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Developing and Evaluating Low Cost Storage Chambers for Horticultural Crops

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Post-harvest losses of horticultural crops cause huge financial, food and nutritive losses in developing countries. One of the major causes for such losses is lack of proper storage infrastructures. There is a need to develop low cost storage structures that can attain and maintain low temperature and high relative humidity (RH). The evaporative cool chamber is a better option as a low cost storage chamber. Evaporative cool chambers are constructed with bricks. Due to high cost of bricks in most areas of Ethiopia, the construction of evaporative cool chambers using bricks is not affordable for common farmers. In the present studies use of bamboo mat and gunny bags was explored as an alternate material in place of bricks for construction of cool chambers. Both bamboo mat and gunny bags were found suitable for attaining low temperature and high humidity in the storage chambers. There was no significant difference in the mean relative humidity and temperature values of Brick chamber and Bamboo mat chamber. Even no significant temperature difference in Brick chamber and Gunny bag chamber was observed. However, the mean values of relative humidity in the two chambers showed a significant difference. The mean value of RH in Brick chamber was 87.01%, whereas the corresponding value in Gunny bag chamber was 84.785% as against 57.58% in ambient storage. Both Bamboo mat and gunny bags proved equally effective in extending shelf life of papaya. The shelf life of papaya was extended from 12 days (Control) to 27 days in Brick chamber, Bamboo mat chamber and Gunny bag chamber. Physiological weight loss during storage was significantly reduced in all the chambers. Thus the findings indicate that bamboo mat and gunny bags can be used in place of bricks for making evaporative cool chambers for storage of horticultural crops.

Keywords: *cool chambers, bamboo mat, low cost storage chambers, evaporative cooling, papaya, bamboo mat cool chamber, gunny bag cool chamber*

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I. Introduction

Horticultural crops are highly perishable in nature. The quality deterioration of fruits, vegetables and flowers starts immediately after harvest. Over 30% of fruits and vegetables are wasted globally [1]. Such losses are higher in developing countries mostly because of lack of required infrastructures. Though 50 % losses in fruits and vegetables in African countries has been reported [2], but some other reports [3] indicated that post-harvest losses in certain horticultural commodities in African countries range from 30-80 % . The main environmental factors contributing to post-harvest losses of fruits and vegetables are temperature and relative humidity [4]. Shelf life of fresh produce can be doubled by reducing temperature from 10 to 5 ^{0} C [5]. High humidity during storage of fresh produce reduces water loss and helps fruits and vegetables to maintain quality attributes.

Lack of appropriate storage facilities is one of the major causes of such losses in developing countries [6]. Handling and storage of fruits and vegetables under low temperature and high humidity is a well-established practice of post-harvest management in developed countries. Cold stores are used in the developed countries for maintaining the temperature and relative humidity of storage chambers and in turn the quality and shelf life of the produce is prolonged. These technologies demand high capital investment and as such farmers and their societies in developing countries are unable to set up such storage structures. Besides high investment costs the operational costs of such storage structures are high. As such there is a need to develop low cost storage chambers for horticultural crops in developing countries. The evaporative cooling is one of the simple and affordable procedures for attaining the low temperatures. The basic principle relies on cooling by evaporation. When water evaporates it draws energy from its surroundings, which results in a significant cooling effect. When air with less humidity or dry air passes over wet surface, the water from wet surface evaporates and evaporative cooling takes place. Based on this principle evaporative cool chambers have been developed for storing horticultural crops. Indian Agricultural Research Institute (IARI) New Delhi developed evaporative cool chambers for storage of fruits and vegetables , using bricks and sand for construction [7].These chambers were subsequently used in other countries also and have shown encouraging results for prolonging shelf life of fruits and vegetables [8]. Construction of these chambers is affordable for the farmers in many countries, but in some countries like Ethiopia the bricks are not generally available in many fruit growing areas or if available they are so costly that a common farmer cannot afford to construct a cool chamber using bricks. In view of this background there is a need to explore some alternate materials that can be used for construction of evaporative cool chambers. In the present study an attempt was made to develop storage chambers based on evaporative cooling principle from locally available cheap materials.

II. Materials and Methods

Experimental Site

The research was conducted at College of Agricultural Sciences, Arba Minch University, Ethiopia. However, the chemical analysis was conducted in the Chemistry Department, College of Natural Sciences, Arba Minch University.

Developing Storage Chambers

Three storage chambers were developed using three materials i.e. bricks, bamboo mat and gunny bags (local name junia). The design and construction of these chambers was followed as per the procedure reported by [9]. Each chamber was constructed with double walled structures having a gap of 7.5 cms within two walls and the chamber dimensions of 165 cms of length, 115 cms of width and 70 cms of height. Bamboo poles of appropriate length were used to fix the bamboo mat and gunny bags (with nails) during construction of Bamboo mat and Gunny bag chambers. The Brick chamber was constructed without using cement or other holding/binding material. The gap between two double walled structures of all chambers was filled with wet sand. In addition to these three chambers one chamber of similar dimensions constructed with bricks in cement already existed at the site of the present studies. The only difference in this chamber and in the one that was constructed now with bricks was the use of cement. The new brick chamber was constructed without cement or any other binding material whereas the already existing chamber had been constructed using cement as a binding material for bricks. The design and dimensions for all chambers were similar. Each chamber was covered with a cover made of bamboo mat and gunny bag. Thus in total four storage chambers; Brick (B) chamber, Gunny Bag (GB) chamber, Bamboo mate (BM) chamber and Bricks in Cement (BC) chamber were available for conducting storage studies. All these chambers were covered within one shed of about 9 ft. height constructed by using bamboo poles. The roof of the shed was covered by a locally available polyethylene sheet and above the sheet dry grass was spread on the entire sheet. Covering the roof of the shed in such a manner was to protect the chambers from rain and heat of the sun. The shed was left open from all the sides to facilitate movement of air. In all the chambers the sand in the cavity of double walled structures was kept moist by sprinkling water twice a day. To assess the performance of these chambers for retaining quality and prolonging shelf life of fruit crop during storage, a normal laboratory room in the same area was used as ambient storage or control (CON).

Fruit Procurement

Papaya fruit of uniform size and maturity was procured from a local farm located about 2.5 Kms from College of Agricultural Sciences, Arba Minch Ethiopia.

Quality Analysis Intervals

The initial analysis of the fruit was conducted before placing it into various storage chambers. Papaya fruit of uniform maturity was placed in plastic crates and stored in four chambers and in the ambient room temperature (Control) for storage studies. Subsequently the fruit was analyzed after every three days interval for various parameters, till the fruit became marketable/spoiled. Once the fruit lost its marketing attributes under any particular storage conditions, it was discarded and no analysis for such storage was conducted.

Assessing Fruit for its Marketing Attributes

Papaya fruit stored under different storage conditions was continuously examined to assess its feasibility for marketing. The major considerations for its marketing attribute included freeness from any visible defect like fungal growth, too soft texture, off flavor, decayed pulp and excessive shrinkage.

Recording Temperature and Relative Humidity (RH)

Wet and dry bulb temperatures were recorded daily in each chamber and in the ambient storage (Control) in the forenoon (FN) and afternoon (AN). With this data the storage temperatures and percentage relative humidity in the F.N. and A.N. was tabulated. Zeal Wet and Dry Bulb Hygrometer (Mason's Type) made in England was used for recording the wet and dry bulb temperatures.

Physiological Weight Loss (PWL)

The physiological weight loss (PWL) of fruit in all the storage chambers including control was measured after every three days intervals till the fruit became unmarketable. An electronic balance (ConTECHModel CT

15005 capacity 15 kgs) was used for measuring the weight. The physiological loss in weight (%) was calculated by using the following formula: -

Physiological loss in weight, % =

$$\frac{\text{Initial weight} - \text{weight at the end of storage interval}}{\text{Initial weight}} \times 100$$

Chemical Analysis

Total Soluble Solids of papaya was measured with Abbe refract meter as per standard [10].

The total titratable acidity (expressed as citric acid), ascorbic acid, reducing & non-reducing sugars were estimated according to prescribed Methods [10].

Statistical Analysis

Significance tests were made by analysis of variance (ANOVA) for Complete Randomized Design (CRD) with SAS software 9.1.3. Comparisons of the treatment means were done using Duncan's Multiple Range Test [11]. P-value less than(<) 0.05 was considered significant. In the present studies the papaya fruit in ambient storage spoiled/turned unmarketable after12 days and as such no analytical data of control for comparison with treatments was available after 12 days. So ANOVA for 12 days storage and 27 days storage was drawn using SAS software 9.1.3.

III. Results and Discussions

The temperature of all cool chambers decreased significantly compared to that of ambient storage (Control) temperatures. However, there was no significant difference within the temperatures of cool chambers. The average mean temperature of 31.745^{0}C was recorded in the ambient storage (Control), whereas the average mean value of the four cool chambers ranged from 23.02 to 23.26^{0}C. Average mean temperature of 29.71^{0}C and 33.78^{0}C was recorded in the FN and AN respectively in the ambient storage (Control), whereas the corresponding mean temperatures in all the cool chambers ranged from 22.44 to 22.89^0 C and 23.28 to 23.78^{0}C respectively. Thus a temperature difference of about 10^0 C was observed between the ambient (Control) and the cool chambers. The rate of deterioration of perishables increases two- to threefold with every 10 ^{0} C increase in temperature, therefore, for most perishable commodities there is a loss of storage potential as handling temperatures increase [12]

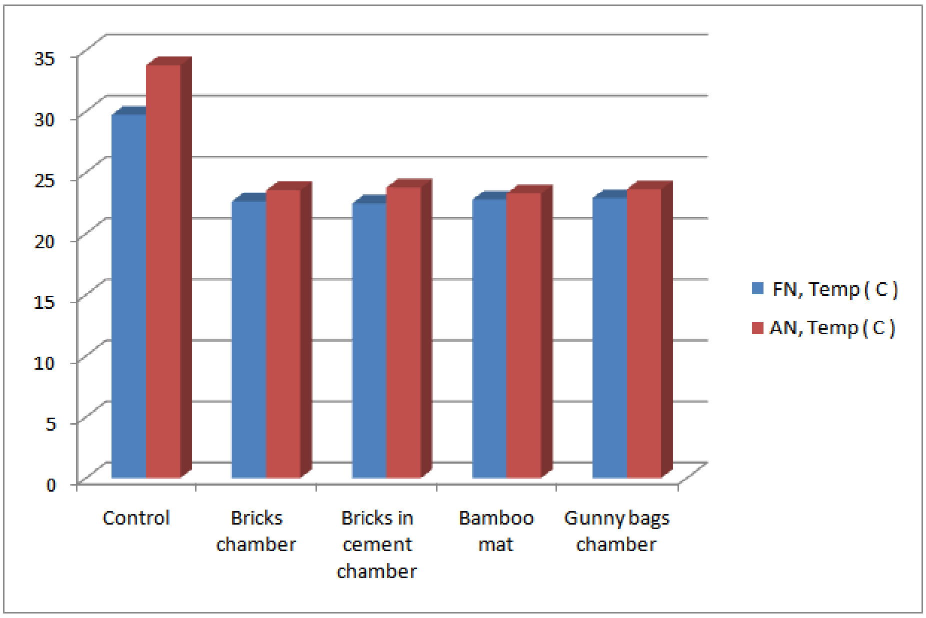

Figure 1: Temperatures (^{0} C) of storage chambers in forenoon (FN) and afternoon (AN)
(P-value= Chamber < .0001; Time< .0001; Chamber x Time<.0001)

Studies were conducted by earlier workers [8] on storage of vegetables in Zero Energy Cool chamber (ZECC) and the researchers observed that temperatures ranged from 23.4 to 25.0^0 C in ZECC as against 29.31 to 31.5^0 C of ambient storage. Thus the researchers have observed a decrease in temperature of about 6.0 to 6.5^{0}C in ZECC. In the present studies a reduction of about 10^{0}C is observed. A temperature difference of 1 to 10^0 C between Evaporative Cool Chambers and ambient temperatures has also been reported earlier [13]. Under low temperature conditions the post-harvest changes in horticultural crops are reduced, thus the quality deterioration is reduced and shelf life is increased. Any technology that helps in reducing storage temperatures will help to increase the shelf life of the produce.

The relative humidity (RH) of ambient storage (Control) was significantly lower than the RH of all other storage chambers as depicted in Figure 2. The average mean RH of 57.68% was recorded in ambient storage, whereas the corresponding values in cool chambers ranged from 84.785 to 88.465%. Though there was no significant difference within RH of Brick chamber and Bamboo mate chamber, but the difference within Gunny bag chamber and Bricks in cement chamber was significant. Higher values of RH in various types of evaporative cool chambers have been reported by many earlier workers [14] Relative humidity ranging from 65.5% to 75.20% at different timings in ambient storage was observed by earlier workers [5] whereas the corresponding values under Zero Energy Cool Chamber in the same studies ranged from 83.6 to 89.3%.

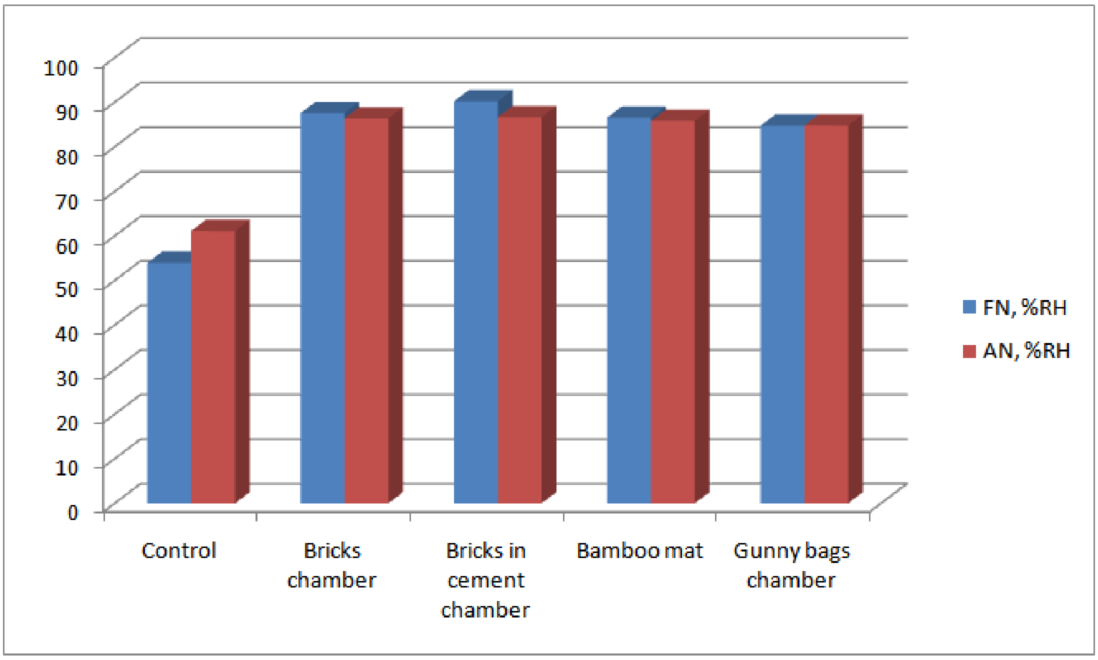

Figure 2: Relative Humidity (%) of storage chambers during forenoon (FN) and afternoon (AN) (P-value= Chamber< .0001; Time 0.2880; Chamber x Time< .0001

The humidity of the air in storage chambers directly affects the keeping quality of the products held in the chambers. If it is too low, wilting or shriveling is likely to occur in most fruits, vegetables and such other products. High humidity is also beneficial for wound healing and periderm formation during curing of certain crops. Relative humidity above 85 percent is recommended for most perishable horticultural products to retard softening and wilting from moisture loss. In the present studies RH of about 85% and above has been observed in all cool chambers and as such these chambers offer a better environment for storage of horticultural crops.

The fruit stored at ambient temperatures turned unmarketable/ spoiled after 12 days and as such no analytical data for the fruit stored at ambient temperatures could be possible after 12 days. Fruit in all the cool chambers became unmarketable after 27 days. The spoilage was assessed by visual observations like visible defect like fungal growth, too soft texture, off flavor, decayed pulp and excessive shrinkage.

A statistically significant physiological weight loss (PWL) was observed in papaya during storage in all the storage conditions. As is depicted in Figure 3 the PWL was highest under ambient storage (Control). The PWL recorded on 12th day in Control was even much higher than the PWL recorded in the cool chambers on 27th day of storage. Since the fruit stored under ambient conditions (Control) spoiled after 12 days only so no comparison of PWL beyond 12 days with control was possible. But the results clearly indicate (Figure 3) a significant reduction of PWL under cool chamber conditions.

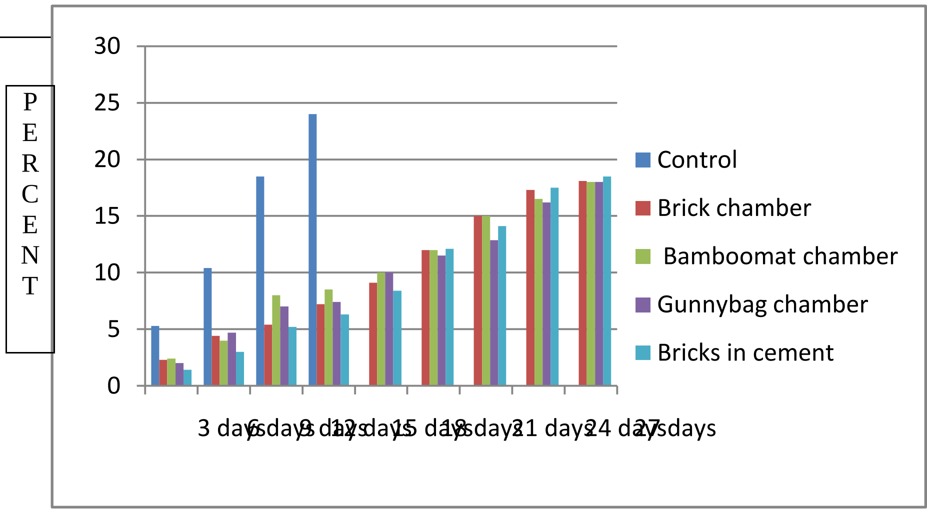

Figure 3: Physiological weight loss during storage under different storage chambers
(P-values for 12 & 27 days= Chamber<.0001; Duration <.0001; Chamber x Duration<.0001)

Physiological weight loss (PWL) of four vegetables was studied earlier [15] and it was observed that PWL ranged from 10.13 to 15.28 % in ZECC compared to 17.75 to 35.12% under ambient storage conditions during storage period of 7 days. Many other researchers [16] have also reported PWL in fruits and vegetables during storage. In the present studies the higher PWL observed in ambient storage could be due to higher storage temperatures and lower RH. At higher RH the loss of water from the produce is expected to be lower than at low RH. Similarly at low temperatures the water loss will be low compared to high temperatures. In the present findings the cool chambers have attained low temperature and high humidity compared to that of ambient storage. Thus the PWL in these chambers are significantly lower than that of Control.

There was a significant change in the acidity during storage of papaya under all storage conditions. In the initial period of 12 days storage the difference of the acidity values within Bricks chamber and Bamboo mat chamber was non-significant. At the end of 27 days storage period the mean value of acidity (0.361%) was highest in the papaya stored in Gunny bag chamber, whereas the corresponding mean values in other three chambers were in the range of 0.335 to 0.337 and as such there was no significant difference within the acidity values of these three chambers.

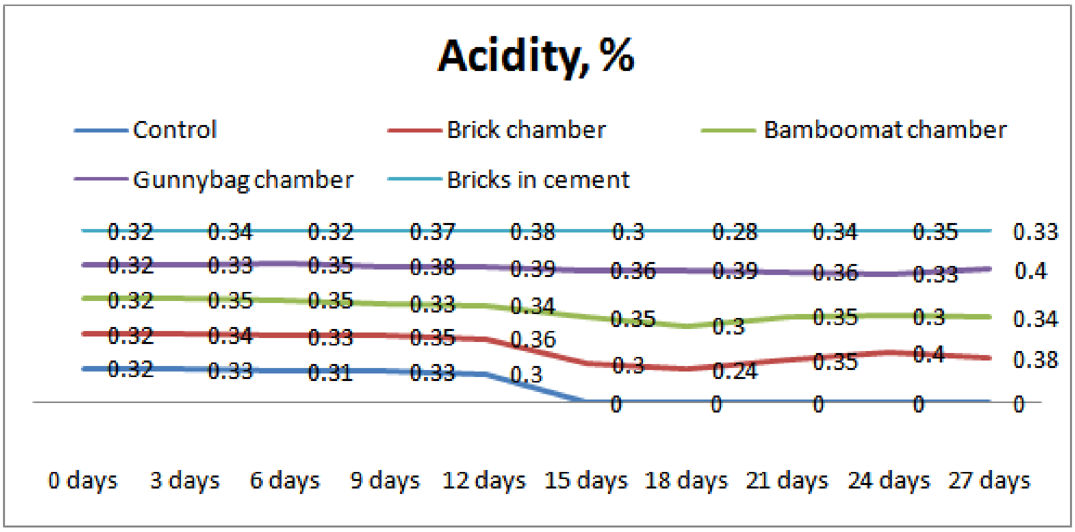

Figure 4: Effect of storage chambers and storage period on acidity of Papaya
(P-values12 days & 27 days= Chamber < .0001; Duration <.0001; Chamber x Duration <.0001)

A significant change in Total Soluble Solids (TSS) was observed during storage in all the chambers. As is reflected in Figure 5 there was an increase in TSS in the initial storage period and subsequently there was a decrease in the TSS. The increase in the TSS in the beginning is generally considered to be due to degradation of starch into simpler sugars. In the initial 12 days storage period the TSS values of Control, Bamboo mat chamber and Bricks chamber were falling in the same Duncan's grouping and there was no significant difference within these chambers. However, the papaya stored in in Gunny bag chamber and Bricks in Cement chamber had significantly lower TSS values than the other chambers. During 27 days of storage period there was no significant difference within the TSS values of the produce stored in Bricks chamber and Bamboo mat chamber, whereas the fruit stored in Gunny bag chamber and Bricks in Cement chamber had significantly lower TSS values and a significant difference in TSS also existed within these chambers.

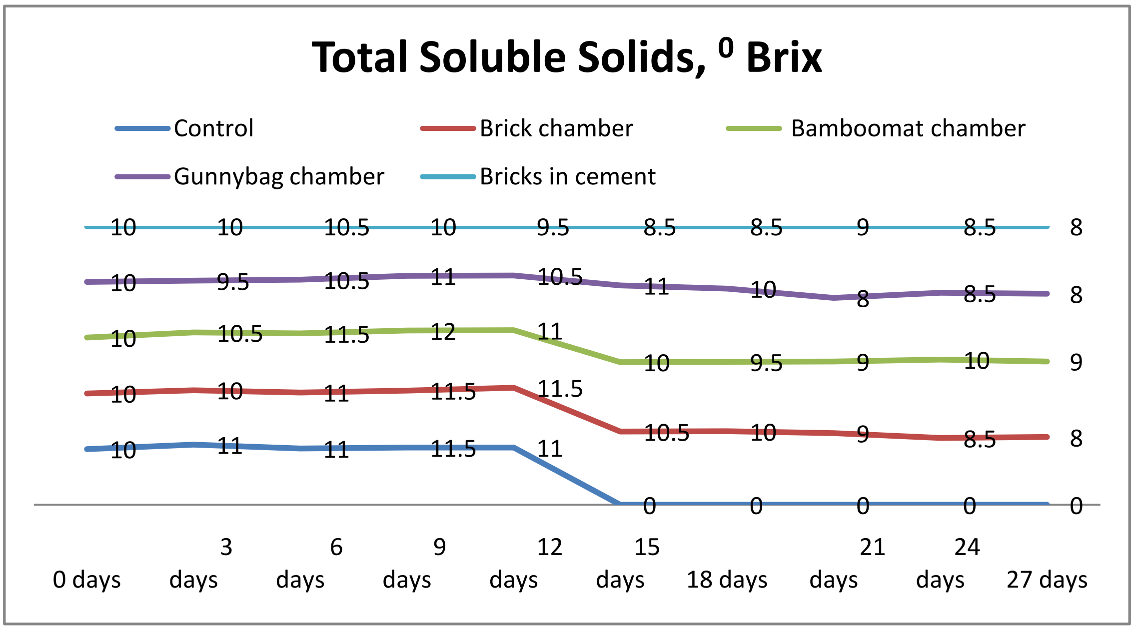

Figure 5: Effect of storage chambers and storage duration on Total Soluble Solids of Papaya
(P-values = 12 days Chamber< .0001; Duration< .0001; Chamber x Duration< .0002
27 Days Chamber< .0001; Duration< .0001; Chamber x Duration< .0001)

Perusal of Figure 5 reveals an increase in TSS in the beginning followed by a decline in TSS values. Similar results have been reported [17] during storage studies of mango fruit in ZECC.

The ascorbic acid content of fresh papaya was 40.7 mg/100g of fruit. At the end of storage period it was reduced to 36.0 to 38.0 mg/100g in various storage chambers and the change was statistically significant. Even the differences in the values of ascorbic acid were significant within the chambers. Reduction in ascorbic acid during storage has also been reported [18] during storage studies on apple. Decrease in vitamin C content of okra from 35.58 mg/100g to 22.34 mg/100g during 7 days storage in ZECC has also been reported by other researchers [8].

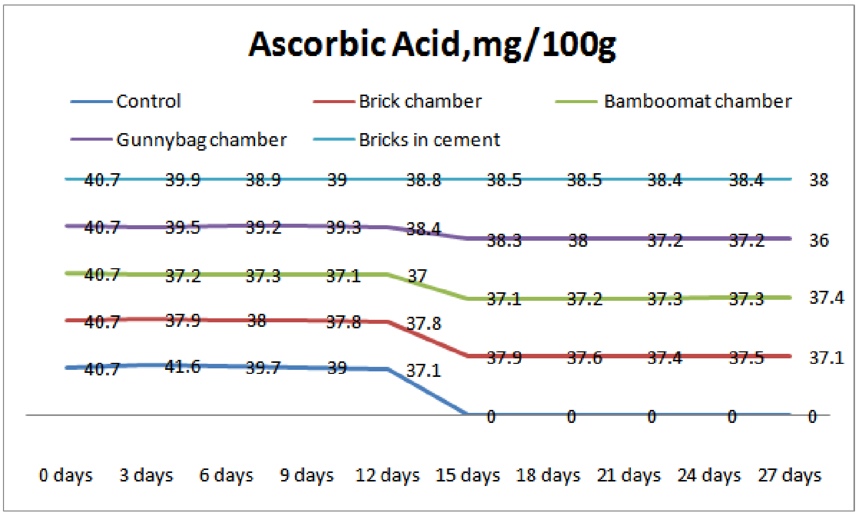

Figure 6: Effect of storage chambers and storage duration on ascorbic acid of Papaya
(P-value= 12 & 27 Days Chamber< .0001; Duration< .0001; Chamber x Duration < .0001)

Reducing sugars increased significantly during storage in all the chambers. The increase was significant even in the first 12 days storage. The rate of increase in reducing sugars was higher at ambient storage (Control) compared to all Cool chambers. Though reducing sugars increased in papaya in all chambers but even significant variations in the values of reducing sugars existed within the chambers.

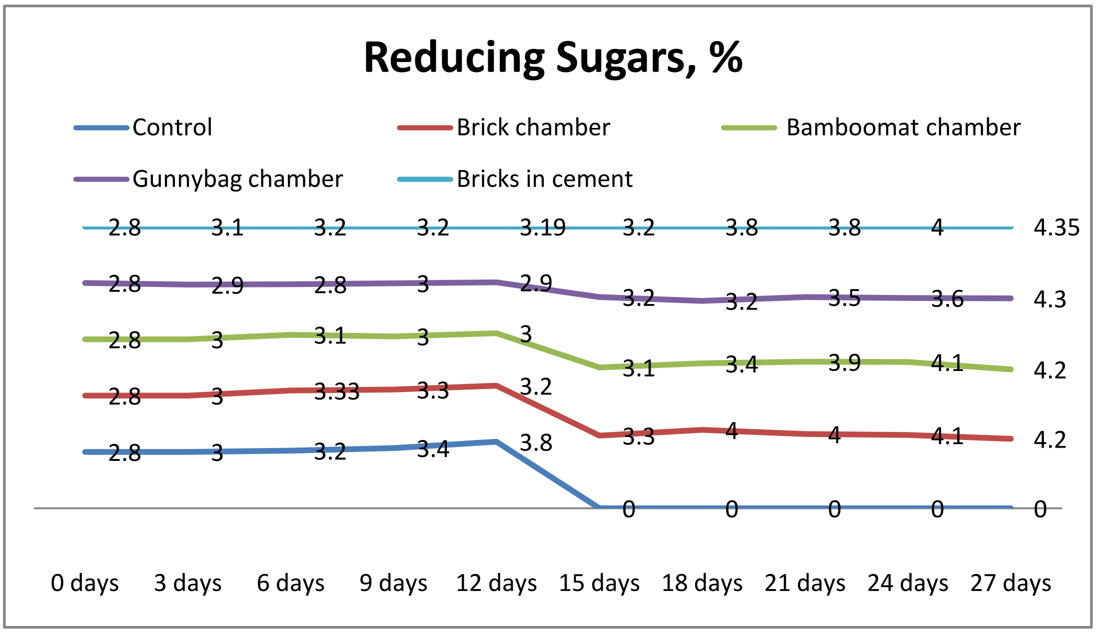

Figure 7: Effect of storage chambers and storage duration on reducing sugars
(P-values= 12 & 27 Days Chamber< .0001; Duration< .0001; Chamber x Duration< .0001)

The present results have shown an increase in reducing sugars during storage. Similar findings have been reported [18] during storage of apple. The researchers reported that reducing sugars in apples increased from 10.15 to 14.30 % during a period of six weeks.s

Non-reducing sugars decreased significantly during storage. The rate of reduction was higher in ambient storage (Control). Though a significant decline in non-reducing sugars was observed during but within the chambers there was no significant difference in the values of non-reducing sugars. Decrease in non-reducing sugars during storage of apples has also been reported by other researchers [18].

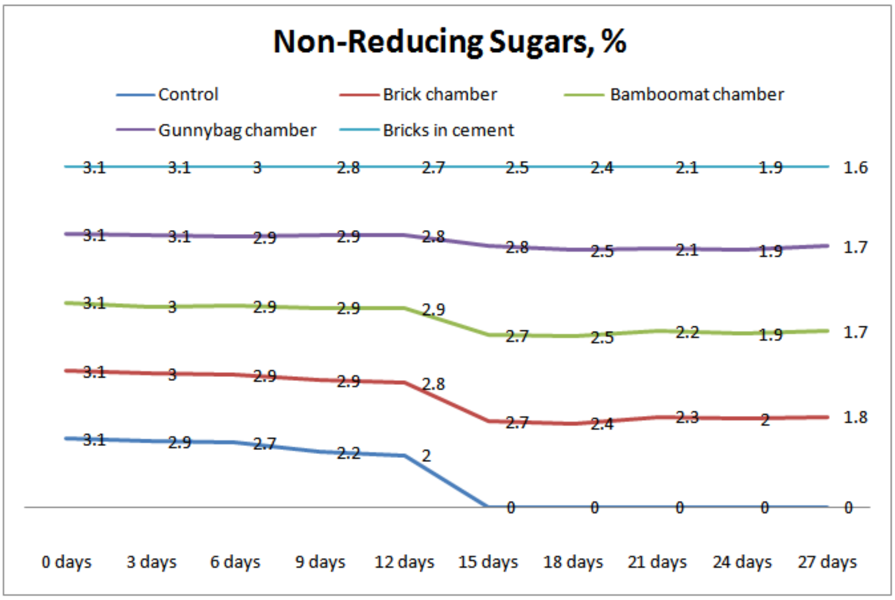

Figure 8: Effect of storage chambers and storage duration on non-reducing sugars
(P-value=12 Days Chamber< .0001; Duration< .0001; Chamber x Duration< .0001
27 Days Chamber< .0791; Duration< .0001; Chamber x Duration< .3364)

IV. Conclusion

Huge post- harvest losses of horticultural crops are one of the major challenges in developing countries. Lack of proper storage facilities is a major cause for such losses. It is established that horticultural crops can retain quality and can be stored for longer periods if temperature in storage chambers is reduced and relative humidity is increased. Cold stores work on the same principle but being highly capital intensive cannot be considered as an immediate option in developing countries because of poor financial resources of farmers' or their societies. Thus low cost and affordable storage structures that can reduce temperature and increase humidity of storage chambers are an alternate option for reducing post-harvest losses. Evaporative cool chambers can be a better option under such situation. Though cool chambers constructed with bricks are being used in many parts of the world but in some rural areas of Ethiopia the bricks are either not available or they are so costly that maximum farmers cannot afford the construction of cool chambers with bricks. In view of these problems alternate materials like bamboo mat and gunny bags (local name junia) were used in the present studies. Both these materials proved effective in reducing temperatures, increasing relative humidity and extending shelf life of fruits. These materials were comparable to brick in extending shelf life and maintaining the temperatures and RH. Bamboo mat is available throughout Ethiopia at very cheap and affordable rates. Gunny bags are also available at affordable rates. The present results reveal that bamboo mat or gunny bags can also be used as a replacement of bricks for construction of cool chambers. In Ethiopia the material cost of bamboo mat for construction of a cool chamber is only about 5 to 6% of brick cost. Moreover, the bamboo mat is available and affordable for the farmers and as such the technology can be adopted without any heavy financial burden.

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