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A Study on Low Cost Post Harvest Storage Techniques to Extend the Shelf Life of Citrus Fruits and Vegetables

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An attempt was made to develop low cost porous evaporative cooling storage structures for extending the shelf life of citrus fruits and vegetables at the Sylhet Agricultural University campus, Bangladesh. Clay soil, bamboo and straw were used as a wall material. Sand, clay, zeolite, rice husk and charcoal etc. were used as a pad material. But the mixture of sand and clay was found as the most efficient pad materials for lowering temperature. Porous evaporative cooling storage structure (PECSS) was developed to reduce the problems of post-harvest losses at farmer level. It is eco-friendly and no energy requirements for storage of vegetables and fruits. PECSS improves the quality and productivity of vegetables and citrus fruits by reducing temperature, prolonging shelf life and reducing post-harvest losses respectively. The study revealed that shelf life of egg-plant (*Solanum melongena)* was 11 days in PECSS condition and it was 6 days in ambient condition. Therefore, weight loss was 4.07% for PECSS and 11.84% in room condition respectively. Storage life of Ladies finger (*Abelmoschus esculentus*) was 6 days more in PECSS

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condition than room condition. Weight loss was 6.62% in PECSS condition and 17.47% loss in ambient condition. In case of Malabar Spinach (*Basella alba*) it was 6 days for PECSS condition and 3 days for room condition and weight loss was found to be 9.48% and 16.17% respectively. The shelf life of stem amaranth (*Amaranthus cruentus*) was 5 days in PECSS condition and 2 days in ambient condition. Weight loss was found 7.05% at PECSS condition and 28.62% as in-room condition. By chemical analysis for fruits lemon (*Citrus limon*) and orange (*Citrus sinensis*) found that pH and TSS were increased both ambient and PECSS condition but in PECSS condition this rate was less than ambient condition. Vitamin C, percentage juice content, citric acid values all were decrease at both condition but in PECSS condition its rate was the less ambient condition. There is scope for intensive study to improve the firmness of the porous evaporative cooling storage structure (PECSS) to reduce the storage loss of vegetables and citrus fruits for different region and its suitability for large scale design.

Keywords: Shelf life; citrus fruits; vegetables; porous evaporative cooling; pad materials.

1. INTRODUCTION

Bangladesh is an agriculturally based country. According to (BBS, 2011) reported that more than 80% of the total population is engaged in agriculture and more than 50% of the population is depend agriculture for their livelihood. Bangladesh is honored with around 90 sorts of vegetables and natural products nearly all through the nation and developed throughout the entire year. The limit of normal yearly temperature is 24.8°C and least temperature is 12°C and yearly precipitation is 3876 mm. Due to the highly perishable nature about 20-30% of total fruits and 30-35% of total vegetables production go waste during various steps of post-harvest chain [1].

Evaporative cooling is the procedure by which the temperature of a substance is decreased because of the cooling impact from the dissipation of water. The change of reasonable warmth to dormant warmth causes a decline in the encompassing temperature as water vanished give helpful cooling. This cooling impact has been utilized on different scales from little space cooling to enormous mechanical applications [2].

Shelf life is defined as the period of time during which the food product will remain safe; be certain to retain its desired sensory, chemical, physical, microbiological, and functional characteristics; where appropriate, comply with any label declaration of nutrition data, when stored under the recommended conditions." Both food safety and quality are important aspects of standard shelf life.

In developing countries, storage has been observed to pose a greater threat to fruits because information on the storage temperature, humidity requirements and the length of time they can be kept without a decline in market value is either inadequate or unknown to those who need the information [3]. Deterioration of natural products during capacity to a great extent relies upon temperature. One approach to expand the timeframe of realistic usability of natural products by bringing down of the temperature. Extraordinary low temperature can make harm farming produce and when the item leaves the area of controlled temperature, decay begins once more [4]. So as to keep up the nature of put away organic products, they are ordinarily kept in moist conditions [5].

Sylhet area is privileged with abundant citrus organic products however because of absence of appropriate storage facilities post-harvest loss is additionally momentous. One way to slow down deterioration and thus increases the length of time citrus fruits can be stored, is by lowering the temperature to an appropriate level. On the off chance that the capacity temperature is too low the item will be harmed and furthermore when the item leaves the cold store, decaying begins again and frequently at a quicker rate. It is essential that citrus fruits are not damaged during harvest and that they are kept clean. Damaged and bruised fruits have much shorter storage lives and very poor appearance after storage [6,7] stated that keeping products at their lowest safe temperature (0°C for temperate crops or 10-12°C for chilling sensitive crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss.

As indicated by a report of the National Academy of Science, Washington, DC (Anonymous, 1978) the post- harvest losses of transitory items like vegetables may be 80-100% in certain occasions. With lost around 10 - 15% in fresh weight, vegetables wilted and arrive at a condition of low market worth and purchaser acceptability. Every item took care of has its own specific temperature prerequisites. The time until cooling, temperature strength and its term should be considered. By bringing down produce temperature at the earliest opportunity after gather, for the most part inside four hours and the accompanying impacts are accomplished: breath rate is diminished, water misfortune is decreased, ethylene creation is stifled, affectability to ethylene is decreased, microbial advancement is eased back. Most leafy vegetables and 'temperate' fruit including pome and citrus fruits are not chill-sensitive and can be stored between 0°C and 2°C for long periods without significant loss of visual quality. Tropical and subtropical fruit and some root vegetables are chill-sensitive and may be damaged at low temperatures. They are generally stored at 13°C or above, although some may be stored safely as low as 5°C if cooled soon after harvest. Temperature must also be stable as changes may affect respiration and marketable quality. The present traditional methods of harvesting, handling, packaging and storing of vegetables can be improved with a little additional coast or interference with the existing marketing practices [8].

Much of the postharvest losses of fruits and vegetables in developing countries are due to the lack of proper storage facilities. Refrigerated cold stores are the best strategy of preserving fruits, yet they are costly. Thus, in the developing countries, for example, Bangladesh and especially in South-East Asia where most organic products are developed there is an enthusiasm for straightforward, minimal effort options, a large number of which rely upon basic evaporative cooling [9].

There is need to anticipate the misuse of new citrus foods grown from the ground during capacity by receiving a more up to date storage technique with or without vitality cooling load has been created and stretched out to the farmer fields from the view purpose of ease. Porous evaporative cooling storage structure (PECSS) is a double wall structure having space between the walls which is filled with porous water absorbing materials called pads. These pads are kept constantly wet by applying water. When unsaturated air passes through wet pad, transfer of mass and heat takes place and energy for the evaporation process comes from the air stream. Evaporative cooling is an adiabatic procedure happening at steady enthalpy. This is the most practical method for diminishing the temperature by humidifying the air. It has numerous points of interest over refrigeration framework, as it doesn't utilize refrigerant so it is agreeable to condition (decrease carbon-dioxide). It doesn't make noise as it has no moving part. It does not use electricity i.e. saves energy. It does not require high initial investment as well as operational cost is negligible. It can be quickly and easily installed as this simple design. Its maintenance is easy. It can be constructed locally available materials in remote area and most important, it is eco-friendly as it does not need CFC.

Previous studies conducted on evaporative cooling storage of fresh produce have shown that temperature can be maintained 10-15°C below the normal ambient while relative humidity can be increased up to 90% [10], Ogbuagu et al. [11] worked on the performance evaluation of a composite-padded evaporative cooling storage bin. The facility was able to sustain tomatoes, garden eggs and carrots for 10 days. Zakari et al. [12] intended and built an evaporative cooler for tomato storage. The tomatoes had a shelf life of 5 days with negligible changes in weight, color, firmness and rottenness. Deoraj et al. [13] stored tomatoes in evaporative cooler and this was initiate to be the best storage method in terms of preserving the acidity of tomatoes as well as their total soluble solids.

Earthenware Cool Chamber (ECC) is an eco-friendly, non-toxic, less expensive and biodegradable pot which is made up of readily available materials. A double vessel ECC is designed to increase the shelf life of stored fruits and vegetables. Working on the principle of evaporation, a Pusa Zero Energy Cool Chamber (PZECC) can be effortlessly constructed anywhere with locally available materials. Evaporative cooling system not only lowers the air temperature surrounding the produce, but also increases the relative humidity of the air. The higher relative humidity retains the water content of post harvested sample. This helps prevent the drying of the products, therefore extending the shelf life of horticultural products. Evaporative cooling system is well suited in areas where temperature is high, humidity is low, and sparse air movement is available. The evaporative chambers are easy and efficient cooling systems that can reduce energy use by

70% and are less expensive to install, operate and maintain. It is economical and can store the fruits and vegetables for 7 to 9 days without any significant loss [14].

Previous studies also shown that evaporative cooling can be used to attain significantly lower than ambient temperatures and higher than ambient relative humidity. Studies presented that a high relative humidity (85–90%) in a zero-energy cool chamber (ZECC) compared to 21–94% in the case of the shed and field which showed great fluctuation. Similarly, relatively low temperatures were attained in ZECC with less fluctuation in maximum and minimum temperatures compared to shed and field conditions. Under ZECC storage, the shelf-life of fruits and vegetables increased with lower physiological weight loss recorded compared to room temperature. A 10–15°C temperature difference between the inside of an evaporative cool chamber and the outside was reported by. In the same chamber, the RH inside was 30–40% higher than the outside. Under these conditions, wilting and loss of freshness were significantly slowed thereby keeping the fruits and vegetables fresh for up to 3–5 days more inside the chamber than outside [15]. Various reports indicate that EC rooms have proved to be useful for short term, on-farm storage of fruits and vegetables in hot and dry regions. These structures work on the principle of evaporative cooling which is an effective and economical means for reducing the temperature and increasing the RH of an enclosure i.e. storage room and has been extensively tried for enhancing the shelf life of horticultural produce [16].

Verploegen, E. et al. [17] showed that the evaluation of six types of ECCs and clay pot coolers provided insights into user preferences as well as performance related to metrics such as interior temperature and humidity, ease of watering, and protection from animals and insects. The low-cost evaporative cooling devices such as clay pot coolers and ECCs have the potential to benefit both off-grid populations with limited access to electricity and on-grid populations with high electricity and/or high equipment costs for refrigerators. The reduced post-harvest losses achieved through the improved storage environment can lead to impacts including monetary savings, less time spent traveling to the market, and increased availability of vegetables for consumption.

Yet, the problem of inadequate storage facilities for fresh citrus fruits and vegetables after being harvested in Sylhet, consequence to the decrease in the quantity that gets to the market; this also has a through effect on the economic distribution and consumption of the needed quantity for human sustainability. Henceforth, the purpose of this work is to design and construct a porous evaporative cooling storage structure that will temporarily store fresh citrus fruits and vegetables to upsurge the shelf life before economical distribution, consumption and for processing. This study established that shelf life of citrus fruits and vegetables can be extended by the practice of porous evaporative cooling storage structure.

1.1 Objectives

- To compare the storability of citrus fruits and vegetables under porous evaporative cooling storage structure and the ambient temperature in this region.
- To justify the economic return of storing fruits and vegetables under this structure.

2. MATERIALS AND METHODS

2.1 Establishment of Modified Cooling Structure

I. Location: The structure was set up in the department of agricultural construction and environmental engineering, Sylhet Agricultural University (SAU) laboratory at room temperature.

II. Wall material: Clay soil, bamboo, straw.

III. Pad materials: Structure Pad is important part of PECSS. Many researchers have studied the effect of cooling pads on cooling efficiency. Used pad materials are sand, clay, zeolite, rice husk, char coal etc. Commercial pads gave good saturation efficiency, as they are specially made but they are expensive and not suitable to low income farmers and traders. Locally and easily available pads performed better with RH above 90% and maximum temperature drop of 12°C. However, performance is dependent on outside weather but saturation efficiency can further be increased by creating good porosity and air-water contact within pad. Performance of the pad material depends on outside weather, both temperature and humidity but the material having good porosity and air-water contact within the pad performed better as compared to others.

IV. Design construction: The structure consisted of a double walled soil structure with one heat insulating drip proof top. A double layered wall on all four sides around the platform was erected with soil and it was with leaving space between double wall was 5 cm. Spaced between double wall was fill up by pad materials. After the construction completed, the top opening was covered by straw materials.

Experimental Method: To ensure low temperature and high RH in the storage, wetting pad materials should be done twice a day by drip system with plastic pipe and micro tubes connected to water source. It can be done manually. At initial stage water is required twice a day but certain period of time water is required, after one or two days later because pad materials remained saturated condition. After installation of all the mechanical aids the effectiveness of the structure will test whether it can lower temperature or not. RH value of the structure can predict the efficiency of the structure. Prediction can be done from the 3 days consecutive recorded values of the RH and temperature on RH/T meter. Then selective types of fruits and vegetables storage in the structure. The fresh citrus fruits and vegetables of uniform size and color was sorted as sample from the farmer's field randomly. Then five kg of sample were collected using sterile polythene bags to protect it from the possible contamination and loss of moisture content. Then the produces were cleaned and put in a box to preserve in the PECSS. Each test day, the box of citrus fruits and vegetables were taken down and sampled from both PECSS and ambient condition. The sample was weighed, organoleptic quality noted, and photos taken for visual documentation of produce condition. After samples were

Fig. 1. Developed double wall with cavity

Fig. 2. Pad materials mixing

Fig. 3. Developed double wall with slightly burned

Fig. 4. Filling pad materials and-installed laboratory

Fig. 5. Finally covering the structure with straw materials

photographed, they were set back into the inside of PECSS. The shelf life of vegetables is determined on the basis of physiological weight loss, off colors and other changes in organoleptic quality. The change in pH, TSS, citric acid, Vitamin C, juice content and physiological weight loss were considered as an index for shelf life determination of citrus fruits. Then the data was compared in both condition in graphical method.

2.2 Method of Storage

Physiological Weight Loss: The differences in weight of the fruits and vegetables stored in both the ambient and in the cooler condition for difference days are estimated. The weight loss was determined by weight balance and the percentage of weight loss was estimated using Equation (1) as given by Fabiyi, [6].

Percentage Weight loss =original weight-new weight original weight ×100

Color Changes and Firmness: The changes in color of the fruits and vegetables were noted both in the cooler and in the encompassing condition related to the physiological weight reduction. The shading changes watched depended on the physical appearance of the foods grown from the ground Fabiyi [6]. The physical surface of the fruits and vegetables was inspected and noted. The distinction in the solidness was likewise noted in the wake of putting away the vegetables in the evaporative cooling system and in surrounding condition.

Chemical analyses: Ten healthy fruits were randomly selected prior to the experiment, after storage inside the evaporative cooing storage structure, for physiological and chemical analysis. These include

(a) Juice pH- pH concentrations in the juice were determined following extraction of juice in 50 ml flux at 27°C with a digital pH meter.

(b) Total soluble solid content (TSS)-Total soluble solid content determined by portable refractometer.

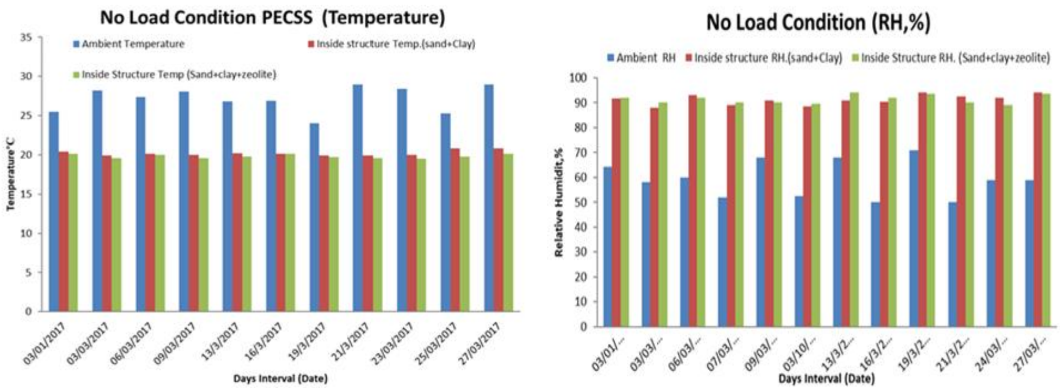
(c) Percent juice content determination: The juice contents were weighed and recorded in grams [18]. The percent juice contents were calculated by using the following formula; % juice contents = juice weight ÷ fruit weight x 100

(d) Ascorbic acid (Vitamin C) content: Vitamin C content was determined following the method of Rangana [19]. A beaker of appropriate volume was used to gather the solutions listed under the materials list. A clean eyedropper was placed in each solution. Standardization of dye solution with standard Vitamin C was done. Using an eye dropper, precisely 5.0 ml of standard Vitamin C solution was added to a 10 ml graduated cylinder. Volume of standard Vitamin C solution and concentration of standard Vitamin C solution was recorded. With an eye dropper, one or two drops of dye solution to the graduated cylinder was added. The graduated cylinder was shaken to mix the standard Vitamin C and dye mixture. Continue adding dye solution until the reaction mixture changes color to a pink color. The volume of the reaction mixture at the end point was recorded. Their action mixture into a waste beaker then rinsed the graduated cylinder with about 1 ml of standard Vitamin C was discarded. The titration was repeated. The total volume of reaction mixture for two titrations agrees to ± 0.2 ml, if the total volume of reaction mixture for two titrations does not agree to ± 0.2 ml, a third titration is needed.

3. RESULTS AND DISCUSSION

3.1 No Load Test of the Evaporative Cooling System

A no-load test of the PECSS was conducted to observe the effect of the evaporation that was expected to take place in PECSS shown in Fig. 6. The dry bulb temperature and relative humidity data determined whether the process was effective or not. This is necessary in order to determine structure efficiency before being loaded with the fruits and vegetables that will be stored within the structure. This was achieved by taking temperature difference and the relative humidity of the PECSS relative to the ambient condition. The average temperature was varied from 24°C-29°C and relative humidity was 50%-71% in ambient condition at winter season. The inside temperature of the PECSS was 19.9 to 20.8°C and relative humidity was 88% to 94% when sand and clay was used as a pad material and after that temperature was varied from 19.5 to 20.2°C and relative humidity 89% to 93% when sand, clay and zeolite was used as a pad material that was shown in Fig. 7. So, the average variation in temperature was 5-9°C and relative humidity was 22-30%. Therefore, it is clear that sand and clay mixture can efficiently use for miniature structures like PECSS. According to Verploegen, 2018 the variation of average temperature is in between 5.1°c to 8.6°c depending on the relative humidity [17].



(a) (b)

Fig. 6. Comparison between (a) ambient temperature and the temperature and (b) ambient relative humidity and the relative humidity inside the porous evaporative cooling storage structure at winter

3.2 Load Test of the Evaporative Cooling System

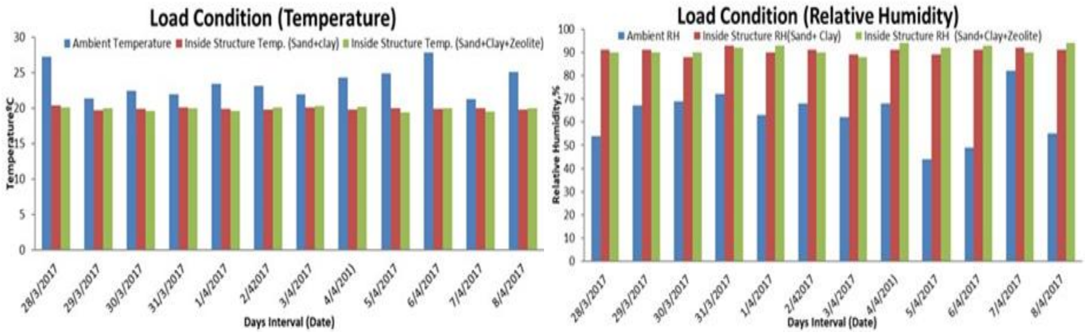
The performance of evaporative cooler was evaluated from 28th March to 8th April, 2017. The average temperature inside the structure varied from 19.4°C to 20.3°C with the pad material of sand, clay and zeolite while in the ambient air temperature varied from 21.3°C to 27.8°C (Fig. 7(a)). If pad material changed to a mixture of sand and clay the variation was found from 19.7°C to 20.4°C. Henceforth, relative humidity in ambient condition was 44 to 82% in the experimental period which was varied to 73 to 93% for the pad material of sand and clay as well as slightly increased to 88 to 94% additional mixture of zeolite in pad material (Fig. 7(b)). So, the average relative humidity increased inside the structure with pad material of sand and clay was 27.8% while it was 28.3% increased inside the structure with pad material of sand, clay and zeolite. It was seen that there is increment in the framework relative moistness in connection to that of the encompassing condition. It has been accounted for by ASHRAE (1982), that the required storage relative humidity of vegetables ranges from 85 to 90%, hence the system relative humidity achieved ranges from 80.0 to 90.0% which closely agrees with that reported by ASHRAE (1982). The after effect of the normal storage temperature of orange, lemon, eggplant, ladies-finger, red amaranth, spinach accomplished in the framework ranges from 19.4 to 20.3°C and in the meantime, the temperature of the surrounding ranges from 21.3 to 32.4°C. This implies that the difference between the ambient and evaporative cooling system was highly significance and therefore the use of evaporative cooling system for preservation of fruits and vegetables cannot be neglected. In any case, high relative humidity expands the timeframe of fresh vegetable and in this way, the permeable evaporative cooling storage framework with mean 90.32% gave the higher relative humidity than that of surrounding condition with mean 60%. Henceforth, the porous evaporative cooling storage system should be used in preservation fresh fruits and vegetables.

3.3 Compare Price between Refrigeration and Porous Evaporative Cooled Storage Structure

In porous evaporative cooling storage structure construction cost was required no need operational cost like electricity or others equipment. Water was supplied daily and it can be considered if have scarcity of water nearby the source. On the other hand, refrigerator needs high initial cost and operational cost like electricity.

3.4 Construction Cost of Porous Evaporative Cooled Storage Structure

For constructing a porous evaporative cooling storage structure labor, pad material cost, thatched shed and plastic basket included. Among them the highest 39% of this total cost were required for bricks, moderate 19% cost was required for labor and the lowest 9% of the total cost were required for bamboo. Total cost for three units of PECSS was TK. 2450. The construction cost of several materials was shown on the Fig. 8.



(a) (b)

Fig. 7. Comparison between (a) ambient temperature and the temperature and (b) ambient relative humidity and the relative humidity inside the porous evaporative cooling storage structure

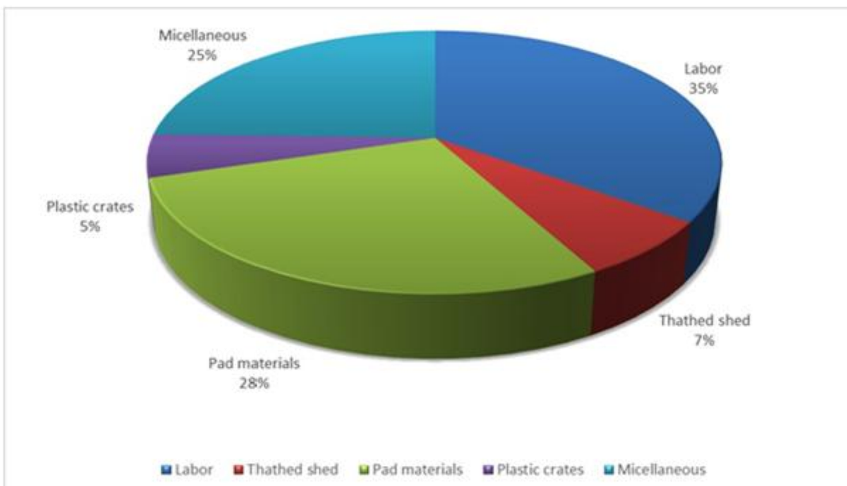


Fig. 8. Construction cost of several materials

3.5 Physiological Weight Measurement of Ladies-Finger

The results of physiological weight loss and percentage of weight loss of ladies-finger during the experiment is shown in Table 1. These results revealed that the weight loss of ladies-finger in the PECSS ranged from1.0 to 1.15 g per day while that of ambient system ranges from 5 to 6 g per day while the percentage of weight loss of ladies-finger in PECSS and ambient ranged from 0.60 to 0.70% and 2.70 to 2.97% per day respectively. This means that the difference between the ambient and evaporative cooling system was highly significant and therefore the use of evaporative cooling system for preserving and improving the shelf life of ladies-finger cannot be avoided. Due to the slower reduction of temperature and higher relative humidity inside the PECSS the mechanical stress is minimal inside the PECSS and this contributes in minimum physiological weight loss. The acceptable limit of physiological weight loss is 10-15% according to Jha [20] and Olosunde [21].

3.6 Physiological Weight Loss of Egg-plants

Table 2 indicated the aftereffects of physiological weight reduction and level of weight reduction of brinjal during the analysis. These outcomes uncovered that the weight reduction of in the PECSS went from1.25 to 1.36 g every day while that of surrounding framework ranges from 3.5 to 3.75 g every day while the level of weight reduction of egg-plants in PECSS and encompassing extended from 0.65 to 0.71% and

1.85 to 1.97% every day separately. This implies the contrast between the surrounding and PECSS was profoundly noteworthy and consequently the utilization of PECSS for protecting and improving the timeframe of realistic usability of egg-plants can't be stayed away from.

In case of physiological weight loss, the range is in between acceptable limit which is also similar in Jha [20] and Olosunde study [21].

3.7 Physiological Weight Loss of Malabar Spinach (*Basella alba*)

Table 3 presented the results of physiological weight loss and percentage of weight loss of Malabar Spinach during the experiment. These results also revealed that the weight loss of Malabar spinach in the PECSS ranged from 3.4 to 3.56 g per day while that of ambient system ranges from 8.30 to 8.40 g per day while the percentage of weight loss after 7 days in PECSS and ambient condition was14.58% and 34.84%. Up to 6 days the physiological weight loss is in between 10-15% in PECSS condition which is satisfactory according to Jha [20] and Olosunde [21].

3.8 Physiological Weight Loss of Stem Amaranth

Table 4 specified the aftereffects of physiological weight reduction and level of weight reduction of stem amaranth during the examination. These results revealed that the weight reduction of spinach in the PECSS went from 2.70 to 2.90 g every day while that of encompassing framework ranges from 9.30 to 9.95 g every day and the level of weight reduction following 7 days in PECSS and surrounding condition was10.92% and 38.72%. Therefore, Stem Amaranth can be stored maximum 7 days within permissible limit [20,21].

Table 1. Physiological weight measurement of ladies-finger

Days after storage	Initial weight both ambient condition and evaporative cooling system	Weight loss of ladies-finger in evaporative cooling system (PECS)	Percentage of weight loss in PECS, %	Weight loss of ladies-finger in ambient condition	Percentage of weight loss in ambient condition, %
2 days		197.45 gm	1.27	192.23 gm	3.88
4 days		195.84 gm	2.08	183.13 gm	8.44
6 days	200 gm	192.21 gm	3.9	163.68 gm	18.16
8 days		190.24 gm	4.88	151.59 gm	24.20
11 days		187.53 gm	7.73	134.65 gm	32.68

Table 2. Physiological weight loss of Egg-plants

Days after storage	Initial weight both ambient condition and evaporative cooling system	Weight loss of Egg-plants in PECSS	Percentage of weight loss in PECSS, %	Weight loss of Egg-plants in ambient condition	Percentage of weight loss in ambient condition, %
2 days		188.98 gm	1.56	185.43 gm	2.40
4 days	190 gm	186.63 gm	1.68	177.51 gm	6.57
6 days		182.45 gm	3.77	167.87 gm	11.64
8 days		179.68 gm	5.43	157.97 gm	16.85
11 days		174.97 gm	7.91	148.65 gm	21.76

Table 3. Physiological weight measurement of Malabar spinach (*Basella alba)*

Days after storage	Initial weight both ambient condition and evaporative cooling system	Weight loss of Malabar Spinach in PECSS	Percentage of weight loss in PECSS, %	Weight loss of Malabar Spinach in ambient condition	Percentage of weight loss in ambient condition, %
2 days		165.0	2.94	158.10	7.0
4 days	170 gm	157.30	7.46	140.80	17.17
6 days		148.0	12.94	128.64	24.33
7 days		145.20	14.58	110.77	34.84

Table 4. Physiological weight measurement of Stem amaranth

Days after storage	Initial weight both ambient condition and evaporative cooling system	Weight loss of stem amaranth in PECSS	Percentage of weight loss in PECSS, %	Weight loss of stem amaranth in ambient condition	Percentage of weight loss in ambient condition, %
2 days		174.16	3.24	160.23	10.98
4 days	180 gm	168.69	6.28	126.93	29.49
6 days		165.98	7.78	116.48	35.26
7 days		160.34	10.92	110.34	38.72

3.9 Weight Loss during Storage in PECSS

The weight of fresh citrus fruits in the PECSS and ambient storage significantly differed over the course of the experiment that was showed in the Fig. 9.

It controlled the weight loss of 8% in PECSS in contrast to ambient condition for orange and 21% for Lemon. In PECSS storage condition physiological weight loss is less than 5% for orange and less than 10% for lemon, so it maintain optimum storage loss according to Jha [20] and Olosunde [21].

3.10 Changes in pH Value

There was a significant difference in the value of lemon fruits either in the evaporative cooling chamber or in ambient storage. An increase in pH value was observed in the ambient storage after 6 days and thereafter it increased significantly as well as in the evaporative cooling chamber.

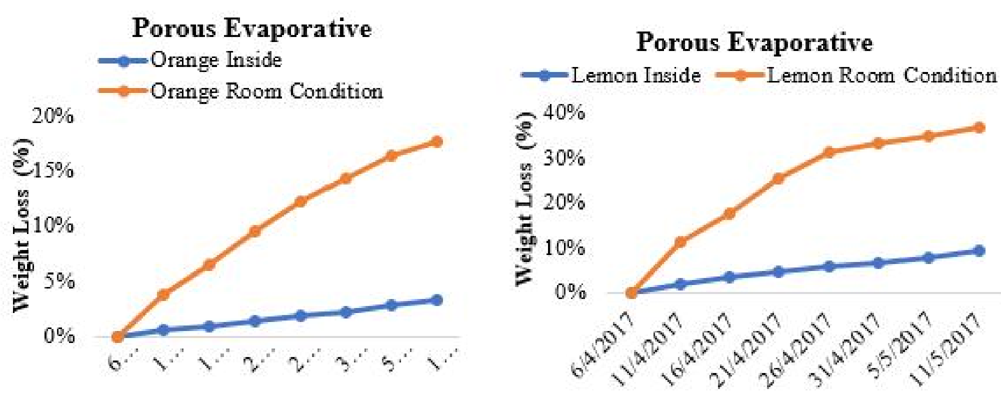


Fig. 9. Graphical representation of Weight loss percentage of (a) Orange/Citrus reticulate and (b) Lemon (Pate lebu)/Citrus lemon in PECSS

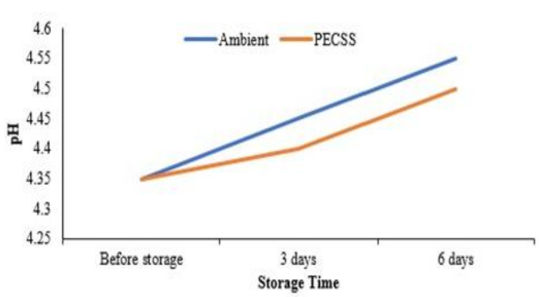


Fig. 10. pH value of orange

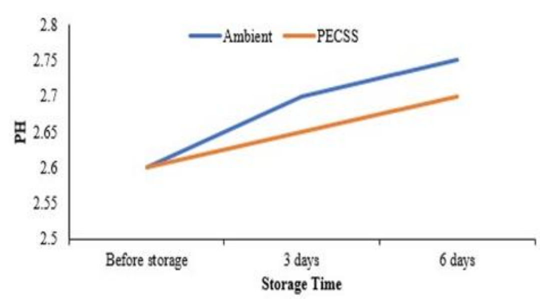


Fig. 11. pH value of lemon

3.11 Changes in TSS Value

A gradual increase in total soluble contents was observed in all samples during storage, which could be attributed to water loss. This result may have been related to the persistent consumption of sugars and organic acids for lime tissue metabolism, rather than the solute concentration effects, during long term storage. Ambient storage time shows significant difference in soluble solid contents even in initial stages.

3.12 Changes of Percentage Juice Content

Juice content decreased in PECSS slowly over day than in ambient condition is shown in Figs. 14 and 15.

3.13 Changes of Vitamin C

Over a period of time it was observed that Vitamin C is gradually decreased both ambient and PECSS but in ambient condition Vitamin C is decreased more than in PECSS is shown in Figs. 16 and 17.

3.14 Changes in Citric Acid

It was observed that citrus acid is continuously diminished both ambient and PECSS however in encompassing condition citrus acid is diminished more than in PECSS is shown in Figs. 18 and 19.

In case of pH, TSS, juice content, Vitamin C and Citric Acid the trend of change is similar with Marikar [22].

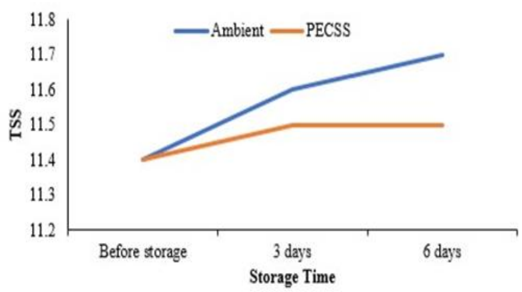


Fig. 12. TSS value of orange

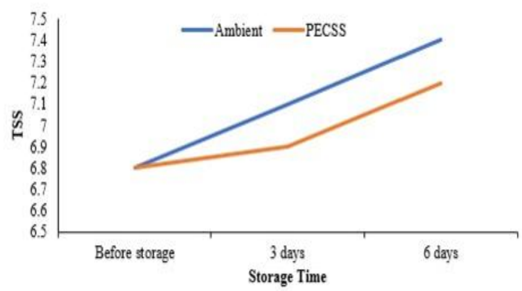


Fig. 13. TSS of lemon

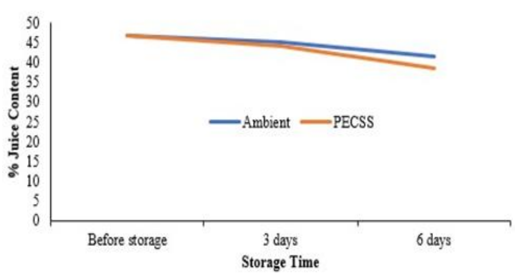


Fig. 14. Juice content of orange

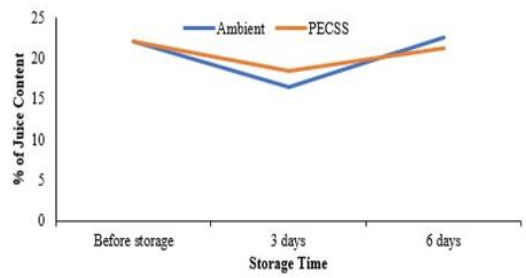


Fig. 15. Juice content of lemon

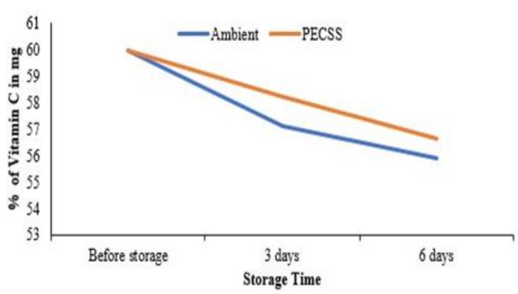


Fig. 16. Vitamin C in orange

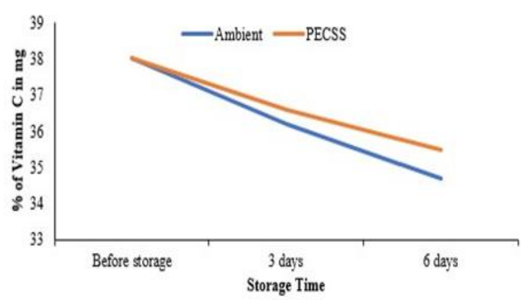


Fig. 17. Vitamin C in lemon

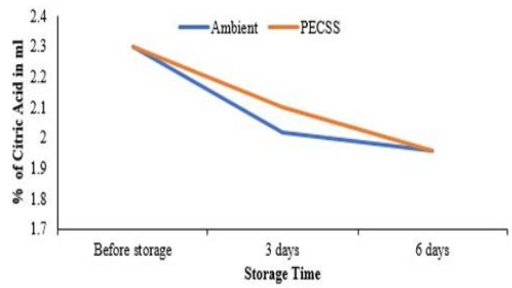


Fig. 18. Citric acid in orange

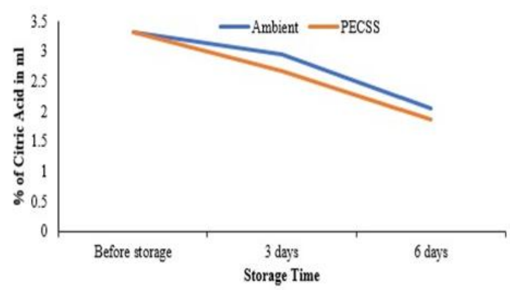


Fig. 19. Citric acid in lemon

3.15 Effect of Storage System on Color and Firmness of Egg-plants (*Solanum melongena)*

Egg-plants were stored in the PECSS and outside the chamber. The changes in color as the storage progressed were observed. The color of the egg-plants in outside chamber and Porous evaporative cooled chamber storage gradually changing with time. From Figs. 20-23 it was observed that the color and firmness were remain unchanged 11 days in PECSS whereas color and firmness were remained pure 6 days in ambient condition. In PECSS shelf life were increased 5 days compared with ambient storage system. According to Verploegen [17] using this type of storage method the shelf life of the eggplants is 10± 5 days.

3.16 Color Changes of Egg-plants Brinjal in Porous Evaporative Cooling Storage System (PECSS)

From Figs. 20-23 indicated the color changes of Egg-plants Brinjal in PECSS storage system.

3.17 Color Changes of Egg-plants in Ambient Condition

From Figs. 24-27 showed the color changes of Egg-plants Brinjal in ambient condition.

3.18 Effect of Storage System on Color and Firmness of Ladies-Finger *(Abelmoschus esculentus)*

The color and firmness changes of ladies-finger were observed and noted in Figs. 28-31. The colors were marginally changed from greenish to yellowish following 8 days yet not being disintegrated in PECSS While in surrounding condition shading and solidness were changed from greenish to yellowish following 5 days and weakened inside 7 days. In PECSS timeframe of realistic usability were expanded 6 days than the ambient condition.

3.19 Color Changes of Ladies-Finger in Porous Evaporative Cooling System (PECSS)

From Figs. 28-31 indicated the color changes of ladies-finger in PECSS storage system.

3.20 Color Changes of Ladies-finger in Ambient Condition

From Figs. 32-35 showed the color changes of ladies-finger in ambient condition.

3.21 Effect of Storage System on Color and Firmness of Malabar Spinach *(Basella alba)*

From Figs. 36-39 predicted that greenish to yellowish color were happened after 5 days but not being fully deteriorated in PECSS however in ambient condition color and firmness were altered from greenish to yellowish after 2 days and fully deteriorated within 4 days. Shelf life were increased 3 days compared with ambient storage system during the PECSS.

3.22 Color Changes of Malabar Spinach *(Basella alba)* in PECSS

Here, Figs. 36-39 showed color changes of Malabar Spinach in PECSS condition.

3.23 Color Changes of Molabar Spinach (*Basella alba*) in Ambient Condition

Therefore this study revealed that inside the PECSS the organoleptic quality change is slower than the ambient condition and it contributed in increasing the shelf life of fruits and vegetables.

Fig. 20. Before storage

Fig. 21. After 7 days

Fig. 22. After 11 days

Fig. 23. After 14 days

Fig. 24. Before storage

Fig. 25. After 3 days

Fig. 26. After 6 days

Fig. 27. After 8 days

Fig. 28. Before storage

Fig. 29. After 5 days

Fig. 30. After 8 days

Fig. 31. After 11 days

Fig. 32. Before storage

Fig. 33. After 5 days

Fig. 34. After 6 days

Fig. 35. After 8 days

3.24 Effect of Storage System on Color and Firmness of Stem Amaranth (*Amaranthus cruentus)*

Stem amaranth color and firmness changes were detected and showed in Figs. 44-47. The color and firmness were changed after 4 days and fully deteriorated within 6 days in PECSS. Although in ambient condition color and firmness were changed following 2 days and completely disintegrated inside 3 days. In PECSS timeframe of realistic usability were expanded 2 days. Using evaporation cooling the shelf life of leafy vegetables can have increased up to 3-5 days according to Ambuko, [15].

3.25 Color Changes of Steam Amaranth Leaf in PECSS

From Figs. 44-47 indicated color changes of stem amaranth leaf in PECSS condition.

3.26 Changes of Steam Amaranth Leaf in Ambient System

Changes of steam Amarnath leaf in ambient system is showed in Figs. 48-51.

Fig. 36. Before storage

Fig. 37. After 3 days

Fig. 38. After 5 days

Fig. 39. After 7 days

Fig. 40. Before storage

Fig. 41. After 2 days

Fig. 42. After 4 days

Fig. 43. After 5 days

Fig. 44. Before storage

Fig. 45. After 4 days

Fig. 46. After 6 days

Fig. 47. After 7 days

Fig. 48. Before storage

Fig. 49. After 2 days

Fig. 50. After 3 days

Fig. 51. After 5 days

4. CONCLUSION

The most convenient ways of preserving the fresh produce in temporary basis at farmer scale is evaporation cooling. The design and development of Porous Evaporative Cooling Storage Structure (PECSS) is to make an evaporation cooler which can be used as a household commodity to reduce the space requirement as well as to increase the shelf life of the citrus fruits and vegetables. The PECSS can maintain relatively low inside temperature and high relative humidity as compared with ambient temperature and relative humidity due to the porosity and evaporative mechanism of pad material which minimal the mechanical stress on samples and slower the organoleptic quality change contributing in increase of shelf life. By this experiment it is observed that in PECSS temperature reduced about 5-9°C.In contrast the relative humidity was increased about 90% in average inside the PECSS which was about 60% in average for ambient condition. Mixture of sand and clay can be efficiently used as the pad material of this types of structures. The average weight loss of ladies-finger *(Abelmoschus esculentus)* both in ambient and PECSS was 17.472% and 6.62% respectively. Similarly, for egg-plant (*Solanum melongena*) both in ambient and PECSS was 11.844% and 4.07% respectively. On an average the marketable quality and shelf life of these types of vegetables can be increased about 5 days. In case of leafy vegetables like Malabar Spinach *(Basella alba*) and stem amaranth (*Amaranthus cruentus*) the shelf life can be increased up to 3 days by using PECSS. The citrus fruits such as lemon (*Citrus limon)* and orange (*Citrus sinensis*) pH was increased both ambient and structure but in PECSS its range was less than ambient. Citrus can be stored in PECSS for prolonging shelf life with marketable quality because of less change was found in TSS, Citric acid and Vitamin C. Therefore, shelf life of the citrus fruits and vegetables were increased due to the storage condition in PECSS similar to other evaporation cooler [5,7,17,18,22]. This structure is fragile in nature. So, an intensive research can improve its firmness in large scale design. If anyone want to made this structure with large size, it will be needed to half burning then full burning because full burning has more possibility to cracking and this problem faced in this research. Due to the power shortage and high expense in conventional cold storage or refrigeration system this types of low cost PECSS is an emerging technique to adopt for reducing the post-harvest losses of fruits and vegetables for low income farmers in Bangladesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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