Post-harvest storage of lime fruits (*Citrus aurantifolia*) following high humidity and low temperature in a modified brick wall cooler

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Abstract: The use of a modified brick wall Evaporative Cooling Chamber (ECC) for extending the shelf life of limes (*Citrus aurantifolia*) was compared with ambient storage. The shelf life inside of the ECC was extended by five to twenty days relative to ambient storage. The inside temperatures were about 4-6℃ less than the ambient temperatures, and humidity was about 10%-20% higher. Study was made to check the weight loss and freshness of lime fruits, and data were observed daily. Weight loss in limes kept inside the chamber for ten days was 1.8% and in ambient conditions it was around 9.8%. The color of the fruit changed to yellowish inside the ECC and control which was kept outside became unmarketable. ECC storage did not adversely affect fruit firmness, or the percentage of soluble solids or titratable acidity of the juice. The modified ECC does not require mechanical or electrical energy input and can be constructed with locally available material by unskilled labour.

Keywords: evaporative cooling systems, lime, temperature, relative humidity, *Citrus aurantifolia,* weight loss, firmness, titratable acidity, soluble solids

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1 Introduction

Sharp-tasting green or greenish-yellow lime citrus fruit (*Citrus aurantifolia*, family Rutaceae.) of the small thorny lime bush, native to India and largely cultivated even in Sri Lanka. Limes are the major citrus crop in Moneragala district in Sri Lanka. During abundant availability of limes people's efforts have been directed towards storage. However, extensive research is required to develop advanced postharvest treatment to maintain high quality during the storage and marketing period[1]. Postharvest decay is the major factor limiting the extension of storage life of many freshly harvested fruit. Furthermore, high energy costs by storing in refrigerators have increased the need for managing fruits and vegetables in environmentally friendly ways.

In developing countries the use of refrigerated storage is seldom economically feasible, as most limes are produced and handled on a small scale and it is not profitable. Usually the only means of keeping the fruit fresh at ambient conditions is by regular sprinkling with water. A brick evaporative cooling chamber[2-4], provides an atmosphere with high humidity and reduced temperature; for perishable commodities it is a low cost alternative to refrigerate[5]. The evaporative cooling effect has been extensively tested in increasing the shelf life of fruits and vegetables in some tropical and subtropical countries[6].

Bindir has designed and developed an evaporative cooler for storage of fruits and vegetables in a rural area of Papua New Guinea (PNG)[7]. The design,

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construction and laboratory testing of this evaporative cooler and an assessment of their effects on the performance of rural farmers of PNG were evaluated as the low cost technology. At the same time scientists from PNG developed an evaporative theory based laboratory model of solar energy assisted desiccant cooling system for preservation of fruits and vegetables[8].

Gupta used a steady state model based on transfer function coefficient approach to determine the temperatures in a zero energy cool chamber at any time[9,10]. However, the study did not consider the effects of change in structural materials or the post harvest stored products. The present study was therefore planned to develop and validate a structural change in the evaporative cooling chamber and model that could be utilized for lime fruit storage structures.

2 Materials and methods

2.1 Construction

In this study an evaporative cool chamber of about 0.5 m^3 storage capacity was constructed to store fruits and vegetables. The walls were constructed using baked bricks and river-bed sand. The design was based on the evaporative cooling of a porous body using water in the traditional cooling pot which is made of clay. A well ventilated area with overhead shade was selected so that the maximum of evaporative cooling can be harnessed. The structure consisted of a double walled brick structure with one heat insulating drip proof top. A platform of 165 cm×110 cm was prepared with a single layer of bricks. A double layered wall on all four sides around the platform was erected with bricks, leaving approximately 7.5 cm space, to a height of 50 cm. Sand from a river bed was used to fill the gap. A clay layer was introduced after every 5th layer of sand. About 450 bricks (20 cm×10 cm×8 cm) were required to complete the chamber. The frame of the structure was prepared using bamboo sticks. Pieces of bamboo were split into two vertically and a frame of 170 cm×120 cm was prepared. Three bamboo splits were used lengthwise and breadth wise. The bamboo splits in the frame were arranged in such a way that the opening of bamboo formed by splitting faces downward while placing on the structure in order to prevent retention of water in the semicircular space. Once saturated, it needed about twenty liters of water a day to keep the structure and sand saturated the whole day. After the construction was complete the top cover was laid over the chamber and moistened by a water line which is made with holes and sprinkling water from it. This top cover was used to cover the fruits and vegetables in the structure and to prevent them from the direct exposure of the sun. Under this cover a plastic sheet was also placed in order to protect the dripping of water over the limes (Figure 1).

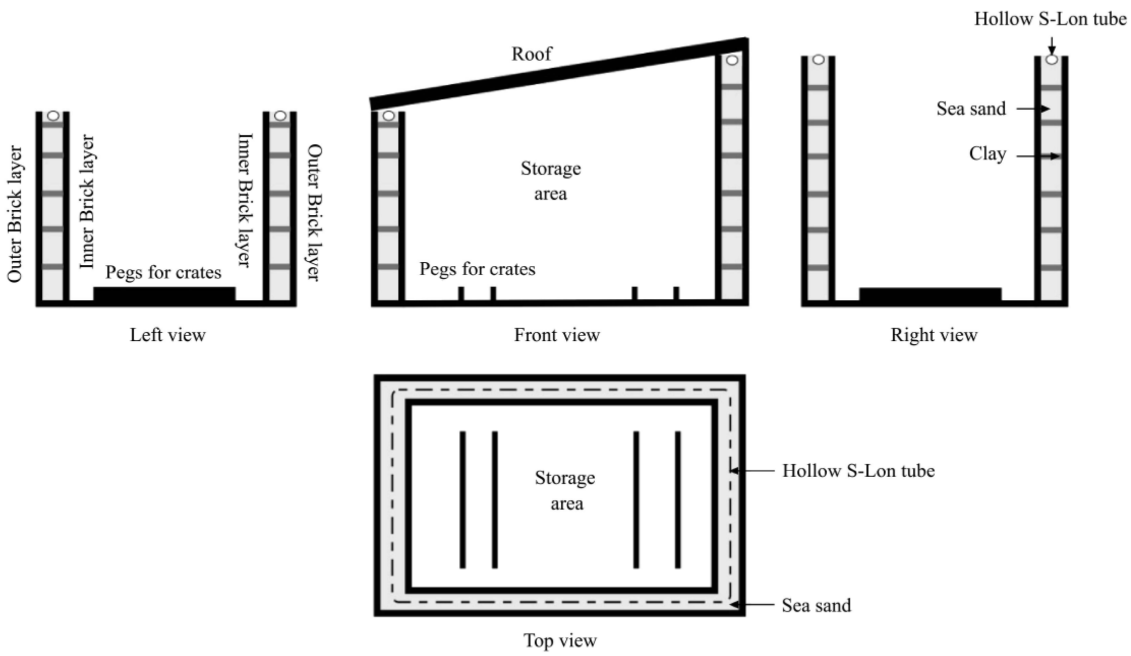

Figure 1 Schematic diagram of the modified evaporative cooling chamber

2.2 Test for effectiveness of the cool chamber

The empty cool chamber was watered daily from the water line which was consisted with holes to saturate the sand and the bricks by using about twenty liters of water. The temperature and relative humidity inside the chamber and outside the chamber were recorded twice a day in the afternoon and evening. The chamber was tested for its ability to reduce the temperature while maintaining the increased relative humidity. The experiment was replicated three times.

2.3 Fruit

Lime fruits (*Citrus aurantifolia*) produced in the area of Moneragala district in Sri Lanka under normal production practices, were harvested in mature sharp green in color and brought to the in house laboratory in plastic trays.

2.4 Method of storage

The limes were kept in plastic baskets in order to avoid absorption of moisture by the container. Limes were weighed separately into 5 kg each (Average 200 lime fruits) basket and three storage crates which is equal for three baskets of limes for each treatment and replicated three times. Stored lime crates inside the evaporative cool chamber and another three sets for ambient storage (as a control sample). For this purpose, a well ventilated cabinet having three sides made of wire-gage was used with a locking facility.

2.5 Weight loss determination

The loss in weight of limes was determined everyday by weighing each sample, using a top pan electronic balance (Electronic balance square pen, WT50001, Pengda, China) with accuracy of 0.05 g, from the evaporative cool chamber and from ambient storage. Those limes showing decay signs were recorded and removed from the samples under study. General cracks, bruise spots, over softening and mould growth were used as indices of deterioration. Cumulative percent loss was determined until lime fruits become pulpy or their freshness was lost.

2.6 Firmness

Firmness was measured in kilograms as the force required before rupturing the rind of the intact fruit. Each fruit was tested four times on the surface of the fruit using a Chatillon force gauge (Model DPP – 10 kg, Chatillon, UK) plunger diameter 2 mm, mounted on a Black and Decker drill stand.

2.7 Colorimetric measurement

Peel color was measured at four equally spaced sites of fruit around the surface, and an average score was calculated and color was measured both subjectively and objectively. The fruits color was rated hedonically (1 = poor; 5 = excellent) for the quality of the fruit and the test was conducted by a panel of six panelists familiar with limes. Color measurements were made daily in each individual fruit at the mid surface using a chromometer (Minolta CR-300, Ramsey, NY, USA) on lime fruits treatment using the CIELAB color parameters; L^*, a^*, and b^* (CIELAB L^* = lightness, a^* = bluish-green/red purple hue component, b^* = yellow/blue hue component)[11]. The meter was calibrated using the manufactures standard white plate.

2.8 Chemical analyses

Twenty healthy fruits were randomly selected prior to the experiment, after storage inside the evaporative cooling chamber, and control, for physiological and chemical analyses. These included: (a) *Juice pH* - pH concentrations in the juice were determined following extraction of juice in 50 mL Erlenmeyer flasks at 27℃ with an Orion Research Model 701A/Digital lonalyzer, pH meter; and (b) *internal* quality attributes [(total soluble solid content (TSS) as "Brix) and titratable acidity (expressed as % of citric acid)]. All analyses were performed as previously described[12]. The percentage of acidity was measured according to the Rangani Method as follows.

$$Z = \frac{V \times N \times Meq.Wt.}{Y} 100$$

Where : Z = Percentage of acid in Sample; V = Volume in ml on NaOH titrated; N = Normality of NaOH (0.1N); *Meq. Wt.*= Millequivalents of acid, 0.064 for citric acid; Y = Volume in ml of weight in grams in sample.

2.9 Taste score and fruit appearance

Initially and at the end of the storage period, 10 trained panelists tasted the fruit. Taste was scored on a subjective hedonic scale of 1–10, where 1: objectionable taste and 10: excellent taste. The fruits were served as cut segments collected from ten different fruits per treatment. After storage fruits were examined for physical damage, fruit freshness (overall visual quality) and rot incidence.

2.10 Experimental design and data analysis

For all the variables measured, the experimental design used was a 2 × 2 factorial; which represents storage inside and outside and with or without the fruit. When ANOVA indicated significant effects of treatments, an LSD test at $p \leqslant 0.05$ was used to separate means[13].

3 Results and discussion

3.1 Temperature and relative humidity variation

The performance of the evaporative cooler without any load to be cooled was evaluated from the 05–24 January/February/March in 2009 and is presented in Table 1. Within these three months in Sri Lanka temperature changes are not significant. The average temperature inside the cool chamber varied from 24℃ to 25℃ while in the ambient air temperature varied from 28℃ to 31℃ when it is unloaded, with wind velocities in the order of 1.5 m/s. Thus, the evaporative cooler temperatures were consistently lower than the ambient air temperatures during the hottest time of the day when insulation was appreciable and cooling most needed. Selected months such as December to March are not so windy in Sri Lanka, so inside the evaporative cooling chamber humidity is 92%-94% while outside it was recorded 85%. The relative humidity in the evaporative cool chamber remained about 10%-20% higher than outside the chamber. Similar findings have been reported by Mordi and Olorunda in 2003[14].

The transient responses of the evaporative cooler with load, with fresh limes during the months are presented in Table 1, and it shows the relative humidity and the average temperature. Low temperatures are necessary to maintain the products in fresh conditions for a significantly longer period. These results clearly demonstrate that the evaporative cooler may be useful in our climate for short term preservation of farm products, especially during the hottest times of the day when cooling is most needed.

Table 1 Changes in average temperatures and relative humidity in the month of December at no load and loaded conditions

Days	Average temp /℃(Ambient)	Average temp /℃(Chamber)	Relative humidity /%(Ambient)	Relative humidity /% (Chamber)
January/February/March (Without Load)				
05	28.8	25.1	85	92
06	28.9	25.1	87	93
07	29.1	24.3	86	93
08	30.1	24.2	87	94
09	29.2	24.9	86	93
10	28.1	24.3	87	93
11	31.2	24.9	86	94
12	30.1	24.1	86	94
13	31.2	24.1	85	94
14	29.1	24.1	86	93
January/February/March (Load)				
15	29.1	26.0	85	93
16	28.9	26.0	86	94
17	30.2	25.4	86	93
18	31.0	26.0	85	95
19	28.8	25.1	87	94
20	29.1	26.1	85	93
21	30.1	26.1	86	95
22	30.0	25.0	87	94
23	29.2	24.8	84	94
24	28.4	24.5	86	95

3.2 Weight loss and firmness during storage

It was observed that the weight loss of limes was minimum when the commodities were stored in the evaporative cooler chamber while it was maximum in ambient storage. The weight of fresh limes in the evaporative cooling chamber and ambient storage significantly differed ($P<0.05$) over the course of the experiment. Firmness of fruits which were stored in ambient conditions significantly firmer ($P<0.05$) compared with those stored in the evaporative cooler (Table 2). The external appearance of cooled chamber fruit after 20 days of storage was judged to be excellent in all three replicates. At the end of shelf-life, the fruit appearance declined slightly but still remained good for almost one and a half months. Conversely, higher relative humidity for a longer period (one month) induced more rapid fungi growth around 30% and fruit became unmarketable.

Table 2 Mean fruit fresh weight loss and mean fruit firmness scores of limes inside the evaporating cooling chamber and ambient for 10 days and 20 days

Treatment	10 days		20 days	
	Weight loss /%	Firmness /N	Weight loss /%	Firmness /N
Cooling chamber	1.8[a]	5.8[b]	2.6[a]	6.4[b]
Ambient	9.8[b]	8.8[a]	21.2[b]	10.0[a]

Note: Means within each column with the same letters (a or b) are not significant at $P < 0.05$.

3.3 Effect of storage system on color

Limes were stored in the evaporative cool chamber and outside the chamber and the changes in the color as the storage progressed were observed and reported in Table 3. Though the limes which were inside the evaporative cool chamber found to be greenish to yellow for all the 20 days. The color of the limes in ambient storage gradually started changing from green/yellowish towards brown after the 10th day and this period showing the aging process. No appreciable difference could be detected during the between first 15 days in the evaporative cooling chamber.

Table 3 Influence of storage period on peel color values for limes

Days	Treatments	Peel color		
		L^*	a^*	b^*
3	Cooling chamber	68.28[a]	-11.23[a]	48.26[a]
	Ambient	60.29[a]	-8.47[a]	41.03[a]
10	Cooling chamber	67.71[a]	-10.21[a]	47.48[a]
	Ambient	47.12[b]	17.65[b]	29.50[b]
20	Cooling chamber	67.01[a]	-7.98[a]	52.45[a]
	Ambient	41.81[b]	18.67[b]	27.68[b]

Note: Mean separation within column groups by Duncan's multiple range test at P=0.05.

* CIELAB color values; L for lightness and a and b for the color-opponent dimensions, based on nonlinearly compressed CIE XYZ color space coordinates

3.4 Changes in pH value and total soluble solid content

There was no significant difference in the pH value of lime fruits in the first 10 days in either the evaporative cooling chamber or in ambient storage. A slight increase in pH value was observed in the ambient storage after 10 days and thereafter it increased significantly (Figure 2). From figure 3, 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 lime shows significant difference in soluble solid contents even in initial stages.

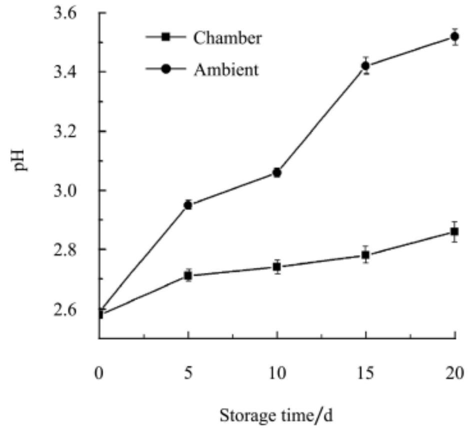

Figure 2 Changes in pH of limes in evaporative cooling chamber and ambient temperature during storage. Error bars show the standard deviation

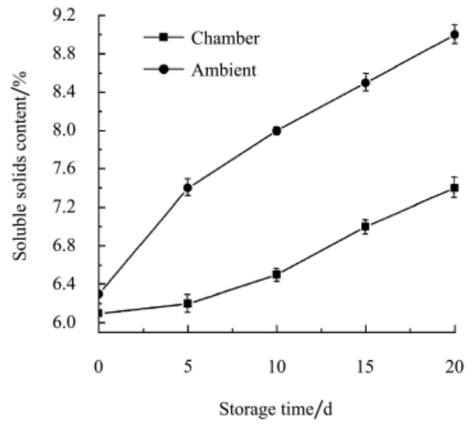

Figure 3 Changes in total soluble solids content of limes in evaporative cooling chamber and ambient temperature during storage. Error bars show the standard deviation

3.5 Overall quality

For limes in the study it was observed that the quality attribute in regard to the freshness and firmness was higher when stored in the evaporative cool chamber. When samples were evaluated for general visual appearance, limes inside the chamber were evaluated as very good during 15 days of storage, whereas samples in ambient temperature reached the limit of marketability after 10 days of storage (Figure 4). Symptoms of mould were observed on lime fruits after 28 days storage in the cooling chamber. During the 20 days storage period, fruit quality was significantly higher than in the control, and disease incidence anthracnose and severity were significantly lower inside the evaporative cooling chamber.

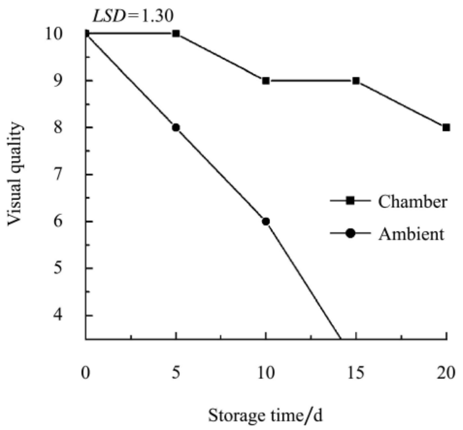

Figure 4 Visual quality of storage fruits inside the chamber and ambient. *LSD* is at 5% Level

The panelists were also asked to rank the samples according to the taste and to evaluate them according to the scale from one to ten. In general, taste of the fruits stored inside the chamber remained acceptable, but ambient storage taste deteriorated after 15 days of storage (Figure 5).

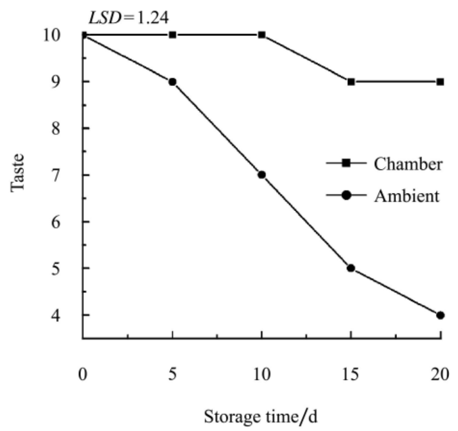

Figure 5 Storage effect on taste of the juice. LSD is at 5% Level

A 100-kg capacity evaporative cool chamber costs about Rs 5,000.00 ($50-60) (Table 4) and small farmers can easily construct it near their field and store the limes for some days before their dispatch to the market at an opportune time. The farmers thus can avoid distress sale.

Table 4 Cost benefit analysis of cool chamber (100 kg capacity)

Materials	Cost in Rupees
Brick (450 Nos)	1,800.00
Sand	200.00
Bamboo, paddy straw for top cover	300.00
Thatched shed	1000.00
Water tank, pipes, tubes etc.	1200.00
Labour	500.00
Total	Rs 5,000.00 (about US $ 50–60)

4 Conclusions

In conclusion, it was confirmed that the use of evaporative cooling chamber for storage of limes or any other agricultural commodities maintain their freshness, and increase storage life better than the ambient conditions (Figure 4). It not only reduces the storage temperature but also increases the relative humidity of the storage, which is essential for maintaining the freshness of the commodities. In addition, it is simple to apply in the citrus industry since it can be incorporated into the packinghouse sorting line and does not require any special handling.

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