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Evaluation of clay pot cooler storage for preserving postharvest quality of leafy vegetables

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ABSTRACT

Purpose: The effectiveness of the evaporative clay pot coolers was studied to preserve the postharvest quality of leafy vegetables, including kankun (*Ipomoea aquatica*), gotukola (*Centella asiatica*), lettuce (*Lactuca sativa*) and thampala (*Amaranthus spp*.). **Research method:** The bundles of leafy vegetables weighed about 200 g and were stored for seven days under room temperature storage, refrigerated storage, and clay pot cooler storage. **Findings:** The average temperatures were 27.7 °C, 7.1 °C, and 25.6 °C, and relative humidity values were 76.1%, 58.2%, and 93.6% in room temperature storage, refrigerated storage, and clay pot cooler, respectively. The average cooling efficiency of clay pot coolers was 66.7%. The physiological weight losses of leafy vegetables were significantly reduced during clay pot cooler storage. The chlorophyll content, soluble solids content, color changes, and visual quality of leafy vegetables were significantly maintained in clay pot cooler storage compared to room temperature storage. **Research limitations:** The main limitation of this study was the seepage of water into the inner pot of the clay pot cooler which enhanced the decay of leafy vegetables. This was successfully controlled by avoiding overwatering the sand that was used as the lining material of the clay pot cooler. **Originality/Value:** The clay pot cooler is one of the alternative low-cost storage methods to preserve the quality of leafy vegetables during storage.

INTRODUCTION

Leafy vegetables are a cheap and readily available food item that is widely consumed as an essential part of a balanced diet and an important source of micronutrients, minerals, fiber, and vitamins, especially vitamin A and vitamin C (Ambuko et al., 2017; Bihon et al., 2020). Further, leafy vegetables are used in Ayurvedic medicinal treatment due to their medicinal value (Kumara & Beneragama, 2020). Leafy vegetables deteriorate very quickly after harvesting owing to their high perishability. They tend to decay early when stored in high-temperature and low-humidity storage conditions (Liberty et al., 2013; Ronoh et al., 2018). The rate of deterioration depends on environmental factors, including storage temperature and relative humidity (Ambuko et al., 2017). Cold storage at low temperatures and high relative humidity is the most commonly used method to prolong fresh produce's storage life by reducing its respiration rate (Ambuko et al., 2017; Ronoh et al., 2020).

Relative humidity and temperature are key factors to consider during storage to extend the shelf-life of perishables. Reducing the temperature and increasing the relative humidity during storage slows down pathological activity and suppresses enzymatic activity and respiratory activity. Thereby it makes the storage environment suitable for the safe preservation of perishables. Further, it reduces the rate of water loss and the respiration rate which slows or inhibits the growth of spoilage microorganisms and minimizes metabolic activities (Chinenye et al., 2013; Liberty et al., 2013; Ambuko et al., 2017; Ronoh et al., 2020).

The use of mechanical/ domestic refrigerators is a common method in handling and preserving perishables. However, it is difficult due to high purchase and maintenance costs and inaccessibility to electricity in low-income rural communities in developed/ developing countries (Yahaya & Akande, 2018). For example, the price of mechanical refrigerators in Sri Lanka is very high (> 85,000 LKR), and increasing electricity bills add to the misery of Sri Lankans. Thus, many people are looking for alternative approaches to reduce electricity use at home. Therefore, there has been an increased focus on non-electrical sources that can be used for food preservation, including renewable energy sources such as water and wind. Among these technologies, a non-electrical method based on the principle of evaporative cooling has also attracted much attention (Odesola & Onyebuchi, 2009; Basediya et al., 2013; Rehman et al., 2020). An evaporative cooling system is an economical, efficient, and environmentally friendly method of maintaining the postharvest quality of perishables with the principle of evaporating water through the passive cooling system (Basediya et al., 2013; Deoraj et al., 2015). These systems do not require electricity to operate. They are more beneficial in terms of energy requirements relative to standard refrigeration systems, lower capital costs, and more potential savings. Moreover, with the increase in global warming and the high inflation rate, the demand for low-cost cooling systems will rise in the future (Manyozo et al., 2018; Rehman et al., 2020). Furthermore, it is beneficial to use simple passive cooling systems to achieve low temperatures for better storage of fruits and vegetables which do not require specific skill sets for the operation (Odesola & Onyebuchi, 2009). In addition to these benefits, these passive cooling systems can be constructed using locally available materials (Ambuko et al., 2017).

There are two basic types of non-electric storage technologies with the principle of evaporative cooling, (1) evaporative cooling chambers (ECC) known as zero energy cooling chambers (ZECC), and (2) clay pot coolers, known as zeer pots (Verploegen et al., 2018). Moreover, various small-scale low-cost self-constructible, evaporative-cooling storage units have been developed based on these simple technologies and their modifications.

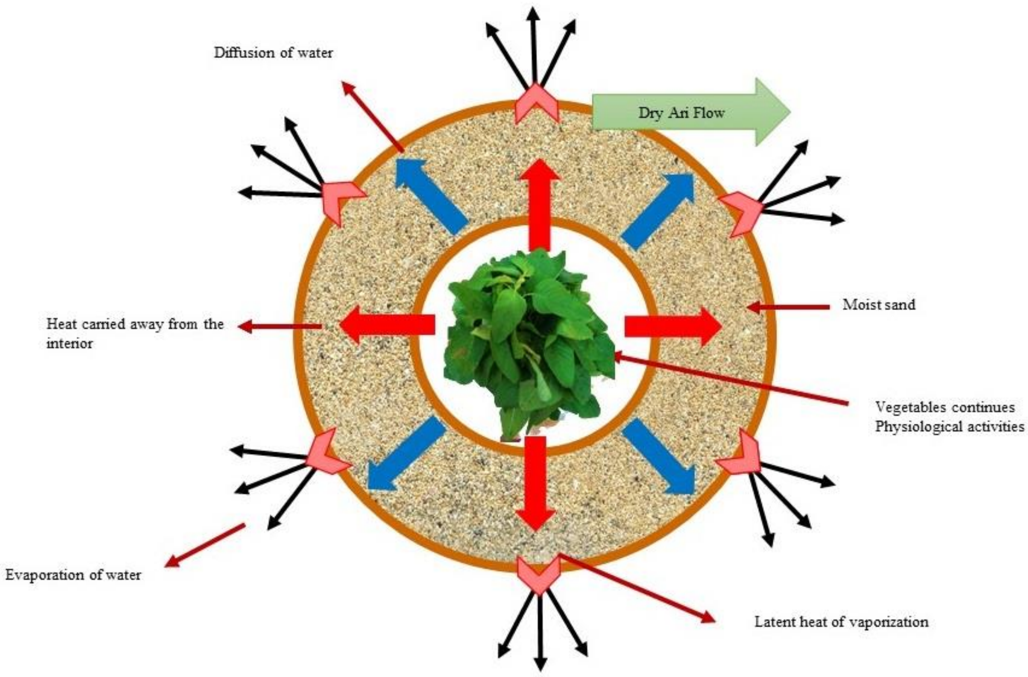

Fig. 1. Principle of evaporative cooling in clay pot cooler. Adapted and modified from Bhaisare et al. (2020).

Evaporative cooling chambers (ECC) are large-scale evaporative cooling chambers used in developed countries by large-scale producers or groups of people which are made of bricks, sand, wood, straw, gunny or burlap sacks, and twine (Verploegen et al., 2018; Rehman et al., 2020). The clay pot cooler consists of two pots with similar shapes and two different sizes. The inner smaller pot acts as the storage pot and the outer larger pot acts as the evaporation surface. The gap between the two pots is filled with sand and moist with water (Verploegen et al., 2018). Evaporative cooling happens with the exchange of heat evaporation which happens due to the latent heat of evaporation. Due to the high latent heat of evaporation in the water, a greater reduction of heat will result. It results in a reduction in the temperature and an increase in the relative humidity in the storage area (Basediya et al., 2013; Ambuko et al., 2017; Fig. 1).

This study was conducted to evaluate the effectiveness of an evaporative clay pot cooler for the preservation of leafy vegetables concerning their quality and shelf-life, including kankun (*Ipomoea aquatica*), gotukola (*Centella asiatica*), lettuce (*Lactuca sativa*), and thampala (*Amaranthus spp.*).

MATERIALS AND METHODS

Experimental site

The study was conducted at the Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka (N 7º 15' 43.92" E 80º 35' 2.76").

Selection of leafy vegetables and sample preparation

As plant materials, four leafy vegetables including, kankun (*Ipomoea aquatica*), gotukola (*Centella asiatica*), lettuce (*Lactuca sativa*), and thampala (*Amaranthus spp.*) were selected. Freshly harvested leafy vegetables were purchased from the market. The samples were cleaned to remove leaf defects and were made into bundles each weighing around 200 g. A total of nine (9) bundles were used per each type of leafy vegetable. Three (3) bundles were used for the weight loss and leaf color measurements. Six (6) bundles were used for destructive measurements during 7 days of storage.

Fig. 2. The details of the clay pot cooler.

Treatments and experimental design

The experimental design was a completely randomized design (CRD) with three storage methods as treatments, including room temperature storage, refrigerated storage, and clay pot storage. All the experiments were conducted in a single laboratory room.

Description of the clay pot cooler

The clay pot cooler was prepared using the '*Kalenimatta'* clay type with the support of a potter at a pottery in Molagoda, Kegalle, Sri Lanka (N 7.2598°, E 80.3988°). The cost of a clay pot cooler was Rs. 2500.00 (LKR). There were six clay pot coolers in the experiment.

The dimensions of the interior pot were 45.72 cm (18 inches) in height and 30.48 cm (12 inches) in diameter and the exterior pot size was 48.26 cm (19 inches) in height and 38.10 cm (15 inches) in diameter (Fig. 2). The gap between the two pots was filled with sieved river sand and moist with water repeatedly.

Data collection

Data were collected every day with three replicates (n=3, bundles) until samples became unusable. The following parameters were measured to evaluate the postharvest life of selected leafy vegetables.

Relative humidity and temperature

The relative humidity and the temperature of different storage methods were recorded using the digital data loggers (CL 11, Rotronic, Taiwan) during the experimental period.

Evaporative cooling efficiency

Evaporative cooling efficiency (ECE) is calculated using the following equation (1) mentioned in Lertsatitthanakorn et al. (2006).

$$ECE = \frac{Td - Tc}{Td - Tw} \qquad (1)$$

T_d = dry bulb temperature of the ambient condition,

T_c = temperature inside the clay pot cooler,

T_w = wet bulb temperature of the ambient condition.

Weight loss

The weight loss was measured using a digital balance (Model-Kern and Sohn GmbH, D-723336, Germany). The results were expressed as the percentage loss of initial weight using the following equation (2).

$$WL\ (\%) = \frac{(W1 - W2)}{W1} \times 100 \qquad (2)$$

WL: the weight loss percentage,

W1: the initial weight (g),

W2: the weight at sampling date during storage (g)

Soluble solids content (SSC)

Leaf samples from the top, middle, and bottom parts were taken and broken into small pieces. Then 1 g of the sample was weighed and ground using a mortar and pestle. The juice was extracted and the soluble solids content (SSC) of the extracted juice was measured using a handheld refractometer (Digital Refractometer, HI96801, Romania). Calibration was done in °Brix, and SSC was expressed as a percentage.

Chlorophyll content

Chlorophyll content was measured using 80% acetone extraction method. A spectrophotometer (Model; AE-S70-2U, United Kingdom) was used to quantify the wavelength at 645, 663, and 652 nm. Chlorophyll content was calculated using the following equations (3-5).

$$\text{Total Chlorophyll content} = \{20.2(D645) - 8.02(D663)\} \times \frac{V}{(1000 \times w)}$$

$$= D652 \times \frac{1000}{34.5} \times \frac{V}{1000 \times W} \qquad (3)$$

$$\text{Chlorophyll a content} = \{12.7\ (D663) - 2.69(D645)\} \times \frac{V}{(1000 \times w)} \qquad (4)$$

$$\text{Chlorophyll b content} = \{22.9\ (D645) - 4.68(D663)\} \times \frac{V}{(1000 \times w)} \qquad (5)$$

V is the volume of the extraction solvent in each sample (1 mL), and W is the fresh tissue weight (1 g) of the sample.

Leaf color

Color values of selected leaves (n=10) from the top, bottom, and middle parts were measured using a colorimeter (CS-10, China) which was calibrated with a white calibration card. L*, a*, and b* values were recorded and a* and b* values were converted into hue angle (H°).

Leaf visual quality evaluation

Visual quality was assessed using a numerical rating scale (hedonic scale) of 1-5 (Kumara & Beneragama, 2020), *i.e.*, 5 - excellent (green and fresh), 4 - good (yellowing and/ or wilting started), 3 - fair (10% leaf yellowing and/or wilting started), 2 - poor (25% leaf yellowing and/or wilting, leaf shedding and decaying started, unmarketable, but usable), 1- unusable (50% leaf yellowing and/or wilting, leaf shedding and decaying continues).

Statistical analysis

The parametric data were subjected to analysis of variance (ANOVA) using statistical analysis software (SAS version 9.0). The significant differences in mean values were evaluated using the least significant difference test (LSD) at the significance level of $P \leq 0.05$. The rank data were analyzed using the Kruskal–Wallis test at the significance level of $P \leq 0.05$. The graphs of the analyzed data were created using Excel (ver. 2013).

RESULTS

Temperature and relative humidity

During the storage period, the temperature in the room temperature storage, clay pot cooler storage, and refrigerator storage varied between 25-30 °C, 20-25 °C, and 5-10 °C, respectively (Fig. 3A). Overall, the temperature fluctuation between the room temperature and the clay pot cooler ranged between 0-3 °C depending on the surrounding environment. Moreover, the clay pot cooler maintained a higher relative humidity (RH, 90-100%) compared to room temperature storage (60-80%) and refrigerated storage (40-60%) (Fig. 3B). Overall, the difference in RH values between the room temperature storage and the clay pot cooler storage ranged between 0% and 33% depending on the environmental conditions.

Cooling efficiency

The changes in temperature, relative humidity, and cooling efficiency in the clay pot cooler for one week are illustrated in Figure 4. The cooling efficiency of the clay pot cooler used in the present study was 66.7% which is more in line with Woldemariam and Abera (2014) who reported a cooling efficiency of 61.6% for the pot-in-pot cooler. Khatun et al. (2019) reported that higher ambient temperature and lower relative humidity will cause higher cooling efficiency, which was similarly reported in the present study with clay pot cooler storage. Compared to other days during the storage period the 2nd, 6th, and 7th-day relative humidity is lower and in those days cooling efficiency is higher.

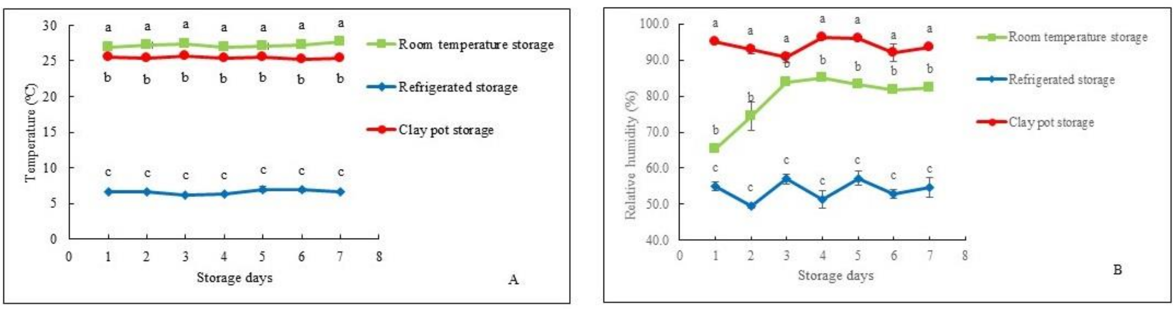

Fig. 3. Changes in temperature (A) and relative humidity (B) in the room temperature storage, refrigerated storage, and clay pot cooler storage.

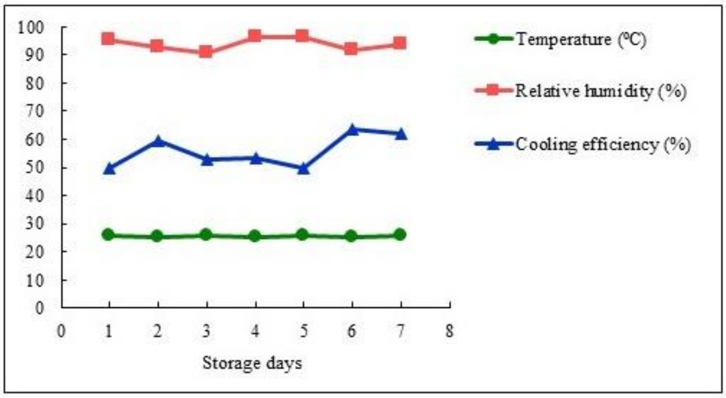

Fig. 4. Changes in temperature, relative humidity, and cooling efficiency in the clay pot cooler.

Weight loss

The changes in weight loss in leafy vegetables during storage are shown in Figure 5. The weight loss of leafy vegetables was significantly (P≤0.05) reduced in clay pot cooler storage compared to the other two storage methods. At the end of the storage, kankun (*Ipomea aquatica*), gotukola (*Centella asiatica*), thampala (*Amaranthus spp*.), and lettuce (*Lactuca sativa*) stored at room temperature showed 20-25%, 0-15%, 12-14%, and 5-6% initial weight loss, respectively. In refrigerator storage, *Ipomea aquatica* showed 10-15% initial weight loss which was greater than clay pot cooler storage, while *Centella asiatica*, *Amaranthus spp.*, and *Lactuca sativa* showed 10-15%, 0-5%, and 0-3% of initial weight loss, respectively. In clay pot cooler storage, *Ipomea aquatica*, *Centella asiatica*, *Amaranthus spp.*, and *Lactuca sativa* showed 0-10%, 0-15%, 0-8%, and 0-4% initial weight loss, respectively.

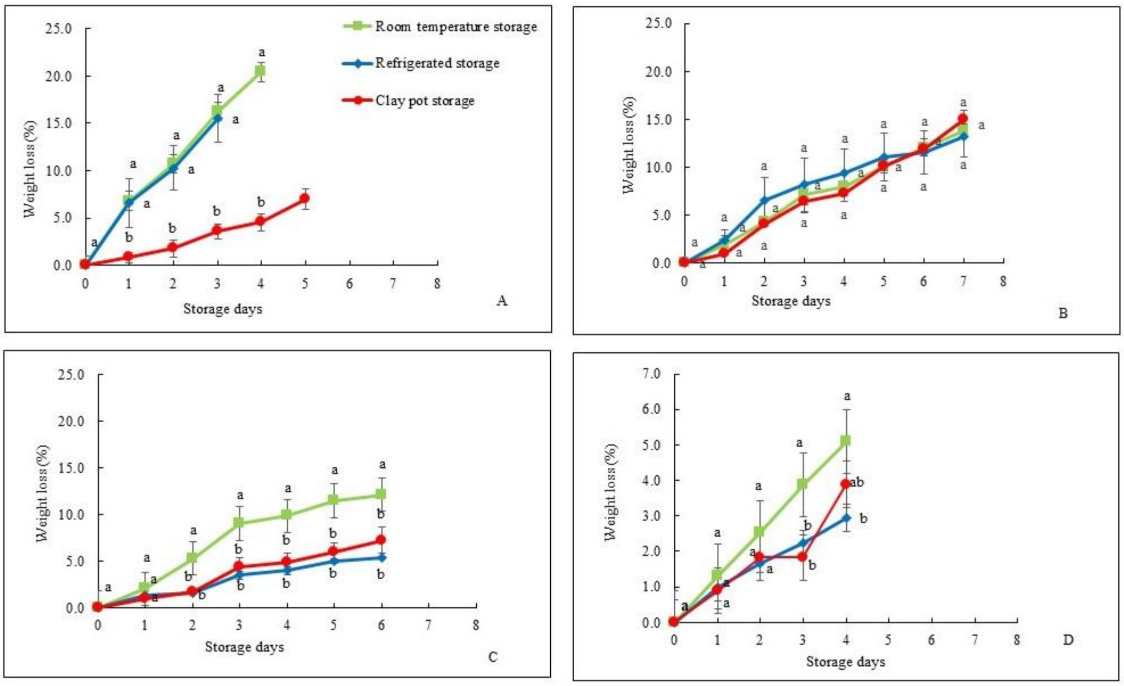

Fig. 5. Changes in weight loss in kankun (*Ipomoea aquatica*, A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp.*, C), and lettuce (*Lactuca sativa,* D) in different storage methods. Vertical bars indicate standard error (n=3). The same letters at each time point indicate means that do not differ significantly at P ≤0.05 according to the least significant difference test (LSD).

Hue angle

The hue value did not change in kankun (*Ipomoea aquatica*) until the 2nd day of storage (Fig. 6). At the end of the storage, the lower hue values were recorded in the room temperature storage compared to the clay pot cooler storage. In thampala (*Amaranthus spp.*) and gotukola (*Centella asiatica*), the changes in hue values were similar in all three storage methods. In lettuce (*Lactuca sativa*), after the 3rd day of storage hue value was changed, and the room temperature storage reported lower hue values than the other two storage methods.

Soluble solids content (SSC)

Figure 7 shows the changes in SSC of leafy vegetables stored with three different storage methods. During the storage period, irrespective of the storage methods, the SSC of kankun (*Ipomoea aquatica*) was increased which may be due to water loss. However, gotukola (*Centella asiatica*), thampala (*Amaranthus spp.*) and lettuce (*Lactuca sativa*) showed a gradual decrease in SSC during their storage period regardless of storage methods.

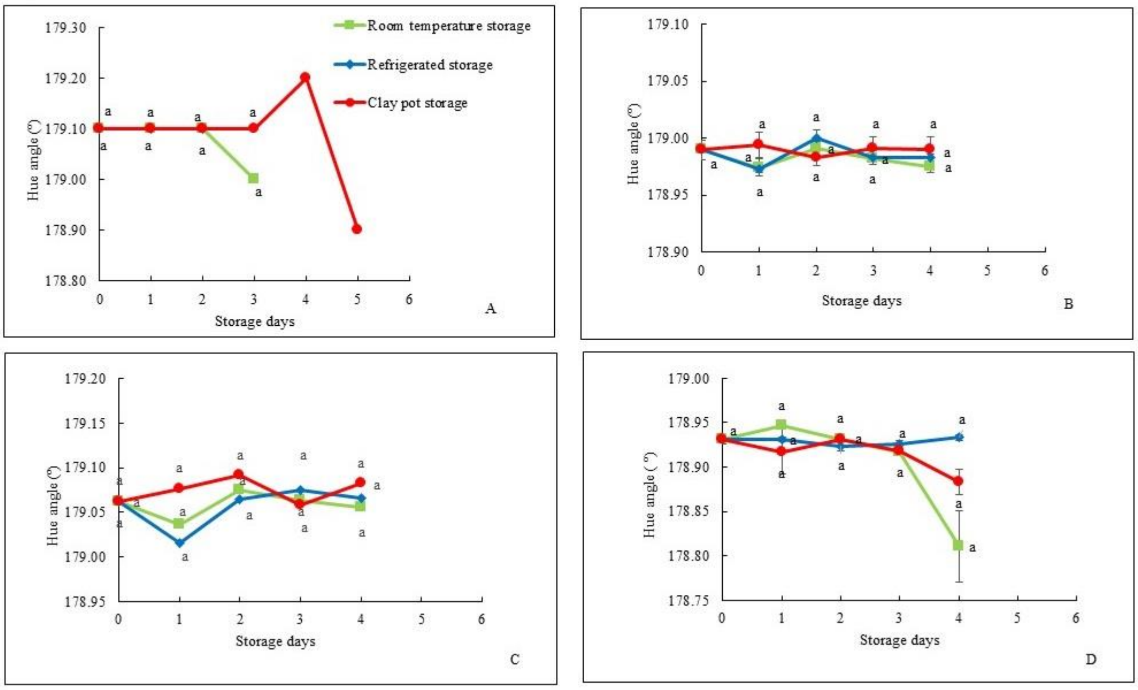

Fig. 6. Changes in hue values in kankun (*Ipomoea aquatica*, A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp.*, C), and lettuce (*Lactuca sativa*, D) in different storage methods. Vertical bars indicate standard error (n=3). The same letters at each time point indicate means that do not differ significantly at P ≤0.05 according to the least significant difference test (LSD).

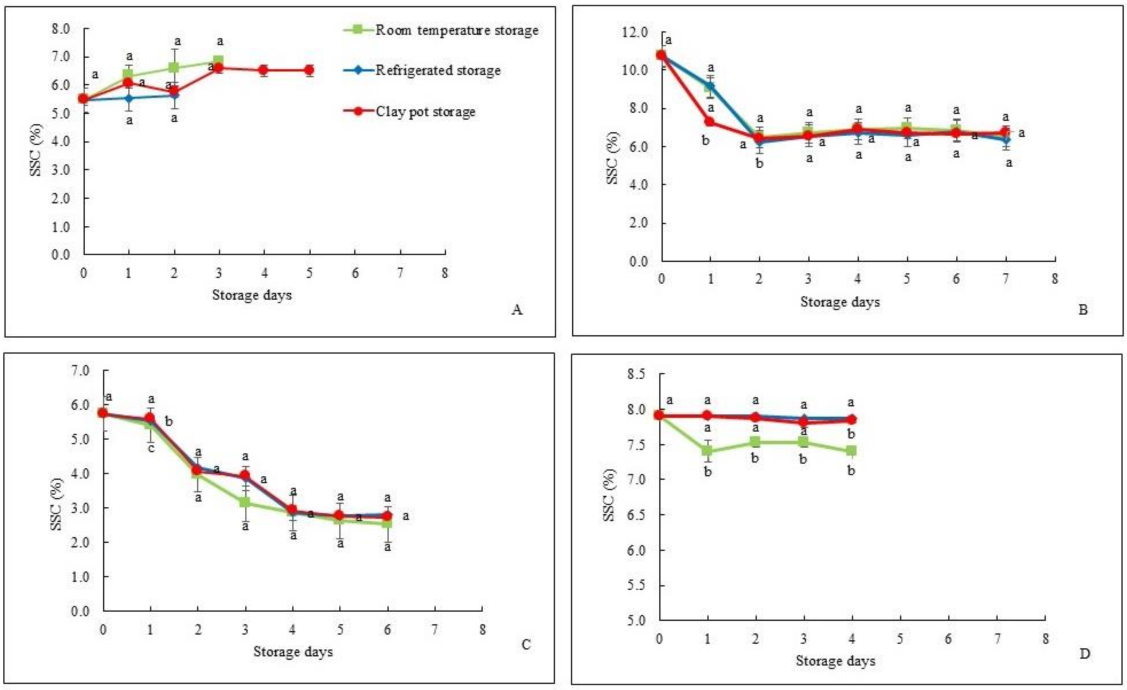

Fig. 7. Changes in soluble solids content (SSC) in kankun (*Ipomoea aquatica*, A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp.*, C), and lettuce (*Lactuca sativa*, D) in different storage methods. Vertical bars indicate standard error (n=3). The same letters at each time point indicate means that do not differ significantly at P≤0.05 according to the least significant difference test (LSD).

Chlorophyll content

Figure 8 illustrates the variation in the chlorophyll content during the storage period. The total chlorophyll content was significantly maintained (P≤0.05) in clay pot cooler storage compared to room temperature storage. Reduction in total chlorophyll content in gotukola (*Centella asiatica*), and lettuce (*Lactuca sativa*) was observed after one day of storage while other leafy vegetables showed chlorophyll reduction after 2 days of storage.

Visual quality

In the present study, visual quality was maintained in the clay pot cooler better than in room temperature storage (Fig. 9 and Fig. 10). The quality of kankun (*Ipomoea aquatica*) was preserved for a longer period (5 days) under the clay pot cooler with lower wilting, yellowing and it maintained the usable quality compared to the other two storage methods (3 days in refrigerated storage and 4 days in room temperature storage).

The *gotukola* (*Centella asiatica*) was stored for 7 days, and the rate of reduction in visual quality such as yellowing and wilting was lower in clay pot cooler storage compared to room temperature storage. From the 5th day of the storage, the visual quality was significantly different between the three storage methods. From the 5th day of storage, leafy vegetables showed leaf shedding, wilting, yellowing, and unusable qualities in three storage conditions.

The visual quality changes in thampala (*Amaranthus spp.*) were significantly different from the one day after storage and the changes were continued until the end of storage. The visual quality reduction rate was lower (wilting, yellowing, and leaf shedding) in the clay pot cooler compared to room temperature storage.

A rapid visual quality reduction (wilting, yellowing, and leaf shedding) starting after 2nd day of storage was observed in lettuce (*Lactuca sativa*), and their storage period was limited to four days. The clay pot cooler was effective in visual quality maintenance compared to room temperature storage.

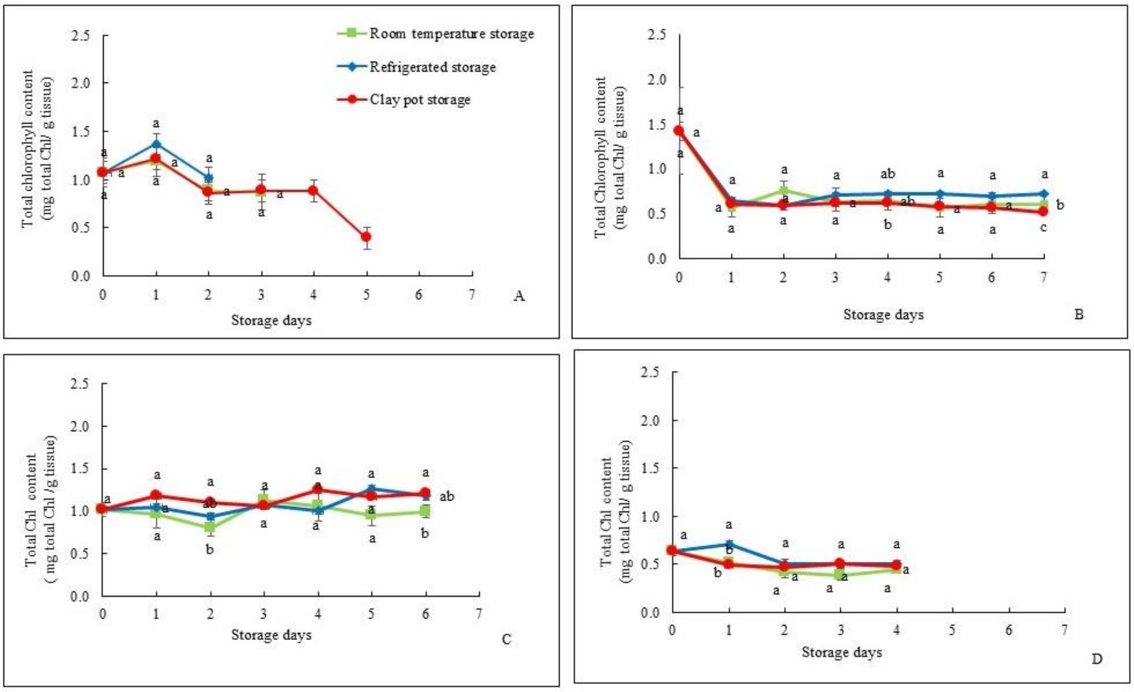

Fig. 8. Changes in total chlorophyll content in kankun (*Ipomoea aquatica*, A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp*., C), and lettuce (*Lactuca sativa*, D) in different storage methods. Vertical bars indicate standard error (n=3). The same letters at each time point indicate means that do not differ significantly at P ≤0.05 according to the least significant difference test (LSD).

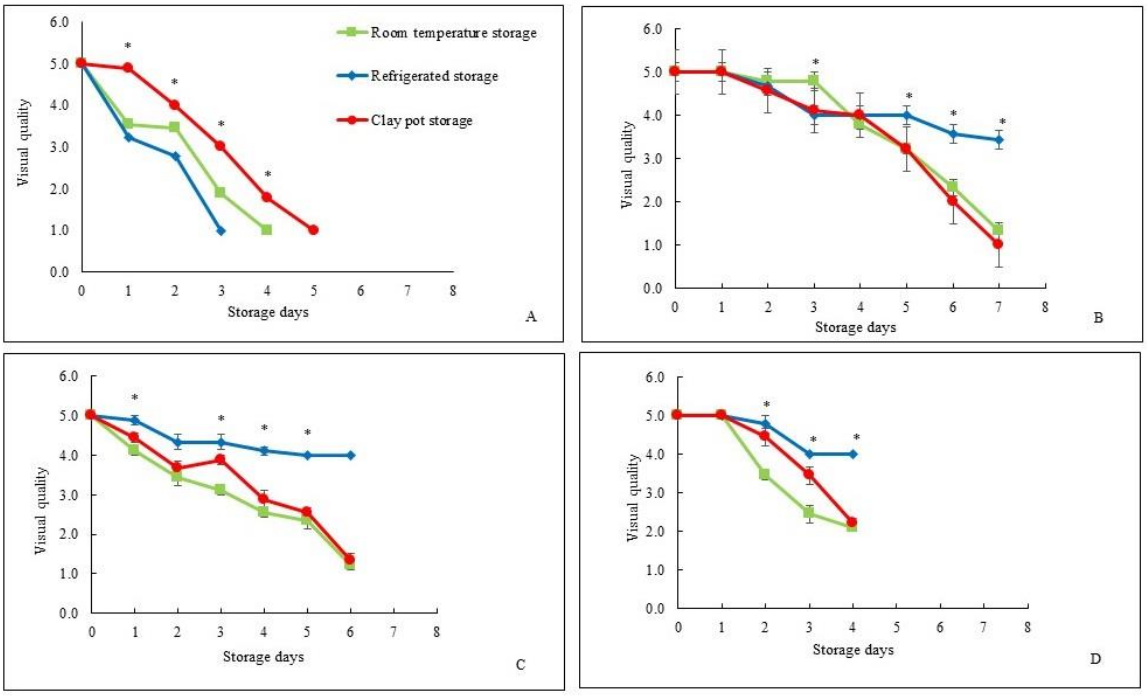

Fig. 9. Changes in visual quality in kankun (*Ipomoea aquatica*, A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp.*, C), and lettuce (*Lactuca sativa*, D) in different storage methods. Vertical bars indicate standard error (n=3). *, at each time point describe treatments that differ significantly at P ≤0.05, according to Kruskal–Wallis test

Fig. 10. Changes in visual quality in kankun (*Ipomoea aquatic,* A), gotukola (*Centella asiatica*, B), thampala (*Amaranthus spp*., C), and lettuce (*Lactuca sativa*, D), in different storage methods, room temperature storage (T1), refrigerated storage (T2), and clay pot cooler storage (T3).

DISCUSSION

As leafy vegetables are perishables, they tend to deteriorate quickly after harvesting. The rate of deterioration depends on storage conditions, including storage temperature and relative humidity. High temperature and low humidity storage conditions enhance the deterioration (Ambuko et al., 2017; Ronoh et al., 2018). Cold storage at low temperatures and high relative humidity is the most commonly used storage method to prolong the storage life of fresh produce by reducing their respiration rate. Clay pot cooler storage maintains high humidity around the harvested produce and reduces water loss and weight loss (Ambuko et al., 2017; Oliy, 2020; Ronoh et al., 2020). As clay pot cooler storage contains low temperature and high humidity conditions, it slows down the pathological activity, enzymatic activity, and respiratory activity, and makes the storage environment suitable for safe preservation.

The evaporative cooling efficiency depends on the relative humidity of the surrounding air. As water evaporates between the two pots, the temperature of the inner pot decreases. Meanwhile, the relative humidity of the inner pot increases due to the respiration of the leafy vegetables stored in the inner pot. Generally, greater temperature difference results in greater evaporative cooling efficiency.

Weight loss in fresh produce is due to continuous metabolic activity, including respiration and transpiration. The energy required to maintain the metabolic activity is obtained from respiration, which involves the oxidation of sugars to produce carbon dioxide and water. Fresh produce weight loss includes both moisture loss due to transpiration and carbon loss due to respiration (Kumara & Beneragama, 2020). The rate of weight loss in leafy vegetables was lower in clay pot coolers compared to room temperature storage. Compared to room temperature clay pot coolers have lower temperatures and higher relative humidity conditions. It slows down the pathological activities and suppresses the enzymatic activity and respiratory activity. It makes favorable storage conditions for the preservation of leafy vegetables. It reduces the rate of water loss by maintaining a higher humidity level around the leafy vegetables and the respiration rate which slows or inhibits the growth of spoilage microorganisms and minimizes metabolic activities (Chinenye et al., 2013; Liberty et al., 2013; Ambuko et al., 2017; Ronoh et al., 2020). A higher rate of weight loss was recorded in room temperature storage as it provides optimum conditions for microbial respiration and metabolic activities (Ronoh et al., 2018). Abdul-Rahaman et al. (2015) reported that lowering the temperature and increasing the relative humidity during storage reduced the weight loss of fresh produce. The weight loss for thampala (*Amaranthus spp*.) found in the present study was similar to the findings reported by Ambuko et al. (2017), which reported a lower rate of weight loss in clay pot cooler storage compared to room temperature storage. It implies that the microclimate of clay pot cooler storage minimizes the weight loss in leafy vegetables while reducing the metabolic activities of fresh produce, including respiration and transpiration. The room temperature storage enhances the respiration and transpiration of fresh produce which lead to the structural decay of the perishables. Preservation of perishables is based on lowering the temperature and increasing the relative humidity in storage conditions. It provides not only preservation but also extends the shelf-life while maintaining the quality and ultimately reducing the postharvest losses of perishables (Ronoh et al., 2018).

Soluble solids content is an indicator of the sugar content in the sample, and it depends on the maturity stage. Usually, SSC increases with the progress of the ripening as a result of the breakdown of polysaccharides (Islam et al., 2012). Soluble solids content increases only in kankun (*Ipomoea aquatica*) and the other three leafy vegetables showed a gradual reduction. Kumara and Benaragama (2020) reported a similar trend of reduction in SSC in leafy vegetables.

Many physiological changes happen with continuous respiration after harvesting. Leaf discoloration and leaf wilting are the main visible changes due to chlorophyll degradation during the storage of leafy vegetables. Further, during the storage of green vegetables, carotenoid pigments were increased, and moisture was lost (Kumara & Benaragama., 2020). Due to the chlorophyll degradation, the total chlorophyll contents of the selected leafy vegetables were gradually reduced with storage time.

Color values (L*, a*, and b*) manifest the color variations of leafy vegetables during the storage period. The hue angle shows the changes in green color from dark green (>130°) to light green (<120°) (Ambuko et al., 2017). Chlorophyll reduction and color changes were interrelated in all tested leafy vegetables. These results may be linked with the production of ethylene which affects chlorophyll degradation.

In leafy vegetables, visual quality is one of the major factors that contribute to aesthetic attributes which is directly linked to their salability. Vegetables contain 65%- 95% water. Loss of water from fresh produce causes quality losses such as visual/ appearance changes, wilting/ shriveling, and textural changes (Chinenye et al., 2013). The leafy vegetables remain fresh as long as they retain enough water. Leaf yellowing, leaf shedding, wilting, and decaying are the signs that consumers look for to determine the acceptability of the leafy vegetable. The lower temperature and high relative humidity in the storage area slow down the deterioration process including wilting and yellowing and loss of salable weight (Ambuko et al., 2017; Bihon et al., 2020; Oliy, 2020). As the clay pot cooler reduced the weight loss compared to room temperature storage, it was able to maintain the visual quality of the leafy vegetables during the storage period.

In refrigerator storage, low temperature and high relative humidity conditions are favorable to prolong the shelf-life of perishable products by reducing pathological activities and suppressing enzymatic activity and respiratory activity (Ambuko et al., 2017; Ronoh et al., 2020). In this experiment refrigerator storage and clay pot cooler showed similar variations in chlorophyll content, soluble solids content, and hue angle in leafy vegetables. Comparatively refrigerator storage showed a lower rate of weight loss and visual quality reduction with room temperature storage and clay pot cooler storage. In conclusion, while comparing the results of all three storage methods tested for leafy vegetables the clay pot cooler storage can be introduced as one of the low-cost and effective storage methods to prolong the postharvest life and preserve the postharvest quality of fresh produce, including leafy vegetables.

CONCLUSION

The present study showed that the leafy vegetables stored in clay pot coolers (25.4 ± 0.1 °C; 93 ± 0.8% RH) had the best quality compared to room temperature storage. The clay pot cooler was significantly effective ($P \leq 0.05$) in maintaining the total chlorophyll content, soluble solids content (SSC), color, and visual quality of leafy vegetables. Therefore, the clay pot cooler is an alternative low-cost storage method to preserve the postharvest quality of leafy vegetables.

Conflict of interest

The authors declare that there is no conflict of interest.

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