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**Evaluation of Solar-Powered Cold Storage and Evaporative Cooling
System as Off-Grid Methods for Postharvest Vegetable Storage**

Evidence from a Laboratory Experiment in Nigeria

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Abstract

This study examined the postharvest storage potentials of a solar-powered cool storage and an off-grid, metal-in-wall evaporative coolant. Temperature drop and relative humidity (RH) increase were used to analyze the performance of cooling systems. Tomato (United Trading Company (UTC) variety), orange (Dan Benue variety) and carrot (Orange Chantenay) were obtained from the international fruits market in Dutse, Jigawa State, Nigeria. The items were sorted and stored in three different storage conditions: room temperature (RT), solar-powered cold storage, and metal-in-wall evaporative cooling systems. Mass loss, color, hardness, total soluble solids and titratable acids, carotenoids, vitamin C, and rate of nutrient degradation were among the quality indicators tested. The study shows that the solar-powered cold storage outperformed all other storage methods across the evaluated parameters; it preserved fruit firmness, significantly reduced the rate of color change, and minimized mass and nutrient losses, outperforming the metal-in-wall evaporative cooling system. For instance, tomato mass losses observed in 24 days were 42.66, 63.79, and 85.45 percent in the solar-powered cold storage, evaporative coolant, and ambient storage, respectively. Economic advantages of the above technologies, however, require careful consideration of investment costs and longer-term durability and benefits.

Keywords: Cold storage, evaporative coolant, vegetables and fruits, quality preservation, postharvest loss

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1. INTRODUCTION

Vitamins, minerals, and fiber can be found abundantly in fruits and vegetables. Eating fruits and vegetables aids in the prevention of a range of ailments (Yeum and Russell, 2002; Yogesh et al., 2015; Ariaahu et al., 2021). Antioxidant-rich fruits and vegetables, in particular, can help prevent health conditions like cancer and cardiovascular/coronary heart disorders. However, fruits and vegetables are often regarded as perishable crops; if not stored quickly after harvest, they can decay rapidly, especially under high temperatures (Taye and Olorunisola, 2011; Ndukwu, 2011; William et al., 2015; Adhikari and G.C., 2021; Prashna et al., 2022). Postharvest losses of perishable crops have been estimated to be as high as 30–40 percent in developing countries (Atanda et al., 2011; William et al., 2015). Nigerian fruit and vegetable growers typically do not have access to cold storage facilities, making it impossible to preserve excess produce. Also, cold storage technologies for fish and meat are not suited for the preservation of fruits and vegetables due to its excessively low temperature that can induce chilling injury (Ndirika and Asota, 1994; Gross et al., 2002; Olosunde et al., 2009; William et al., 2015).

In this paper, we evaluate the effectiveness of two cold storage technologies for fruits and vegetables. The first is a metal-in-wall evaporative coolant developed by the Nigerian Stored Products Research Institute (NSPRI). The cooling operation of this technology is achieved by evaporating water in riverbed sands, which are filled between an exterior brick wall and an inner metal wall. A water system is integrated into the system to facilitate the rewetting of sand, ensuring continuous evaporation. Similar to most existing evaporative cooling systems, condensation remains a major challenge, as it reduces efficiency and promotes reabsorption of water molecules by the stored fruits, thereby increasing microbial spoilage activity. In the improved design, absorbents are used to fill in holes at side walls to reduce condensation effects normally in the night. This modification successfully addressed the condensation issue without compromising the system's efficiency.

The second technology is a solar-powered cold storage designed by Cold Hub Ltd., in collaboration with the International Food Policy Research Institute (IFPRI). This system incorporates a direct current (DC)

air conditioning unit powered by solar energy, maintaining temperatures between 10-16°C and a relative humidity of 82 percent, which are optimal conditions for fruit and vegetable storage.

Both innovations were introduced as postharvest management strategies for produce in northern Nigeria as alternatives to grid-based refrigeration systems, which are impractical in rural areas of Nigeria and other low- and middle-income countries due to unreliable electricity supply. The objectives of this study are to (1) comparatively evaluate these storage systems against the status quo of storage at ambient temperature based on various quality metrics of the stored fruits and (2) to provide recommendations for their appropriate application.

2. MATERIALS AND METHODS

Sample Preparation

Tomato (United Trading Company (UTC) variety), orange (Dan Benue variety), and carrot (Orange Chantenay) were obtained from the international fruits and vegetable market in Dutse, Jigawa State, Nigeria. The produce were sorted, washed, and graded prior to storage. Selection was based on uniform color and firmness, which were measured before storage. For each type of produce, ten samples were selected and tagged for non-destructive testing (physical properties) during storage, while one hundred samples were designated for destructive testing (chemical properties). The ten labeled samples were periodically assessed for physical attributes, including weight loss, color change, and firmness.

Additionally, three samples from each type of produce were taken for chemical analyses, including carotene, lycopene, vitamin C, total soluble solids, and titratable acidity. Measurements were conducted every four days, corresponding to days 0, 4, 8, 12, 16, 20, and 24.

Indicators

The study examined several variables, including temperature, relative humidity, cooling efficiency of the evaporative cooler, physical qualities (mass loss, color, and firmness), chemical qualities (total soluble

solids, titratable acidity, vitamin C, and carotenoids), and the kinetic shelf life of the stored fruits and vegetables, to determine how they were influenced by different storage conditions.

Temperature and Relative Humidity

For all storage conditions, both temperature and relative humidity were monitored. Measurements were obtained using a data logger (Tzone TempU03 Multi-use USB Temp & RH Data Logger), with readings recorded every two hours between 6:00 a.m. and 6:00 p.m. over a 24-day period.

Cooling efficiency

The cooling efficiency of the evaporative cooling systems, a key parameter for evaluating their performance, was calculated as a ratio of temperature differences using the equation:

$$\text{Cooling efficiency} = \frac{T_{db} - T_c}{T_{db} - T_{wb}} \times 100 \dots\dots\dots (1)$$

where T_{db} is the dry bulb temperature of ambient conditions, T_c is the dry bulb temperature of the cooled air, and T_{wb} is the wet bulb temperature.

Mass loss

The samples were weighed individually using a calibrated weight scale immediately after harvest and at the end of each storage period. For each sample, the initial and final masses were recorded, and the difference between them was taken as the total mass loss during storage. The percentage mass loss at the end of each storage interval was calculated using the equation:

$$\text{Mass loss} = \frac{m_1 - m_2}{m_1} \times 100 \dots\dots\dots (2)$$

where m_1 was the mass measured immediately after harvest and before storage, and m_2 was the mass measured after storage according to days spent inside the various cooling systems.

Color Determination

The color of each sample was measured following the method described by López-Camelo and Gómez (2004), using a Lander Color Meter (Model CM200S, Serial No. N974978). Each sample was scanned at three different points, and readings were obtained from the chromameter. The recorded color coordinates included L*, a*, and b* values.

Firmness

Firmness was assessed using a durometer (Model 3345, Buckingham, United Kingdom). Measurements were taken along the equatorial region of each tomato, orange, and carrot and at a right angle to the first measurement point. The average impact force (N) from the two tested locations was recorded.

total soluble solids

The total soluble solids (TSS) content of each fruit sample was determined using a digital hand-held Brix refractometer with a measurement range of 0–90 percent Brix. Sample preparation followed the procedure outlined by Tigist et al. (2013), in which fruits were blended and filtered through cloth to obtain clear juice. A two to three drop aliquot of juice was then placed on the refractometer for TSS measurement, and results were recorded in Brix.

Titrateable Acidity

Titrateable acidity (TA) was determined by mixing 10 mL of juice with 50 mL of distilled water, followed by the addition of three drops of phenolphthalein indicator. The mixture was titrated with 0.1N NaOH until a color change from clear to pale pink was observed. The percentage acidity was then calculated using Equation (5) described by Pinheiro et al. (2009).

$$\text{Percentage acidity} = \frac{\text{Tire}(mlNaOH) \times \text{acidfactor} \times 100}{10(ml\text{juice})} \dots\dots\dots (3)$$

Extraction and Measurement of Vitamin C Content

Samples were washed with clean water and dried on absorbent paper before being crushed and thoroughly homogenized. A 5 g portion of the homogenate was mixed with 25 mL of extracting solution, homogenized for one minute, sonicated in an ultrasonic bath for 15 minutes, and centrifuged at $12,000 \times g$ for 20 minutes at 4°C . The supernatant was collected, and 1 mL was diluted with mobile phase to a final volume of 6 mL, filtered through a $0.45 \mu\text{m}$ Millipore membrane, and injected into a high-performance liquid chromatography (HPLC) system for ascorbic acid (AA) quantification. For total ascorbic acid (TAA) determination, 1 mL of the supernatant was combined with 0.2 mL of dithiothreitol (DTT) solution (5 mg L^{-1} DTT prepared in 2.58 M potassium phosphate dibasic). The mixture was kept in the dark at room temperature for approximately two hours before being diluted with mobile phase to a final volume of 6 mL, filtered through a $0.45 \mu\text{m}$ Millipore membrane, and analyzed by the HPLC system. Samples were protected from light and processed in an ice bath to minimize oxidative losses. Dehydroascorbic acid (DHA) content was calculated as the difference between TAA and AA values.

Determination of Carotenoids (Carotene and Lycopene)

Carotenoids were extracted using a hexane/acetone/ethanol mixture (50:25:25 v/v/v). A 3 g portion of homogenized fruit was placed in a light-protected vessel and mixed with 100 mL of extraction solvent. The mixture was magnetically agitated for 30 minutes, after which 15 mL of water was added. The upper layer was collected into a round-bottom flask, and a 10 mL aliquot was evaporated to dryness to increase concentration and improve compatibility with the mobile phase. The residue was diluted to 4 mL, filtered through a $0.45 \mu\text{m}$ membrane, and $100 \mu\text{L}$ was injected into the HPLC system for analysis.

Rate of Nutrient Degradation

The degradation of carotene, lycopene, and vitamin C during storage was modeled using first-order kinetics, as supported by previous studies (Aur lie et al., 2010; Thakur et al., 2017; Song et al., 2017;

Przybysz et al., 2018; Liu et al., 2019; Ariaahu et al., 2021). The degradation rates of vitamin C in oranges, lycopene in tomatoes, and beta-carotene in carrots under different storage conditions were determined through linear regression analysis. The first-order kinetic model is expressed as (Awagu et al., 2017; Camila et al., 2017; Ariaahu et al., 2021):

First order model (n = 1)

$$\ln(Q) = \ln(Q_0) - kt \dots\dots\dots (4a)$$

$$\Delta \ln(Q) = kt \dots\dots\dots (4b)$$

where Q is the amount of nutrient degraded at time (t), Q_0 is the amount of the nutrient at the starting period, and k is the rate constant (rate of degradation).

Experimental design

A completely randomized design in a 3 × 3 (produce × storage methods) factorial experiment was used to evaluate quality degradation. The nine treatments were applied to three replicates on each day of the experiment. .

Statistical Analysis

Analysis of variance (ANOVA) was conducted to assess whether means differed across treatments using the SPSS statistical package. Quality degradation kinetics were determined by fitting the experimental data into the first-order kinetic equation to determine the rate of degradation of vitamin C in oranges, lycopene in tomatoes, and beta-carotene in carrots as a result of storage conditions.

3. RESULTS AND DISCUSSION

Temperature and Relative Humidity Variation

Temperature differences among the three storage systems were highly significant (p < 0.001) throughout the trial period. Likewise, relative humidity (RH) differed significantly (p < 0.05) across the storage

settings, and this trend persisted over time. During ambient storage, temperatures ranged from 19.29 to 29.19°C, while RH varied between 48.67 percent and 65.44 percent. In the evaporative cooling system (ECS), temperatures ranged from 17.24 to 19.84°C, with RH between 69.84 percent and 83.91 percent. The solar-powered cold storage maintained temperatures between 10.45 and 13.23°C and RH between 81.12 percent and 90.23 percent (Fig. 1 and Fig. 2). These findings align with Azene et al. (2014), who reported ECS temperature ranges of 17–26°C and RH ranges of 43–98 percent. Similarly, Jahun et al. (2014) observed RH increases ranging from 51 percent to 93 percent. Throughout the evaluation, the solar-powered cold storage consistently exhibited lower temperatures and higher RH than both ambient storage and the metal-in-wall ECS. The ECS also achieved lower temperatures and higher RH than ambient storage. Lower temperatures combined with higher RH are optimal for storing fruits and vegetables, as they reduce moisture loss and extend shelf life (Tilahun, 2010). Kenghe et al. (2015) noted that most fruits and vegetables require RH between 80 percent and 90 percent; thus, the 81.12–90.23 percent RH observed in the solar-powered cold storage makes it ideal for preserving postharvest quality and minimizing weight loss. Although the ECS effectively reduced temperature and increased RH, its average temperature of 18.52°C may not be suitable for certain crops—such as lettuce, red ripe tomatoes, cucumbers, and cabbage—which, according to FAO (2016), require 0–12°C during storage. Nevertheless, the metal-in-wall ECS offers clear advantages for smallholder farmers without access to advanced refrigeration, as it provides better conditions than room-temperature storage. This makes it suitable for crops such as pumpkins, mature green tomatoes, peas, beans, carrots, and turnips, which can be maintained in better condition than under traditional storage methods.

Cooling Efficiency

The reduction in temperature and the corresponding increase in relative humidity were used to determine the cooling efficiency of the ECS, with results presented in Table 1. Cooling efficiency ranged from 31.79 percent to 86.96 percent over the monitoring period. At 6:00 a.m., the efficiency was 31.79 percent and gradually increased to 48.35, 57.05, 86.96, and 79.82 percent at 8:00 a.m., 10:00 a.m., 12:00 p.m., and

2:00 p.m., respectively. A decline in efficiency was recorded from 4:00 p.m. to 8:00 p.m. It was observed that higher ambient temperatures enhanced the cooling efficiency of the ECS. This finding aligns with Prashna et al. (2022), who reported that increased solar intensity during the day accelerates evaporation, thereby improving cooling performance. Helmy et al. (2013) also noted that peak cooling efficiency typically occurs around 2:00 p.m., coinciding with the highest dry bulb temperatures. The decline in cooling efficiency from 58.78 percent at 4:00 p.m. to 48.30 percent at 8:00 p.m. is consistent with Seweh et al. (2016), who attributed evening efficiency reductions to decreased ambient temperatures and reduced solar intensity—observations that were also true in this study.

Mass Loss

The effects of storage conditions and duration on mass loss are illustrated in Figures 3 (tomatoes), 4 (carrots), and 5 (oranges). Storage conditions had a significant impact ($p < 0.05$) on mass loss for all tomatoes, carrots and oranges. In the solar-powered cold storage, mass losses were 42.66 percent for tomatoes, 8.33 percent for carrots and 18.93 percent for oranges over 24 days. In the ECS, mass losses increased to 63.79, 37.50 and 45.26 percent for tomatoes, carrots and oranges, respectively. The highest mass losses were recorded under ambient storage: 85.45 percent (tomatoes), 68.67 percent (carrots) and 73.40 percent (oranges). Across all storage conditions, mass loss was greatest in carrots, followed by oranges, with tomatoes showing the least loss. These differences are likely driven by variations in storage temperature and RH. The solar-powered cold storage, being more insulated from the external environment, maintained stable temperature and humidity levels, thereby minimizing mass loss more effectively than the ECS. Previous studies (Liu, 2014; Nkolisa et al., 2018) have linked postharvest mass loss to respiration and transpiration rates. Low RH in storage environments accelerates water loss from moisture-saturated fruits, leading to mass reduction (Arah et al., 2015; Nkolisa et al., 2018). This water loss results in wilting and shriveling, reducing both market value and consumer acceptability (Znidarcic and Pozrl, 2006; Nkolisa et al., 2018). Present findings confirm earlier reports by Mogaji and Fapetu (2011) and Nkolisa et al. (2018), which showed that ECS storage can significantly reduce mass loss

compared to ambient conditions. Similar trends were noted by Godana et al. (2015), who observed the highest mass loss in tomatoes stored under ambient conditions. Differences in mass loss between fruit/vegetable types may also be attributed to their biological and structural characteristics. For instance, higher mass loss observed in carrots could be due to their larger capillaries, which facilitate greater moisture loss to the surrounding environment. Variations in fruit/vegetable structure, genetic makeup, and maturation stage (Boyette et al., 1994; Nkolisa et al., 2018) may further explain these discrepancies.

Color

Color is a key quality attribute in fruits and vegetables, influencing consumer perception, maturity evaluation, marketability, and purchase decisions (Ahmed et al., 2012; Nkolisa et al., 2018; Brandt et al., 2006). In this study, the color parameters (L^* , a^* , and b^*) of tomatoes, carrots, and oranges changed significantly ($p < 0.05$) under all three storage conditions throughout the experiment. The L^* value, which measures lightness, decreased over time for all fruits stored in the solar-powered cold storage, metal-in-wall ECS, and ambient storage (Table 2). For tomatoes, L^* ranged from 16.48 to 26.44 in the solar-powered cold storage, from 9.47 to 38.56 in the ECS, and from 2.56 to 39.23 in ambient storage. For carrots, these ranges were between 15.22 and 33.52, 11.48 and 36.59, and 2.32 and 36.18, respectively; oranges ranged from 22.02 to 38.93, 9.77 to 42.09, and 0.11 to 39.93, respectively. The most rapid decline in L^* occurred under ambient storage, followed by the ECS, and the smallest decline occurred in the solar-powered cold storage. These differences are attributed to higher temperatures accelerating color degradation, consistent with the findings of Kassim (2013) and Nkolisa et al. (2018). The a^* value represents the red–green color spectrum and shows the most notable changes. For tomatoes, a^* ranged from 47.09 to 57.92 in the solar-powered cold storage, 46.50 to 80.02 in the ECS, and 41.54 to 88.44 in ambient storage. For carrots, values ranged from 19.72 to 28.23, 18.66 to 45.19, and 19.66 to 58.89, respectively. For oranges, a^* values ranged between -16.32 and -18.34 in the solar-powered cold storage, -15.10 and $+80.02$ in the ECS, and -16.23 and $+42.13$ in ambient storage. Positive a^* values in tomatoes and carrots indicated ripening (red coloration), while negative values in oranges reflected their green hue

at harvest. Oranges stored in the solar-powered cold storage retained negative a^* values throughout storage, while those in the ECS and ambient storage showed positive shifts as ripening progressed. The faster increase in a^* under ambient conditions suggests accelerated ripening due to higher temperatures, in agreement with Pinheiro et al. (2009) and Nkolisa et al. (2018).

The b^* value, which measures the blue–yellow spectrum, followed a similar pattern across storage conditions. For tomatoes, b^* ranged from 3.80 to 13.11 in the solar-powered cold storage, 3.29 to 23.22 in the ECS, and 3.62 to 32.63 in ambient storage. For carrots, values ranged from 13.38 to 22.24, 14.28 to 36.44, and 15.33 to 29.78, respectively; for oranges, 38.36 to 39.45, 42.38 to 56.82, and 40.27 to 51.88, respectively. Higher b^* values indicate increased yellowing (Nkolisa et al., 2018), with the greatest yellowing observed in oranges stored under ambient conditions. Overall, the results demonstrate that lower temperatures, such as in the solar-powered cold storage, slow changes in color components, thereby delaying ripening and preserving visual quality. The ECS also delayed color changes compared to ambient storage, although less effectively than the solar-powered cold storage. These findings align with earlier reports (Lopez-Camelo & Gomez, 2004; Takahashi et al., 2013; Nkolisa et al., 2018) that temperature strongly influences color development and ripening rates.

Firmness

Table 3 presents the results of the effects of storage conditions on firmness, total soluble solids (TSS), and titratable acidity (TA) of the preserved fruits. The interaction between storage condition and storage duration was significant ($p < 0.05$), indicating that softening of fruits and vegetables was influenced by the storage environment. For tomatoes, firmness ranged from 0.109 to 0.379, 0.055 to 0.363, and 0.001 to 0.384 N in the solar-powered cold storage, metal-in-wall evaporative cooling system, and ambient storage, respectively. For carrots, firmness ranged from 0.049 to 0.754, 0.069 to 0.768, and 0.001 to 0.753 N, while oranges ranged from 0.306 to 0.683, 0.091 to 0.632, and 0.001 to 0.664 N across the same storage conditions. No noticeable changes in firmness were observed for any fruit type stored in the solar-powered cold storage during the first eight days. However, a highly significant difference ($p < 0.001$) was

observed between fruits stored at ambient conditions and fruits stored in the ECS compared to the solar-powered cold storage. Overall, firmness declined across all fruit types during storage, with the most pronounced reduction occurring under ambient conditions likely due to higher temperatures compared to the ECS. Type of produce significantly influenced the rate of firmness loss, with carrots showing the greatest reduction, followed by tomatoes and oranges. These findings are consistent with Brashlyanova et al. (2014) and Nkolisa et al. (2018), who reported that firmness is influenced by both storage temperature and produce type. Similar conclusions were drawn by Cantwell et al. (2009) and Nkolisa et al. (2018), who found that temperature affects firmness in grape tomatoes, and by Sualeh et al. (2016), who observed that lower storage temperatures slow metabolic activity, thereby preserving firmness. Collectively, these findings confirm that firmness is regulated by storage temperature, which in turn affects the ripening rate of stored produce. The metal-in-wall ECS maintained firmness better than ambient storage, thereby extending shelf life and preserving quality. This suggests that ECS technology is a viable and affordable storage solution for farmers and marketers in northern Nigeria who currently lack adequate storage facilities.

Total Soluble Solids

A significant interaction ($p < 0.05$) was observed between storage condition, type of produce, and postharvest storage duration. For tomatoes, total soluble solids (TSS) ranged from 5.74 to 6.82, 5.74 to 8.77, and 5.74 to 9.55 in the solar-powered cold storage, metal-in-wall ECS, and ambient storage, respectively. For carrots, the ranges were between 8.32 and 8.92, 8.32 and 9.23, and 8.32 and 11.17, while for oranges they were 9.54 to 9.95, 9.54 to 11.43, and 9.54 to 13.42 across the same storage conditions. An upward TSS trend was observed in all storage conditions, though the rate varied with storage environment. No significant differences were detected among those fruits and vegetables stored in the solar-powered cold storage, suggesting that the lower temperatures delayed ripening. In contrast, fruits and vegetables stored at ambient conditions exhibited the highest TSS increase, consistent with accelerated ripening at higher temperatures compared to the ECS. This rise in TSS may be attributed to

the hydrolysis of pectin, starch, hemicellulose, and other polysaccharides into soluble sugars (Baloch & Bibi, 2012; Vinha et al., 2013; Nkolisa et al., 2018). Produce type also influenced TSS trends, with oranges showing a greater increase than tomatoes or carrots. This may be due to oranges being stored at the mature-green stage and, as climacteric fruits, continuing to ripen in storage, unlike tomatoes, which were stored fully ripe. Previous studies (Tigist et al., 2013; Nkolisa et al., 2018) similarly reported that TSS is dependent on the type of fruit or vegetable and is strongly linked to storage temperature.

Total Titratable Acidity

The interaction between produce type and storage condition significantly affected ($p < 0.05$) total titratable acidity (TA). For tomatoes, total TA ranged from 0.55 to 0.81, 0.398 to 0.81, and 0.13 to 0.81 in the solar-powered cold storage, ECS, and ambient storage, respectively. For carrots, these ranges were 0.12 to 0.29, 0.09 to 0.29, and 0.06 to 0.29, and for oranges, 0.61 to 0.89, 0.47 to 0.89, and 0.41 to 0.89. A downward trend in total TA was observed across all storage conditions, with the fastest decrease occurring under ambient storage, followed by the ECS; solar-powered cold storage showed the slowest decline. This reduction is likely related to higher respiration rates under warmer conditions, which accelerate ripening and lead to the utilization of organic acids as respiration substrates. These findings align with earlier reports (Isack & Monica, 2013; Nkolisa et al., 2018) identifying acidity as a maturity indicator, decreasing as fruits and vegetables ripen. Similar observations were reported by Tigist et al. (2013), Duma et al. (2017), and Pinheiro et al. (2009), noting that citric acid depletion during tomato ripening is linked to respiration. Messina et al. (2012) documented comparable trends in climacteric fruits, while Tilahun et al. (2017) attributed the drop to conversion of organic acids into sugars. Variations in total TA can also be influenced by differences in the weights of fruits and vegetables (Tigist et al., 2013).

Overall, the cooler conditions of the ECS slowed ripening in climacteric fruits, extending shelf life and making it a viable short-term storage option for smallholder farmers.

Changes in Nutritional Quality of Stored Fruits and Vegetables

The trends in lycopene (tomatoes), carotene (carrots), and vitamin C (oranges) content over the storage period are shown in Figure 6. All three nutrients declined steadily across all storage conditions, confirming that while nutrient degradation in stored produce cannot be fully prevented, it can be reduced through improved storage conditions. Degradation was slowest in the solar-powered cold storage, followed by the metal-in-wall ECS, with the fastest losses occurring under ambient conditions. This indicates that the metal-in-wall ECS is a viable alternative for nutrient preservation in areas without access to electricity or solar-powered cold storage. Similar findings have been reported by Camila et al. (2017), Burdurlu et al. (2006), Derossi et al. (2010), Kamaldeen et al. (2020), and Ariaahu et al. (2021), who highlighted that nutrient degradation is strongly influenced by storage method and produce type.

Nutrient Degradation Kinetics

The rate constants for lycopene, carotene, and vitamin C degradation are presented in Table 4. Regression coefficients (R^2 and adjusted R^2 values) ranged from 0.915 to 0.992, indicating that first-order kinetics adequately described the degradation patterns of all three nutrients. Degradation rates were strongly influenced by temperature and relative humidity. In the solar-powered cold storage (average temperature = 11.84°C, RH = 89.67 percent), rate constants were lowest at 0.007 (lycopene), 0.041 (carotene), and 0.304 (vitamin C). In the metal-in-wall ECS (18.54°C, RH = 76.88 percent), the respective values increased to 0.018, 0.062, and 0.311. The highest rates occurred under ambient conditions (24.24°C, RH = 57.01 percent) at 0.049, 0.106, and 0.317. Since higher rate constants indicate faster degradation, these results confirm that nutrient losses occur most rapidly under ambient conditions. Conversely, the solar-powered cold storage's lower degradation rates highlight its suitability for nutrient preservation and shelf-life extension. Previous studies have shown that storage temperatures between 5–12°C and RH between 80–95 percent can slow respiration and senescence, minimize moisture loss, prevent shriveling, and maintain micronutrient content (Arebu, 2021; Kailash & Kshitij, 2022; Yohannes, 2024).

4. CONCLUSIONS

The study demonstrates that the solar-powered cold storage outperformed all other storage methods across the evaluated parameters. The system effectively preserved fruit and vegetable firmness, significantly reduced the rate of color change, and minimized mass and nutrient losses, outperforming the metal-in-wall evaporative cooling system. Nevertheless, the metal-in-wall evaporative cooling system also proved effective, maintaining lower temperatures and higher relative humidity levels than ambient storage conditions. Importantly, it provided a substantial improvement over ambient storage in prolonging shelf life and retaining the quality of stored fruits, particularly tomatoes. For improved evaporative cooling system efficiency, future studies should investigate an underground design, in which the system is partially or fully submerged. This configuration could reduce exposure to fluctuating ambient conditions and enhance cooling performance

5. REFERENCES

- Adhikari, B., and G.C., A., (2021). Post-harvest practices of horticultural crops in Nepal: Issues and management. *Archives of Agriculture and Environmental Science*, 6(2), Pp. 227–233.
<https://doi.org/10.26832/24566632.2021.0602015>
- Ahmed, L., Martin-Diana, A.B., Rico, D., Barry-Ryan, C., 2012. Quality and nutritional status of fresh-cut tomato as affected by spraying of delactosed whey permeate compared to industrial washing treatment. *Food Bioprocess Technol.* 5, 3103–3114.
- Ariahu C. C, Kamaldeen O.S. and Yusufu M.I. (2021). Kinetic and thermodynamic studies on the degradation of carotene in carrot powder beads. *Journal of Food Engineering* 288 (2021) 110145
- Ashenafi H. (2018). Shelf Life and Quality of Tomato (*Lycopersicon esculentum* Mill.) fruits as affected by different packaging materials. *African Journal of Food Science*, 12(2) 21 – 28.
- Atanda, S.A., Pessu, P.O., Agoda, S., Isong, I.U. and Ikotun, I. 2011. The concepts and problems of post-harvest food losses in perishable crops. *Afr. J. Food Sci.* 5, 603–613.
- Aurelie, B., Claudie, D., Manuel, D., Keith, I.T., Renaud, B., Dominique, D., Andrew, W., 2010. Relationship between the kinetics of b-carotene degradation and formation of norisoprenoids in the storage of dried sweet potato chips. *Food Chem.* 121, 348–357.
- Awagu, E.F., Ekanem, E.O., Kolo, A.M., Adamu, M.M., 2017. Kinetic modeling of vitamin c (ascorbic acid) degradation in blanched commonly consumed salad vegetables using computer simulation analysis. *J. Appl. Chem.* 10, 2278–5736.
- Baloch, M.K., Bibi, F., 2012. Effect of harvesting and storage conditions on the postharvest quality and shelf life of mango (*Mangifera indica* L.) fruit. *S. Afr. J. Bot.* 83, 109–116.
- Boyette, M.D., Ritchie, D.F., Carballo, S.J., Blankenship, S.M., Sanders, D.C., 1994. Chlorination and postharvest disease control. *Hort Technology* 3, 395–400.
- Brandt, S., Pek, Z., Barna, E., Lugasi, A., Helyes, L., 2006. Lycopene content and colour of ripening tomatoes as affected by environmental conditions. *J. Sci. Food Agric.* 86, 568–572.

Brashlyanova, B., Zsivanovits, G., Ganeva, D., 2014. Texture quality of tomatoes as affected by different storage temperatures and growth habit. *Emir. J. Food Agric.* 26, 750–756.

Cantwell, M., Nie, X., Hong, G., 2009. Impact of storage conditions on grape tomato quality. In: ISHS Postharvest Symposium, 6th Ed. Antalya, Turkey.

Camila, C.L., Caciano, P., Zapata, N., 2017. Thermodynamic and kinetics study of phenolics degradation and color of yacon (*smallanthus sonchifolius*) microparticles under accelerated storage conditions. *J. Food Sci. Technol.* 54, 4197–4204.

Duma, M., Alsina, I., Dubova, L., Erdberga, I., 2017. Quality of tomatoes during storage. In: 1th Baltic Conference on Food Science and Technology "Food Science and Technology in a Changing World" Foodbalt 2017. Jelgava, Latvia, 27-28 April 2017. pp. 130–133.

FAO, 2016. Food and agriculture organization of the United nations). Manual for the Preparation and Sale of Fruits and Vegetables. Available online @. <http://www.fao.org/docrep/008/y4893e/y4893e00.HTM> [Accessed July 2017].

Godana, E.A., Satheesh, N., Hailu, A., 2015. Effect of storage methods and ripening stages on postharvest quality of tomato (*Lycopersicon Esculentum* Mill.) Cv. Chali. *Ann. Food Sci. Technol.* 16, 127–137.

Gross, K.C., Wang, C.Y. and Saltveit, M., eds. 2002. The Commercial Storage of Fruits, Vegetables and Florist and Nursery Crops, Agricultural Research Service, Beltsville Area, MD. An Adobe Acrobat pdf of a draft version of the forthcoming revision to U.S. Department of Agriculture, Agriculture Handbook 66 on the website of the USDA. <http://www.ba.ars.usda.gov/hb66/index.html> (accessed December 10, 2014).

Helmy, M.A., Eltawil, M.A., Abo-shieshaa, R.R., El-Zan, N.M., 2013. Enhancing the evaporative cooling performance of fan-pad system using alternative pad materials and water film over the greenhouse roof. *Agric. Eng. Int. CIGR J.* 15, 173–187.

Isack, M.E., Monica, L., 2013. Effect of post-harvest handling practices on physico-chemical composition of tomato. *J. Agric. Technol.* 9, 1655–1664.

Jahun, B.G., Abdulkadir, S.A., Musa, S.M., Umar, H., 2014. Assessment of evaporative cooling system for storage of vegetables. *Int. J. Sci. Res.* 5, 1197–1203.

Kassim, A., 2013. Evaluating the Effects of pre-Packaging, Packaging and Varying Storage Environment Treatments on the Quality of Avocados (*Persea americana* Mill.). PhD Dissertation. University of KwaZulu-Natal, South Africa, Durban.

Kenghe, R., Fule, N., Kenghe, K., 2015. Design, development and performance evaluation of an on-farm evaporative cooler. *Int. J. Sci. Technol. Soc.* 2, 1–5.

Koraddi, V.V., Devendrappa, S., 2012. Analysis of physiological loss of weight of vegetables under refrigerated conditions. *Int. J. Farm. Sci.* 1, 61 – 68.

Liu, W., 2014. Effect of different temperatures and parameters analysis of the storage life of fresh cucumber and tomato using controlled atmosphere technology. *Am. J. Food Technol.* 9, 117–126.

Liu, X., Liu, J., Bi, J., Cao, F., Ding, Y., Peng, J., 2019. Effects of high-pressure homogenization on physical stability and carotenoid degradation kinetics of carrot beverage during storage. *J. Food Eng.* 263, 63–69.

Lopez-Camelo, A.F., Gomez, P.A., 2004. Comparison of color indexes for tomato ripening. *Hortic. Bras.* 22, 534–537.

Łukasz S., Sylwia S., Juliusz W., Krzysztof R., Katarzyna P., and Jan D. (2025). Challenges and Future Directions in Evaporative Cooling: Balancing Sustainable Cooling with Microbial Safety. *Building and Environment*, Volume 267, 112292.

Messina, V., Dominguez, P.G., Sancho, A.M., Walsøe de Reça, N., Carrari, F., Grigioni, G., 2012. Tomato quality during short-term storage assessed by colour and electronic nose. *Int. J. Electrochem.* 2012, 1–7.

Mogaji, T.S., Fapetu, O.P., 2011. Development of an evaporative cooling system for the preservation of fresh vegetables. *Afr. J. Food Sci.* 5, 255–266.

Ndirika, V. I. D. and Asota, C. N. 1994. An Evaporative Cooling System for Rural Storage of Fresh Tomato. *J. Agric. Eng. Technol.* 2, 56–66.

Ndukwu, M.C. 2011. Development of a Low-Cost Mud Evaporative Cooler for Preservation of Fruits and Vegetables. *Agric. Eng. Int. CIGR.* 13, 1–8.

Nkolisaa, N., Magwazaa, L. S. Tilahun S. W., and Annie C. 2018. Evaluating evaporative cooling system as an energy- free and cost- effective method for postharvest storage of tomatoes (*Solanum lycopersicum* L.) for smallholder farmers. *Scientia Horticulturae*, 241, 131–143.

Olosunde, W. A., Igbeka, J. C. and Taiwo, O.O. (2009). Performance Evaluation of Absorbent Materials in Evaporative Cooling System for the Storage of Fruits and Vegetables. *Int. J. Food Eng.* 5, 1–15.

Pinheiro, J., Alegria, C., Abreu, M., Gonçalves, E.M., Silva, C.L.M., 2009. Temperature Effect on Stored Tomato (*Lycopersicum esculentum* L.) Quality Parameters. (Accessed 12/10/2017).
http://repositorio.ucp.pt/bitstream/10400.14/6227/4/com-int_2009_ESB_1294_Silva_Cristina_313%203%20pdf.pdf.

Prashna B., Shreejan K. P., Prajwal D. M. (2022). Review on Post-Harvest Handling of Fruits And Vegetables to Minimize Loss. *Food and Agri Economics Review (FAER)* 2(1) (2022) 37-40.

Przybysz, MA, Arkadiusz, S, Edyta, S, Małgorzata, G, El_zbieta, D, 2018. a- and b- Carotene stability during storage of microspheres obtained from spray-dried microencapsulation technology. *Pol. J. Food Nutr. Sci.* 68, 45–55.

Seweh, E.A., Darko, J.O., Addo, A., Asagadunga, P.A., Achibase, S., 2016. Design, construction and evaluation of an evaporative cooler for the storage of sweet potatoes in the north Ghana. *Agric. Eng. Int. CIGR J.* 18, 435–448.

Song, J., Wang, X., Li, D., Meng, L., Liu, C., 2017. Degradation of carotenoids in pumpkin (*cucurbita maxima* l.) slices as influenced by microwave vacuum drying. *Int. J. Food Prop.* (20), 1479–1487.

Spokowski, A.L., 2010. Effect of Refrigerated Vacuum Storage on the Shelf Life of Comingled Broccoli, Cauliflower, and Carrots. PhD Dissertation. Clemson University.

Sualeh, A., Daba, A., Kiflu, S., Mohammed, A., 2016. Effect of storage conditions and packing materials on shelf life of tomato. *Food Sci. Qual. Manage.* 56, 60–67.

Taye, S.M. and Olorunishola, P.F. 2011. Development of an Evaporative Cooling System for the Preservation of Fresh Vegetables. *Afr. J. Food Sci.* 5, 255–266.

Thakur, D., Jain, A., Ghoshal, G., Shivhare, U.S., Katare, O.P., 2017. Microencapsulation of β -carotene based on casein/guar gum blend using zeta potential-yield stress phenomenon: an approach to enhance photo-stability and retention of functionality. *AAPS PharmSciTech* 18, 1447–1459.

Tigist, M., Workneh, T.S., Woldetsadik, K., 2013. Effects of variety on the quality of tomato stored under ambient conditions. *J. Food Sci. Technol.* 50, 477–486.

Tilahun, W.S., 2010. Feasibility and economic evaluation of low-cost evaporative cooling system in fruit and vegetables storage. *Afr. J. Food Agric. Nutr. Dev.* 10, 8–15.

Vinha, A.F., Barreira, S.V., Castro, A., Costa, A., Oliveira, M.B.P., 2013. Influence of the storage conditions on the physicochemical properties, antioxidant activity and microbial flora of different tomato (*Lycopersicon esculentum* L.) cultivars. *J. Agric. Sci.* 5, 118–125.

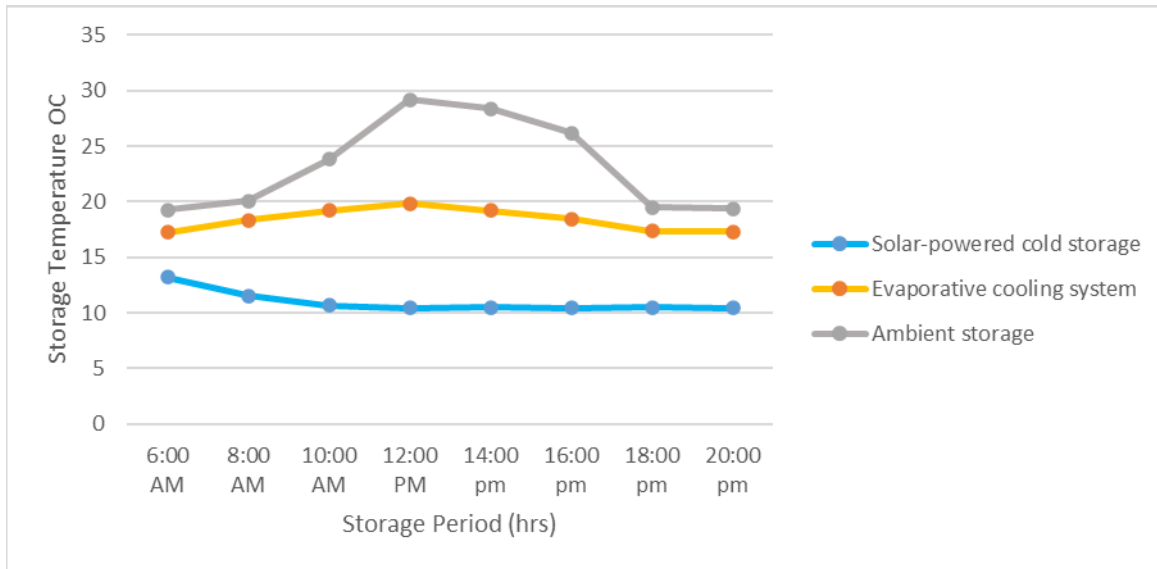
William A. O., Ademola K. A. and Daniel I. O. (2015). Development of a Solar Powered Evaporative Cooling Storage System for Tropical Fruits and Vegetables. *Journal of Food Processing and Preservation* ISSN 1745-4549.

Yeum, K.J., Russell, R.M., (2002). Carotenoid bioavailability and bioconversion. *Annu. Rev. Nutr.* 22, 483–504.

Yogesh, K., Prateek, S., Praneeta, S., Vinay, K.T., Mukesh, K.T., Vikas, S., (2015). Effect of dried carrot powder incorporation on quality attributes of chicken cutlets. *Journal of Ready to Eat Food* 2, 89–95.

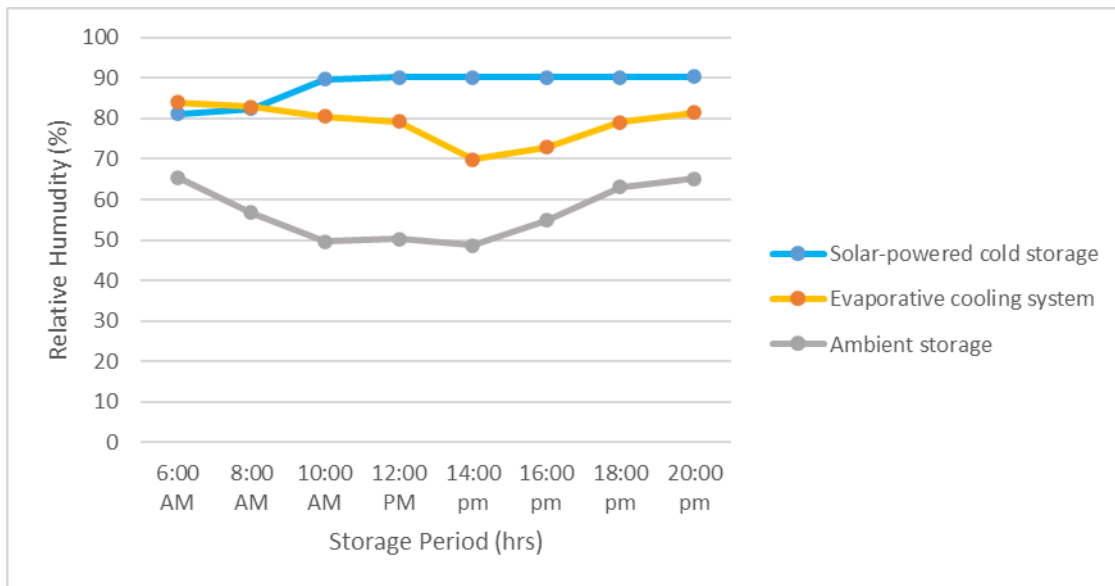
Znidarcic, D., Pozrl, T., 2006. Comparative study of quality changes in tomato cv. 'Malike' (*Lycopersicon esculentum* Mill.) whilst stored at different temperatures. *Acta Agric. Slovenica* 87, 235–243.

Figure 1. Effect of storage conditions on the temperature gradient



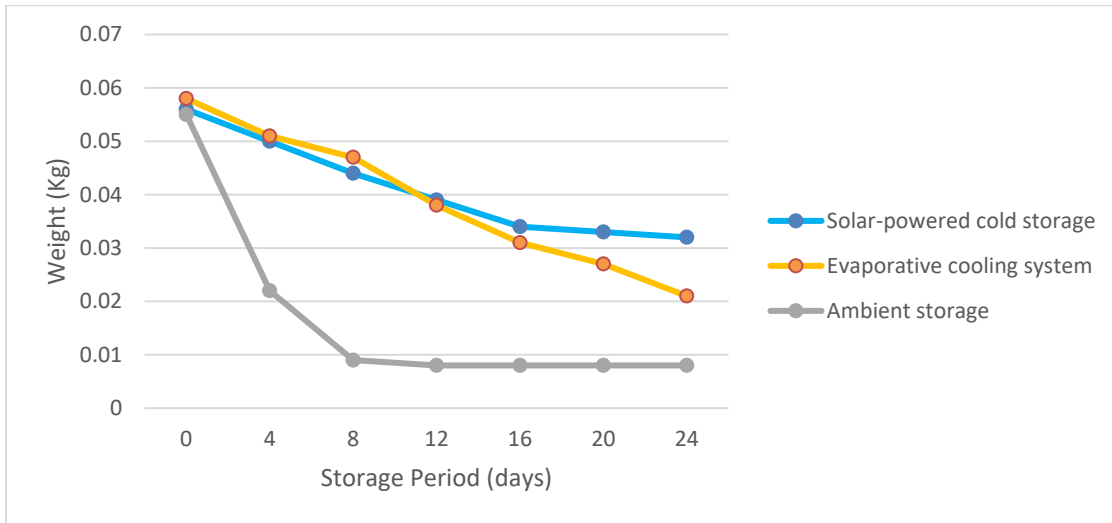
Source: Laboratory experiment data.

Figure 2. Effect of storage conditions on the relative humidity



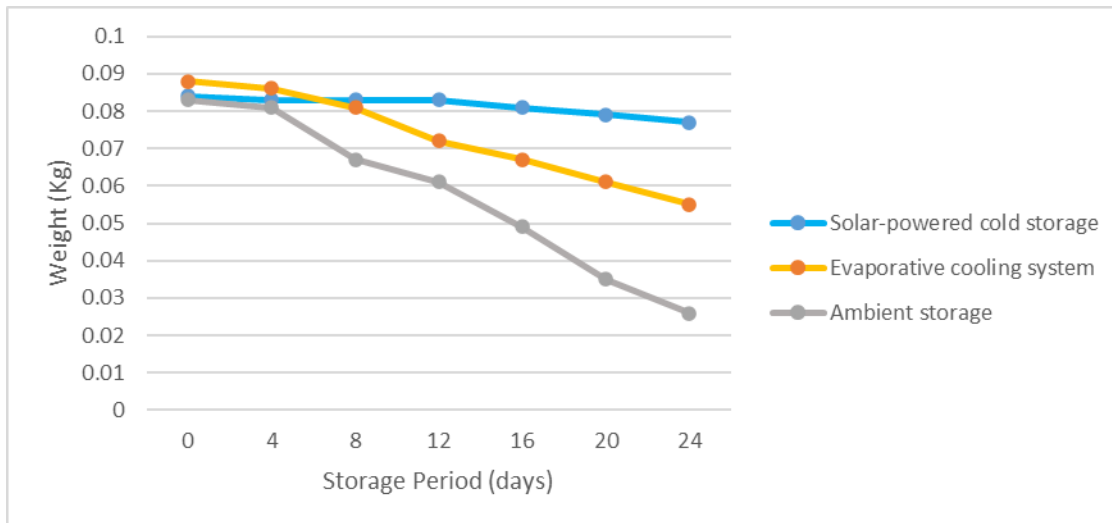
Source: Laboratory experiment data.

Figure 3. Effects of storage conditions on percentage mass loss of stored tomatoes



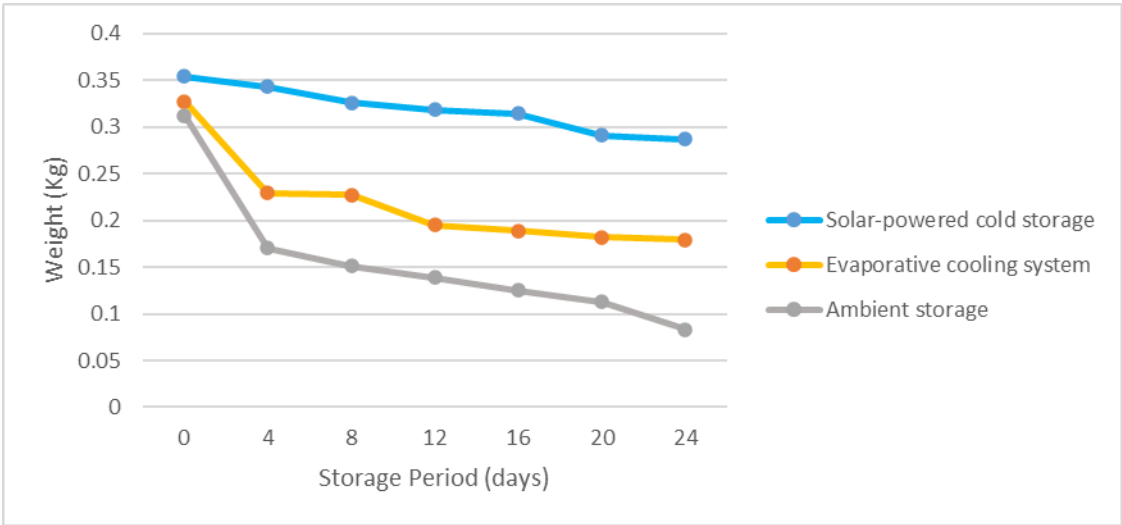
Source: Laboratory experiment data.

Figure 4. Effects of storage conditions on percentage mass loss of the stored carrots



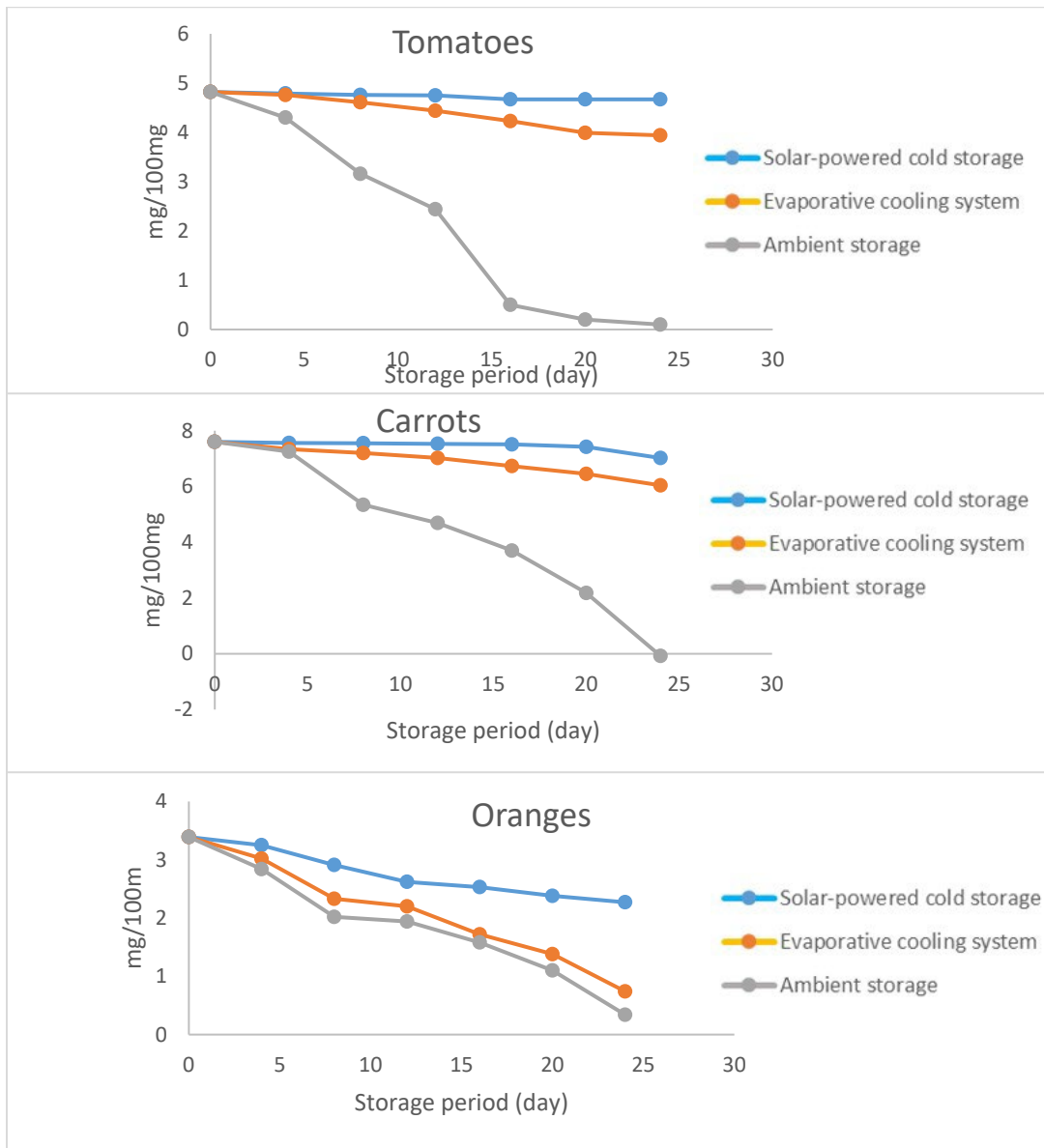
Source: Laboratory experiment data.

Figure 5. Effects of storage conditions on percentage mass loss of stored oranges



Source: Laboratory experiment data.

Figure 6. Nutrients degradation kinetics of stored fruits and vegetables as affected by the storage conditions



Source: Laboratory experiment data.

Table 1. Cooling efficiency of the metal-in-wall evaporative cooling system

Time	Ambient air T (°C)	Ambient air RH (%)	Evaporative coolant T (°C)	Solar-powered cold storage T (°C)	Temp. (wet bulb)	Cooling efficiency ECS
6:00 am	19.29	65.44	17.24	13.23	15.05	31.79
8:00 am	20.05	56.82	18.33	11.55	14.64	48.35
10:00 am	23.82	53.66	19.20	10.65	16.93	57.05
12:00 pm	29.19	48.17	19.84	10.45	21.33	86.96
14:00 pm	28.41	49.31	19.21	10.48	20.98	79.82
16:00 pm	26.20	54.89	18.47	10.45	19.80	58.78
18:00 pm	19.53	63.12	17.34	10.48	14.98	50.13
20:00 pm	19.41	65.18	17.30	10.45	15.13	49.30

Source: Laboratory experiment data.

Table 2. Effect of storage conditions on color components of the stored fruits and vegetables

Fruits	days	Color components								
		L*			a*			b*		
		Solar-powered Cold Storage	ECS	Room Temps	Solar-powered Cold Storage	ECS	Room Temps	Solar-powered Cold Storage	ECS	Room Temps
Tomatoes	0	23.42	38.56	39.23	47.09	46.50	41.54	3.80	3.29	3.62
	4	26.44	32.67	22.65	49.68	58.74	53.37	3.94	4.67	8.07
	8	21.97	21.07	16.11	51.82	64.66	64.61	9.34	10.57	12.53
	12	18.41	18.55	10.35	56.54	77.81	78.07	10.72	17.25	27.25
	16	17.43	15.07	5.01	56.67	51.50	81.52	12.45	22.92	30.89
	20	16.48	10.13	4.14	57.86	79.72	86.19	12.03	21.69	31.17
	24	16.77	9.47	2.56	57.92	80.02	88.44	13.11	23.22	32.63
Carrots	0	33.52	36.59	36.18	19.72	18.66	19.66	13.38	14.23	15.33
	4	30.20	23.48	23.81	20.72	24.31	30.34	15.96	17.44	16.41
	8	26.28	21.87	12.29	21.62	30.23	38.25	17.64	17.48	16.46
	12	25.81	18.42	8.43	26.90	34.32	44.18	19.78	27.57	16.87
	16	19.64	13.22	3.27	26.15	44.77	54.79	19.00	31.54	22.59
	20	14.10	12.22	2.32	27.54	44.67	58.66	21.12	37.25	29.17
	24	15.22	11.48	0.93	28.23	45.19	58.89	22.24	36.44	29.78
Orange	0	38.93	42.09	39.93	-16.32	-15.10	-16.23	38.36	42.38	40.27
	4	36.13	37.45	21.15	-16.48	-16.66	-19.56	38.62	45.11	45.16
	8	31.13	21.05	11.53	-16.68	-23.30	-33.37	36.41	48.48	43.48
	12	29.13	10.91	6.11	-17.93	22.75	39.75	38.50	45.68	45.68
	16	23.38	13.57	3.71	-17.07	24.25	39.21	39.94	49.71	45.71
	20	22.54	10.59	0.19	-18.02	26.48	41.82	39.85	56.11	51.11
	24	22.02	9.77	0.11	-18.34	27.01	42.13	39.45	56.82	51.88

Source: Laboratory experiment data.

Table 3. Effects of storage conditions on firmness, total soluble solids, and titratable acidity of the stored fruits and vegetables

Fruits	Storage	Period (days)	Firmness	TTA	TSS	
Tomato	Solar-powered cold storage	0	0.379	0.81	5.74	
		4	0.366	0.78	5.43	
		8	0.351	0.77	6.06	
		12	0.298	0.78	6.44	
		16	0.244	0.68	6.61	
		20	0.169	0.63	6.82	
		24	0.109	0.55	6.82	
	Evaporative cooling system	0	0.363	0.81	5.74	
		4	0.301	0.766	5.94	
		8	0.273	0.722	6.22	
		12	0.109	0.601	7.68	
		16	0.082	0.557	8.02	
		20	0.056	0.502	8.33	
		24	0.055	0.398	8.77	
	Ambient storage	0	0.384	0.81	5.74	
		4	0.276	0.72	5.88	
		8	0.149	0.67	6.45	
		12	0.056	0.57	8.34	
		16	0.015	0.42	9.22	
		20	0.001	0.35	9.53	
		24	0.001	0.13	9.55	
	Carrot	Solar-powered cold storage	0	0.754	0.29	8.32
			4	0.621	0.26	8.45
			8	0.487	0.26	8.53
12			0.369	0.23	8.67	
16			0.237	0.2	8.71	
20			0.091	0.16	8.84	
24			0.049	0.12	8.92	
Evaporative cooling system		0	0.768	0.29	8.32	
		4	0.532	0.236	8.82	
		8	0.261	0.201	9.17	
		12	0.096	0.176	9.29	
		16	0.084	0.155	9.45	
		20	0.071	0.11	9.55	
		24	0.069	0.091	9.23	
Ambient storage		0	0.753	0.29	8.32	
		4	0.171	0.23	9.07	
		8	0.001	0.18	9.41	
		12	0.001	0.14	9.73	
		16	0.001	0.11	10.02	
		20	0.001	0.06	10.47	
		24	0.001	0.06	11.17	
Orange		Solar-powered cold storage	0	0.683	0.89	9.54
			4	0.642	0.86	9.61
			8	0.640	0.83	9.67
	12		0.564	0.78	9.74	
	16		0.533	0.73	9.76	
	20		0.49	0.68	9.84	
	24		0.306	0.61	9.95	
	Evaporative cooling system	0	0.632	0.89	9.54	
		4	0.591	0.822	9.77	
		8	0.383	0.761	10.12	

Fruits	Storage	Period (days)	Firmness	TTA	TSS
		12	0.166	0.712	10.46
		16	0.104	0.682	10.69
		20	0.094	0.533	11.23
		24	0.091	0.477	11.43
	Ambient storage	0	0.664	0.89	9.54
		4	0.535	0.81	9.83
		8	0.001	0.68	10.59
		12	0.001	0.62	11.37
		16	0.001	0.55	12.17
		20	0.001	0.47	12.61
		24	0.001	0.41	13.42

Source: Laboratory experiment data.

Table 4 Rate of nutrients degradation of the stored fruits

Fruits	Storage	R	R²	Rate constant
Tomatoes (Lycopene)	Solar-powered cold storage	0.957	0.915	0.007 ^a
	Evaporative cooling system	0.988	0.977	0.041 ^b
	Ambient	0.983	0.975	0.304 ^c
Carrots (carotene)	Solar-powered cold storage	0.944	0.931	0.018 ^a
	Evaporative cooling system	0.988	0.976	0.062 ^b
	Ambient	0.983	0.966	0.311 ^c
Oranges (vitamin C)	Solar-powered cold storage	0.98	0.962	0.049 ^a
	Evaporative cooling system	0.992	0.985	0.106 ^b
	Ambient	0.984	0.969	0.417 ^{bc}

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