dry-bulb temperatures. As the temperature of the air rises, its capacity to hold water increases. Conversely, when the relative humidity decreases, the vapor pressure also decreases, which enhances the air's ability to remove moisture from damp surfaces (Wiley, 1994), When the relative humidity exceeds the equilibrium relative humidity, increasing the ventilation airflow rate helps reduce product losses during storage. However, when the relative humidity is lower than the equilibrium value, higher airflow rates result in greater losses of the stored product. This highlights the importance of maintaining appropriate humidity levels to minimize deterioration and ensure optimal preservation during storage (Zhang et al., 2021)

During storage and transportation, prolonged exposure to low temperatures can cause chilling injury (CI) to fruits and vegetables, particularly solanaceous vegetables that are highly sensitive to temperatures below 12°C. This leads to various physiological disorders, including immaturity, softening, decay, and flavor degradation. Statistics show that cold-sensitive fruits and vegetables make up 50% of the total fruit and vegetable supply, with annual post-harvest economic losses amounting to hundreds of billions of yuan. Of these losses, more than one-third is attributed to chilling injury (Zhang and Jie, 2016). Chilling injury (CI) presents a significant challenge to the development of the fruits and vegetables. As a result, understanding the mechanisms behind CI in solanaceous fruits and vegetables, along with developing effective strategies to minimize its impact, has become a key area of research in the industry.

Injuries can occur when fruits and vegetables are stored below their critical temperature, which varies depending on the type of produce. Both the critical temperature and storage duration are crucial factors in determining the extent of damage. Generally, fruits and vegetables are vulnerable to cold injury when exposed to temperatures between 8°C and 12°C. Symptoms of cold injury include tissue and surface darkening, ripening defects, and other abnormalities. These storage-related injuries are not solely caused by low temperatures but can also result from high relative humidity and refrigerant leakage. The objective of this study is to design a locally made multipurpose cold storage system and evaluate its performance with selected fruits and vegetables. The aim is to enhance storage facilities for fruits and vegetables, thereby prolonging shelf life and maintaining quality for perishable products. Kwara State's climate, influenced by the Inter-Tropical Convergence Zone (ITCZ), results in two distinct seasons: wet and dry (Oyedokun et al., 2022).

**2.0 MATERIALS AND METHODS**

The method adopted for the performance evaluation of the low-cost cold storage system involved the experimental testing of a prototype unit using readily available and affordable materials. The system was equipped with temperature and humidity sensors to monitor internal conditions, and a thermostat-controlled cooling mechanism to regulate the environment. Selected fruits (mango and pineapple) and vegetables (cabbage and carrot) were used to evaluate the system’s performance under controlled storage temperatures of 0°C and 9°C, while control samples were stored at ambient room temperatures ranging from 31.4°C to 35.2°C. The methodology included recording the initial and final weights of the produce over a 5-hour storage period to determine weight loss, which served as an indicator of freshness and preservation efficiency. Comparative analysis was conducted between the cold storage and ambient storage conditions. The experimental data were then analyzed to assess the effectiveness of the system in maintaining produce quality, reducing deterioration, and minimizing postharvest losses.

**2.1 Materials**

Fruits and Vegetables used for this study are (Mango, Pineapple, Carrot and Cabbage) were purchased from Mandate market, Ilorin west local government area of Kwara state, Nigeria.

**2.2 Sample preparation**

The fruits and vegetables (Mango, Pineapple, Carrot and Cabbage) used for the study were sorted, washed and allowed to drain for two (2) minutes, before storage.

**2.3 Experimental procedure**

The experiment was carryout at no load and at load, measure the temperature of the cold storage system were measured for the period of two hours.

The fruits and vegetables were introduced into this cold storage with a control on jute bag; the temperature and relative humidity measurement from the cold storage system and the control on the jute bag was measured and recorded at an interval of 1 hour for five hours.



Figure 1: Cold storage with fruits and vegetables.

**3.0 RESULTS AND DISCUSSIONS**

The result of raw data obtained from the experiment is presented in Figure 2 to Figure 5 and Table 1.

Table1: Summary of the result of Weight Loss of the selected fruits and vegetables

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S/no. | Time (Hr.) | Mango | Pineapple | Cabbage | Carrot |
|  Cooling  | Control |  Cooling  | Control |  Cooling  | Control |  Cooling  | Control |
| 1 | 0 | 1000 | 1000 | 800 | 800 | 1000 | 1000 | 1000 | 1000 |
| 2 | 1 | 997 | 997 | 795 | 797 | 994 | 987 | 982 | 985 |
| 3 | 2 | 995 | 990 | 793 | 786 | 993 | 980 | 980 | 970 |
| 4 | 3 | 995 | 985 | 794 | 780 | 992 | 975 | 980 | 966 |
| 5 | 4 | 994 | 983 | 794 | 779 | 992 | 969 | 979 | 938 |
| 6 | 5 | 993 | 981 | 794 | 778 | 990 | 965 | 979 | 924 |

**3.1 Discussion**

The discussion of the data obtained in Table 1 is as follows:

Discussions on weight loss on Mango

1. Mango stored in the cold storage weight loss range within 993g to 1000g equivalent to 7g amount to 0.7% while the control weight loss range within 981g to 1000g equivalent to 19g amount to 1.9%, this gives a different of 12g within the period of 5 hours as shown in Figure 2.

Figure 2: Effect of Weight Loss on Time of Storage of Mango

Discussions on weight loss on Pineapple

1. Pineapple stored in the cold storage weight loss range within 794g to 800g equivalent to 6g amount to 0.75% while the control weight loss range within 778g to 800g equivalent to 22g amount to 2.75% this gives a different of 16g within the period of 5 hours as shown in Figure 3.

Figure 3: Effect of Weight Loss on Time of Storage of Pineapple

 Discussions on weight loss on Cabbage

1. Cabbage stored in the cold storage weight loss range within 990g to 1000g equivalent to 10g amount to 1% while the control weight loss range within 965g to 1000g equivalent to 35g amount to 3.5% this gives a different of 25g within the period of 5 hours as shown in Figure 4

 Figure 4: Effect of Weight Loss on Time of Storage of Cabbage

 Discussions on weight loss on Carrot

1. Carrot stored in the cold storage weight loss range within 979g to 1000g equivalent to 21g amount to 2.1% while the control weight loss range within 924g to 1000g equivalent to 76 g amount to 7.6% this gives a different of 55g within the period of 5 hours as shown in Figure 5.

Figure 5: Effect of Weight Loss on Time of Storage of Carrot

1. Carrot has the highest loss of 55g which is loss different between the cold storage and the control while the Mango has the lowest loss of 12g different between the cold storage and the control.
2. There is high significant difference between the fruits and vegetable stored in the developed cold storage systemcompared with the controlled on the jute bag as shown from the results of the evaluation displaced through Table 1 and Figure 2 to Figure 5.

Table 2: Summary of the String result of Weight Loss of the selected fruits and vegetables

|  |  |  |  |
| --- | --- | --- | --- |
| S/no | Product | Weight(g) Cooling System | Weight (g) Control |
| 1 | Mango | 993 | 981 |
| 2 | Pineapple | 794 | 778 |
| 3 | Cabbage | 990 | 965 |
| 4 | Carrot | 979 | 924 |

Figure 6: Summary graph of the string result of weight Loss of the selected fruits and vegetables

Discussion on the effect of Temperature on time of storage.

Table 3: Cooling Storage Temperature at no-load and at load

|  |  |  |  |
| --- | --- | --- | --- |
| **S/no** | **Time** | **Temperature at no load** | **Temperature at load** |
| 1 | 0 | 32.1 | 31.1 |
| 2 | 10 | 25 | 25.1 |
| 3 | 20 | 0.85 | 20.7 |
| 4 | 30 | -0.9 | 16.2 |
| 5 | 40 | -3.7 | 13.1 |
| 6 | 50 | -5.2 | 10 |
| 7 | 60 | -6.2 | 8.2 |
| 8 | 70 | -6.8 | 6.7 |
| 9 | 80 | -7.2 | 5.1 |
| 10 | 90 | -7.3 | 3.7 |
| 11 | 100 | -7.4 | 2.8 |
| 12 | 110 | -7.4 | 1.8 |
| 13 | 120 | -7.4 | 1 |

Figure 7: Graph of the Cooling Storage temperature at no-load and at load against time

The following can be deduced from the Table 3 and Figure 7

i The maximum the cooling storage at no load is -7.4°C

ii It takes the cooling system 100 minutes to attain the maximum cooling level of the storage system

iii The ambient temperature of the cooling system is 32.1°C

iv The develop cold storage system will successfully store farm produce with the storage temperature range -7.4°C to 32.1°C this make the developed cold storage to serve beyond storage of farm produce alone as it can be useful in hospital for storing vaccines and other items that request a specific storing temperature withinn-7.4°C to 32.1°C without temperature overshot

**4 CONCLUSIONS**

This paper has provided valuable insights into the effectiveness and potential impact of a low-cost cold storage system on food preservation and agricultural sustainability. The findings reveal that such a system offers a practical and reliable means of extending the shelf life of perishable fruits and vegetables, significantly reducing post-harvest losses. Developed using affordable, locally sourced materials, the system successfully maintained optimal temperature and humidity conditions, as evidenced by the substantial reduction in weight loss of stored produce compared to ambient storage. Its affordability, simplicity, and adaptability make it an ideal solution for low-income and rural farming communities, where access to conventional cold storage is limited. Additionally, its energy-efficient design and compatibility with renewable energy sources further support its application in off-grid environments. Overall, this study confirms the viability of the system as a sustainable approach to improving postharvest handling, enhancing food security, and minimizing food waste. With further refinement and broader field deployment, the system holds great potential for scalability and positive impact across a wide range of agricultural settings.

**5 RECOMMENDATIONS**

Based on the findings from the performance evaluation of the low-cost cold storage system, the following recommendations are proposed to enhance its effectiveness and facilitate wider adoption:

1. Integration with Renewable Energy Sources: To improve reliability and support deployment in off-grid or rural areas, the system should be integrated with renewable energy sources such as solar panels to ensure continuous operation.
2. Scaling for Commercial Use: Further development should focus on scaling the system for larger storage capacities while maintaining its low-cost advantage, making it suitable for use by cooperatives, markets, and agribusinesses.
3. Real-Time Monitoring and Automation: Adding sensors and IoT-enabled features for real-time monitoring of temperature, humidity, and load levels would allow for smarter control, reduce manual oversight, and improve produce management.
4. Training and Awareness Programs: To encourage adoption among local farmers, training programs and awareness campaigns should be conducted, focusing on the economic and quality benefits of using cold storage systems.
5. Extended beyond agriculture: The developed system potential is beyond agriculture the system should be thoroughly evaluated beyond agriculture as it can serve as multi-purpose including hospital and pharmaceutical use, sensitive equipment among others

**6 LIMITATION**

The research on performance evaluation of a low-cost cold storage system on fruits and vegetables in rural areas is limited to evaluating the cold storage system with selected fruits and vegetables (mango, pineapple, cabbage and carrots).

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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