RESEARCH PAPER
FOOD SCIENCE
RESEARCH JOURNAL
ISSN-0976-1276 ■ Visit us : *www.researchjournal.co.in*
Volume 10 | Issue 2 | October, 2019 | 221-231
DOI : 10.15740/HAS/FSRJ/10.2/221-231

Development of a low-cost evaporative cooling storage structure for perishable commodities

Amina Khatun, Ravi Pratap Singh and Avinash Kumar

All fruits and vegetables are not consumed immediately after their harvest. Proper storage of perishable commodities is one of the most important post-harvest operations to reduce the giant food scarcity crisis. Controlling the temperature and relative humidity of the storage environment are the key steps of extending the shelf-life of the perishable commodities. In this study, a double-wall evaporative cooler was developed using low cost and locally available porous materials: saw dust in outer wall and rice husk in inner wall for storage of perishable commodities for a short period of time. The performance of the evaporative cooler was evaluated under no load condition for 3 days. The cooling efficiency throughout the day of the evaporative cooler was calculated. Tomatoes and grapes were stored in the evaporative cooler. The quality of tomatoes and grapes were evaluated in terms of physiological weight loss, moisture content and the change in colour. Comparison of the performance of the evaporative cooler was made keeping same amount of tomatoes and grapes at room temperature and in refrigerator. The total cost of the evaporative cooler was calculated. The results indicated a temperature drop of 10-12°C and an overall increase of 62-68 per cent relative humidity inside the evaporative cooler in comparison to the ambient condition. It is also found from the results that tomatoes and grapes could be stored in good condition for 31 days and 19 days, respectively without significant weight loss, gain in moisture content and colour change. The use of locally available materials kept the cost of evaporative cooler to a low amount of Rs. 1926. The evaporative cooler developed is robust and technically sound equipment providing optimum temperature and relative humidity for storage of perishable commodities. This type of structure is low-cost and feasible giving good results in comparison to refrigerator and can be adopted by farmers anywhere in the globe.

Key Words : Evaporative cooling, Cooling efficiency, Storage condition, Temperature drop, Perishable commodities

How to cite this article : Khatun, Amina, Singh, Ravi Pratap and Kumar, Avinash (2019). Development of a low-cost evaporative cooling storage structure for perishable commodities. *Food Sci. Res. J.,* **10**(2): 221-231, **DOI : 10.15740/HAS/FSRJ/10.2/221-231**.Copyright@ 2019: Hind Agri-Horticultural Society.

INTRODUCTION

India is a developing country having tropical climate. After Brazil and China, it is the largest producer of fruits and vegetables. According to a report presented by Anonymous (2010), India produces a total of 209.72 million tonnes (MT) of perishable commodities out of which 73.53 MT are fruits and 136.19 MT are vegetables. Due to the short shelf-life of these crops, it is estimated that about 30 to 35 per cent of India's total fruits and vegetables production is lost during harvest, storage, grading, transport, packaging and distribution in a year which reduces the growers share. Only 2 per cent of these crops are processed into value added products (Basedia *et al.*, 2013).

Fruits and vegetables are rich sources of

MEMBERS OF RESEARCH FORUM

Author for correspondence :
Amina Khatun, Department of Agricultural Engineering, Assam University, **Silchar (Assam) India**
Email: aminakhatun9286@gmail.com

Associate Authors' :
Ravi Pratap Singh and Avinash Kumar, Department of Agricultural Engineering, Assam University, **Silchar (Assam) India**

carbohydrates and proteins (Abdul, 1989; Salunkhe and Kadam, 1995 and Adetuyi *et al*., 2008), which are very important for normal growth of a human body.They are rich in vitamins and minerals such as carotene (provitamin A), ascorbic acid, riboflavin, iron, iodine, calcium etc (Ihekoronye and Ngoddy, 1985).Vegetables are also rich in fibres which are essential for good digestion (Liberty *et al.,* 2013). Vegetables and fruits are generally classified as perishable crops, if not quickly preserved when harvested; they shrivel, wither or rot away rapidly, especially under hot conditions (Ndukwu, 2011). Due to their high moisture content, fruits and vegetables have very short life and are liable to spoil. Metabolism in fresh horticultural produce continues even after harvest and the deterioration rate increases due to ripening, senescence and unfavourable environmental factors. Hence, preserving these types of foods in their fresh form demands that the chemical, bio-chemical and physiological changes are restricted to a minimum by close control of space temperature and humidity (Chandra *et al.,* 1999). Storage of fruits and vegetables at low temperature, immediately after harvesting reduces the rate of respiration resulting in reduction of respiration heat, thermal decomposition, and microbial spoilage and also it helps in retention of quality and freshness of the stored material for a longer period (Chopra *et al*., 2003).

According to FAO (1995), fruits and vegetables processing is the most important agriculturally based activity. Loss of water from produce is often associated with a loss of quality, asvisual changes such as wilting or shrivelling and textural changes can take place. Another aspect to consider when handling fruits and vegetables is the relative humidity of the storage environment. Low temperature and high humidity slows pathological activity, therefore the storage environment for safe preservation of fruits and vegetables must replicate them (Ndukwu *et al*., 2013). Low relative humidity increase transpiration rates. On the other hand, when the relative humidity is high, the rate of water evaporation is low and therefore cooling is also low (Odesola and Onyebuchi, 2009).Any method that will reduce the temperature and increase the relative humidity of the storage environment relative to the ambient will suppress enzymatic degradation and respiratory activity. It will also reduce the rate of water loss, slow or inhibit the growth of moulds and bacteria, slow the rate of the production of ethylene or minimize the product's reaction to ethylene and other metabolic activities (Katsoulas *et al.,* 2001 and Boyette *et al.,* 2010).

Habibunnisa *et al.* (1988) coated apples with wax emulsion and analyzed the effects on physiological weight loss, shriveling and fungal spoilage. Bhardwaj and Sen (2003) examined the effect of *Neem* leaf extract treatment on physiological weightloss, loss in juice content, organoleptic taste, diameter, total soluble solids, total sugar and retention of acidity of Nagpur Santra. Olosunde *et al.* (2009) carried out a performance evaluation of hessian, jute and cotton waste as adsorbent material in an evaporative cooler. Adetuyi *et al.* (2008) analyzed the effect of shea butter coating on the storage duration of *Pawpaw carica papaya* in terms of its nutrient, sugar and mineral content. Jadhav *et al.* (2010) constructed drip cooling chambers with gunny bag walls and vetiver mat walls and a charcoal cooling chamber to analyze the effect on atorage duration of tomatoes. The results indicated that the shelf-life of tomatoes increased to 21, 18 and 15 days, respectively. Franco *et al.* (2014) evaluated the energy efficiency of evaporative cooling in a hermetic greenhouse using evaporative pads and extractor fans.

Numerous efforts have been made based on the principle of evaporative cooling since the past century to preserve the perishable commodities for a longer period of time. A simple and relatively efficient, low cost storage structure was developed by FAO (1983).Anonymous (1985) and Roy and Khurdiya (1982) constructed a zero energy cool chamber with two layers of bricks with river bed sand in between them.Provisions were made to cover the top of storage space with gunny bags without any mechanical ventilation. They attained a temperature less 28ºC inside the chamber. Chouksey (1985) developed an evaporative cooling storage chamber ventilated with solar-cum-wind aspirator for potatoes and attained a temperature drop of 17-19ºC and a relative humidity of 30-35 per cent. Mordi and Olorunda (2003) built an evaporative cooler structure for fresh tomatoes storage with an average temperature drop of 8.2°C while the RH increase was 36.6 per cent over an ambient 60.4 per cent. Anyanwu (2004) used a cooling pad made of coconut husk for direct evaporative cooling and attained a temperature drop above 22ºC. apart from these, a number of evaporative coolers have been developed till date and the impact on the shelf of different commodities is evaluated (Datta *et al.*, 1987; Umbarkar *et al.*, 1991;

Ganesan *et al*., 2004; Jha and Aleksha Kudos, 2006; Jain, 2007; Jany *et al*., 2008; Jha, 2008; Metin *et al*., 2009; Rayaguru *et al*., 2010; Vala and Joshi, 2010; Mogaji and Fapetu, 2011; Sunmonu *et al*., 2014 and Vala *et al*., 2016).

From the literature reviewed, it is clear that several studies on the evaluation of evaporative cooling storage structures have been presented till date, but relatively less number of studies are reported based on the effect of storage conditions on the shelf-life of tomatoes and particularlyon grapes. The storage of perishable commodities like fruits and vegetables after harvest is one of the critical problems of the rural areas of the country. The short lifetime of these perishable commodities are mostly hampering the farmers as because they cannot afford high tech equipment for storing these commodities. Due to this, large amount of spoilage of these products is observed. The past studies on evaporative coolers have involved the use of clay, gunny bags, coconut husk etc. The main aim of this study is to develop a low-cost structure working on the principle of evaporative cooling and evaluate its performance using storing tomatoes and grapes so that no extra investment on power consumption is added. Such a structure will aid the farmers to store their products to a longer period of time after harvest. Keeping in mind this broad goal, the following objectives have been formulated: To develop an evaporative cooling storage structure using low-cost commodities, to evaluate the performance of the evaporative cooler and the quality of the stored commodities and to assess the cost of the evaporative cooling storage structure. This type of study is one of its kind and no such study has been carried out for tomatoes and grapes till now. In order to increase the shelf-life of perishable commodities, such type of study should be conducted in different parts of the globe.

METHODOLOGY

Principle of evaporative cooling:

An evaporative cooling system operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists, specifically, in water evaporation, induced by the passage of an air flow, thus, decreasing the air temperature. When water evaporates into the air to be cooled, simultaneously humidifying it, that is called direct evaporative cooling (DEC) and the thermal process is the adiabatic saturation. The main characteristic of this process is the fact that it is more efficient when the temperatures are higher, that means, when more cooling is necessary for thermal comfort (Camargo, 2008). Evaporation of water produces a considerable cooling effect and the faster the evaporation the greater is the cooling. When the temperatures are the same, no net evaporation of water in air occurs, thus, there is no cooling effect. The principle of working of this system is ‘when a particular space is conditioned and maintained at a temperature lower than the ambient temperature surrounding the space, there should be release of some moisture from outside the body’. This maintains low temperature and elevated humidity in the space compared to the surrounding. This evaporative cool chamber fulfils all these requirements and is helpful to small farmers in rural areas (Dadhich *et al*., 2008). Thus, in evaporative cooling, there is conversion of sensible heat to latent heat.

Design consideration:

The following factors were considered while proposing the design of the evaporative cooling storage structure:

– The evaporative cooler was designed with locally available materials to reduce its cost.

– The shape of the cooler is cuboids to provide maximum exposed area for evaporation.

Material selection:

The selection on the type of materials to be used in the structure was based upon the basic factors affecting evaporation. Generally, an evaporative cooling structure is made of a porous material that is fed with water. (Liberty *et al*., 2013). As evaporation speeds up when larger surface area is available for the purpose, so porosity of the material should be such that it fulfils the requirements and give faster rate of evaporation. Along with this the thermal conductivity of the materials used, their cost and availability were the other important factors for the selection of the material.In this study, the materials used for developing the evaporative cooler were rice husk and sawdust. Rice husk has porosity of 63.64-68.94 per cent (Zhang *et al*., 2012) and its thermal conductivity ranges from 0.79-1.53 W/mK (Sisman *et al*., 2011). Apart from this, rice husk is also light-weight having a unit weight of about 1797-2268 kg/m^3 (Sisman *et al*., 2011). Sawdust has a porosity of about 84 per cent and 60 per cent water retention capacity (Horisawa *et al*., 1999). Its thermal conductivity is about 0.08W/mK (Source:*http://www.engineeringtoolbox.com*). In addition, rice husk and sawdust are the by-products of different activities and are often thrown away. They were easily available at a cheaper rate.

Design layout and general description:

The evaporative cooling storage structure was a double-wall structure, each wall having a thickness of about 2 cm. The structure was made double walled with a view that two different materials having different properties good for storage purpose could be collaborated and better results could be obtained. In addition, when two insulators are kept in series the net resistance becomes more than the greater one. This will lead to lesser heat flow inside the structure. As this double wall concept has not been used yet, we found it a better option for obtaining better conditions inside the structure for storage of perishable commodities. The structure was constructed cuboid shaped (50cm long x 50cm wide x 90cm deep) so that greater surface area was exposed to the surroundings.The frame was made of wood and plastic sheets were placed as packing in between the gaps. Two stacks were made with the help of bamboo sticks for keeping the perishable commodities. Having higher water retention capacity and porosity as compared to the two, sawdust was kept in the outer wall of the structure. In contrast, rice husk placed in the inner wall was not a very good absorbent of the water. This prevented the relative humidity inside the structure to attain a very high value and remain in an optimum condition.

Experimentation:

The evaporative cooling storage structure was kept in open under the shed. Water was applied manually (about 12 litres) on the inner and outer side of the structure including the top cover once every day (in the morning). Readings for the variation of dry bulb temperature and relative humidity both inside and outside the structure were taken in no load condition for 3 days. As it is evaporative cooling the wet bulb temperature remained constant.

Tomatoes and grapes have shorter shelf-life at normal room condition.They are suggested to be kept in cool and humid conditions.In this study, locally available hybrid tomatoes and grapes were loaded in the evaporative cooling storage structure after 3 days of no load condition. About 900g of grapes and 2 kg tomatoes were placed in the upper and lower stack, respectively. The structure was unloaded every day in the morning, watered and when all excess water was drained out it was loaded again thereby closing all open spaces. Equal weight of tomatoes and grapes were also kept in refrigerator and at room temperature for comparison.The experimentation was performed on tomatoes and grapes in the evaporative cooling storage structure, at room temperature and in refrigerator for 40 days while monitoring their performance in terms ofcooling efficiency, quality and overall cost.

Performance evaluation:

The performance of the evaporative cooling storage structure is evaluated on the basis of its cooling efficiency. It is a measure of temperature drop in the inside environment of the evaporative cooling storage structure. Cooling efficiency is calculated using the equation given by Lertsatitthanakorn *et al.* (2006) as,

$$\eta_{cooling} = \frac{T_a - T_d}{T_a - T_w} \qquad ....(1)$$

where, T_a is the dry bulb temperature of the ambient condition in K, T_d and T_w are the dry bulb temperature inside the structure and wet bulb temperature in K, respectively.

Quality evaluation:

Percentage weight loss:

Most fresh produce contains from 65 to 95 per cent water when harvested. Water is an important constituent of most fruits and vegetables and it adds upto the total weight. Losses of water will definite reduce the weight. When the harvested produce loses 5 or 10 per cent of its fresh weight, it begins to wilt and soon becomes unusable (FAO, 1986). Percentage weight loss is the loss of weight of the materials used for experimentation due to their continuous respiration and water loss. Perishable commodities respire even after harvest, so water and carbon dioxide is produced during respiration. Weight loss occurs due to transpiration of water and release of carbon dioxide from the perishable commodities. The materials kept in the evaporative cooling storage structure, at room temperature and in refrigerator were weighed in every 2 days. The percentage weight loss is calculated by the following formula given by Jadhav *et al.* (2010):

$$\text{Weight loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad ...(2)$$

Table A : Strategy table for quality evaluation

	Tomatoes kept as sample (g)			Total tomatoes removed			Weight loss (%)			Dry weight (g)			Moisture content (% wet basis)		
Day	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C

Note: A: Refrigerator; B: Room temperature; C: Evaporative cooling storage structure

Table B : Strategy table for cost evaluation

Materials used	Unit price (Rs.)	Units used	Cost for ECSS (Rs.)
Total material cost			
Cost of fabrication			
Total			

Note: ECSS: Evaporative cooling storage structure

where, W_1 and W_2 are the weight of commodities before and after storage in grams, respectively.

Moisture content:

Water is continuously produced in the perishable commodities due to respiration. This leads to the accumulation of water within the fruit or vegetable. Determination of the amount of moisture present is very necessary asexcessive moisture content of the fruit or vegetable may lead to its spoilage. Samples from the materials kept in the evaporative cooling storage structure, room temperature and in refrigerator were taken for moisture content determination using standard hot air oven dry method in every 2 days interval. The formula used for calculation of moisture content is as follows:

$$\text{Moisture content (\%wb)} = \frac{M_1 - M_2}{M_1} \text{ x } 100 \qquad ...(3)$$

where, M_1 and M_2 are the weight of commodities before and after drying in grams, respectively.

Colour analysis:

The change in quality of the tomatoes and grapes kept in the refrigerator, at room temperature and in evaporative cooler was also assessed by analyzing the change in colour.In this study, colour determination is done by using hunter colour lab. It gives the measurement in the form of ‘L’, ‘a’, ‘b’ values. The value of ‘L’ ranges from 0-100 indicating darkness to brightness. However, ‘a’ and ‘b’ does not have any particular range of values. Negative to positive value of ‘a’ indicates the greenness to redness, while for ‘b’ it measures the transformation of blue to yellow colour. In this study, same sample was used repeatedly to get the appropriate result after selecting almost similar samples when experiment started. The total change in colour (ΔE) can be calculated by using the initial and final values of ‘L’, ‘a’ and ‘b’ by the following formula:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \qquad ....(4)$$

Rate of change of colour can be calculated using the formula:

$$\text{Rate of colour change} = \frac{\Delta E}{\Delta t} \qquad ....(5)$$

where, Δt is the change in time.

Cost evaluation:

Cost evaluation involves assessment of all the costs associated in the development of the evaporative cooling storage structure. It includes the cost of materials used in the construction of the structure as well as its fabrication cost. It was done to analyze the total cost involved in the development of the structure. The cost efficiency of the evaporative cooling storage structure was investigated in terms of refrigeration keeping in consideration the performance of the structure. The strategy table for the cost analysis is shown in Table B.

OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Performance of the evaporative cooling storage structure under no load condition:

The variation in temperature outside and inside the evaporative cooler is shown in Fig. 1(a-b). From the figures, it is revealed that the dry bulb temperature outside the evaporative cooling storage structure ranged between 29-35°C in 17 hours and that inside the evaporative cooler, it ranged between 19-25°C. The slope of temperature outside the evaporative cooler is found to be steeply decreasing. In contrast, inside the evaporative cooler, the

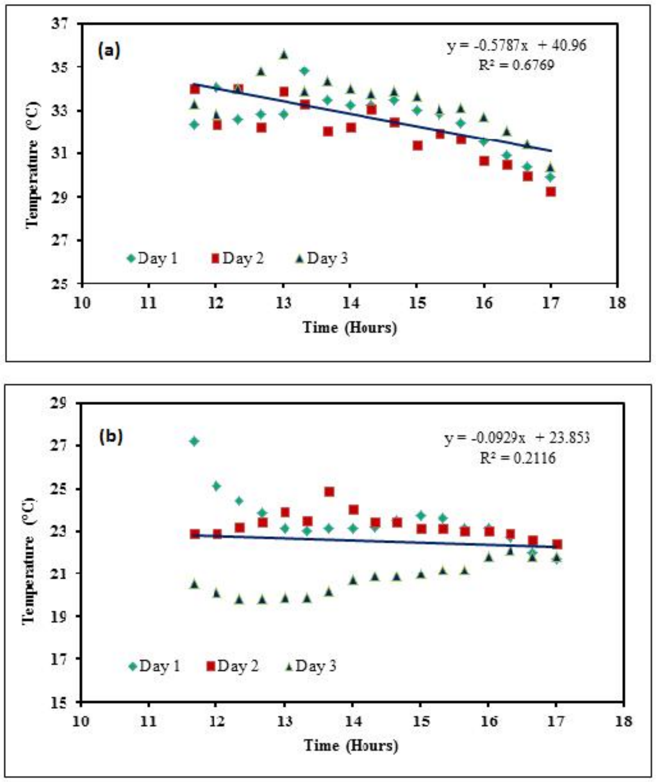

Fig. 1 : Variation of temperature (a) outside and (b) inside the evaporative cooling storage structure under no load condition

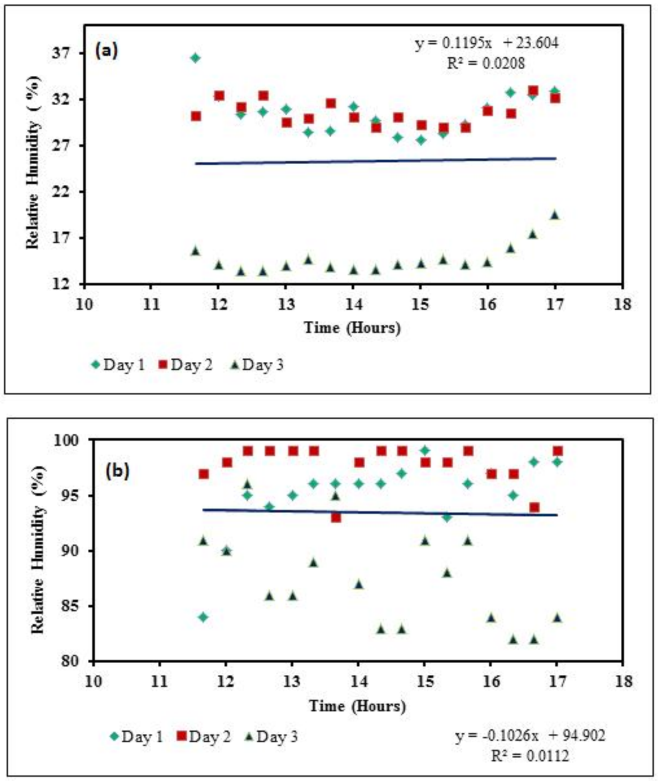

Fig. 2 : Variation of relative humidity (a) outside and (b) inside the evaporative cooling storage structure under no load condition

temperature trend line shows a moderate decrease in slope. This indicates that an overall drop of 10-12°C temperature is obtained inside the evaporative cooler without any sudden erratic changes in temperature. The variation inrelative humidity outside and inside the evaporative cooler is shown in Fig. 2(a-b). It is found from the figures that the relative humidity of the surrounding ranged from 12-37 per cent during the period of 17 hours whereas inside the evaporative cooler, it varied between 80-99 per cent showing an overall increase of 62-68 per cent relative humidity inside the evaporative cooling storage structure. Maintaining an optimum temperature and relative humidity for most of the perishable commodities in no load condition infers the desired performance of the evaporative cooler.

Performance of the evaporative cooling storage structure under loaded condition:

The cooling efficiency of the evaporative cooling storage structure throughout the day is measured on the basis of the dry bulb temperature inside the evaporative cooler and in ambient conditions and the variation is shown in Fig. 3. It is found from the figure that the cooling efficiency varied from 70-95 per cent. The results also indicate that the cooling efficiency attains its highest values between 13-15 hours of the day. This is because at this time of the day, the ambient temperature is at its maximum values and the relative humidity reaches the minimum for the day. This is in agreement with the work of Jain (2007), which indicated that higher the ambient temperature and lower the relative humidity, higher will be the cooling efficiency.

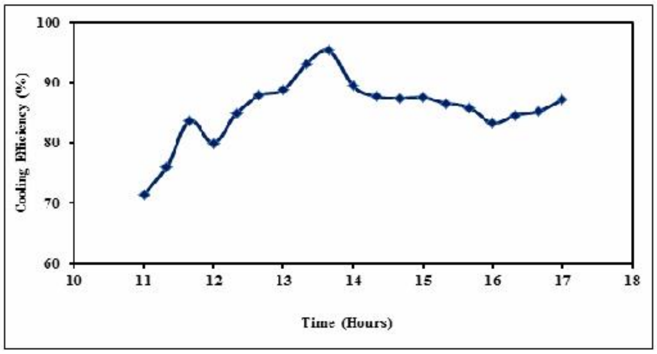

Fig. 3 : Variation of cooling efficiency with time

Effect on percentage weight loss:

The loss of weight in the tomatoes and grapes kept in the evaporative cooling storage structure, room temperature and in refrigerator were measured in every 2 days and the results are presented in Fig. 4(a-b).The physiological weight loss is found to be maximum at room temperature, followed by the evaporative cooler and refrigerator in case of both tomatoes and grapes. The tomatoes kept at room temperature were discarded on the 19th day due to attack of insects on it. It can also be inferred from Fig. 4(a) that on the 35th day, the tomatoes underwent significant weight loss (7.7%) in the evaporative cooler and were in good and edible condition till the 31st day. In contrast, the grapes in the evaporative cooler underwent a significant weight loss of 4.65 per cent on the 19th day. However, the grapes in the refrigerator were still in good condition.

Effect on moisture content:

The amount of moisture in percentage wet basis present in the tomatoes and grapes were measured at every 2 days interval and the results are shown in Fig. 5(a-b). It can be seen from the figures that the moisture content of tomatoes and grapes were initially at 95.27 per cent and 81.57 per cent, respectively. It showed an increasing trend and varied from 95.27-97.44 per cent in case of tomatoes and 81.5-85.66 per cent in case of grapes. The tomatoes and grapes were in good and edible condition until the 31st and 19th day with moisture content of 96.57 per cent and 85.66 per cent, respectively.

Effect on colour:

The change in colour of the tomatoes was measured in terms of ‘L’, ‘a’ and ‘b’ values and is shown in Fig. 6 (a-c). Ripening of tomatoes is seen with the increase in duration of storage till the 35th day. A change of darker colourfrom pinkish green to brighter red colour is observed. The L-value changed from 67.68 to 25.506 in the tomatoes stored in the evaporative cooler and refrigerator in 35 days (Fig. 6a). The a-value varied from 6.37 to 51.08 and 56.78 in the evaporative cooler and refrigerator, respectively (Fig. 6b). In addition, the b-value varied from 42.12 to 15.99 in evaporative cooler and 16.77

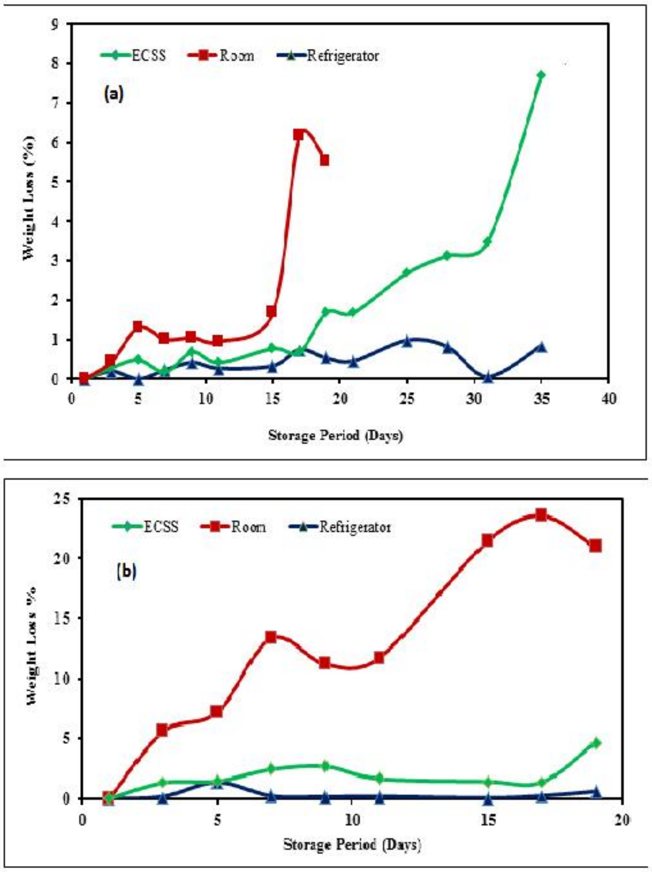

Fig. 4 : Variation of percentage weight loss with time in (a) tomatoes and (b) grapes

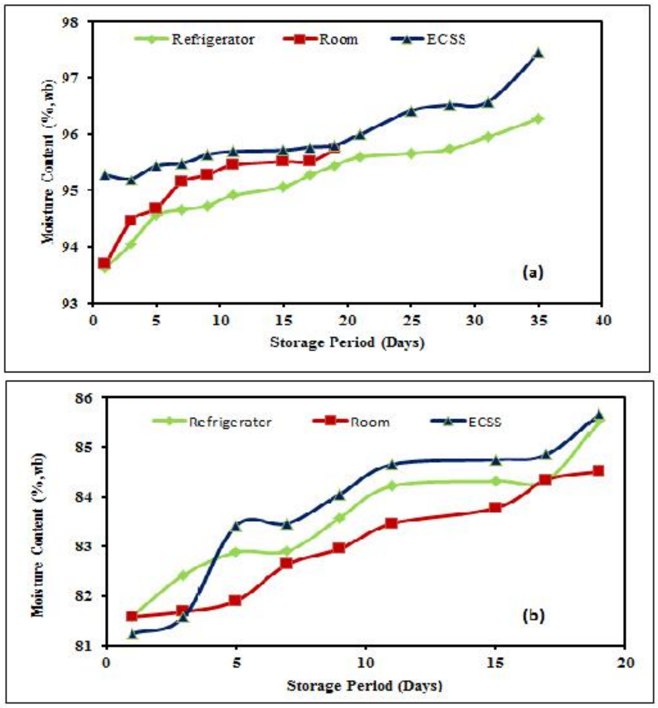

Fig. 5 : Variation of moisture content with time in (a) tomatoes and (b) grapes

in the refrigerator (Fig. 6c). It can also be seen from the figures that the L-value and b-value of tomatoes are almost stable from the 19th to 35th day. However, the tomatoes kept at the room temperature attained a value of 27.11, 50.55 and 18.08 for 'L', 'a' and 'b', respectively on the 19th day when it was discarded.

Like the tomatoes, colour of grapes was also measured in terms of 'L', 'a' and 'b' values and is shown in Fig. 7(a-c). It can be inferred from the figures that decrease in L-value is higher and faster in case of grapes kept inevaporative cooler (from 88.55 to 62.78) and at room temperature (from 88.55 to 63.47), whereas it is comparatively slower in case of that in refrigerator (from 88.55 to 74.52) in 19 days. In the observation period the a-values remained negative indicating the greenness of grapes. The increase in the a-valueis highest in the grapes at room temperature (from -29.54 to -20.37) followed by refrigerator (from -29.54 to -22.33) and the evaporative cooling storage structure (from -29.54 to -24.43). The b-value of grapes in evaporative coolerand refrigerator increased from 37.85 to 41.75 and 44.18, respectively indicating the ripening of the grapes. However, the b-value decreased in case of grapes at room temperature from 37.85 to 29.11. This decrease can be attributed to the development of spots on the surface of grapes in the course of 19 days.

The rate of change of colour in tomatoes is 1.92 in evaporative cooling storage structure, 3.44 at room temperature and 1.99 in refrigerator. In case of grapes, it is 1.53 in evaporative cooling storage structure, 1.65 at

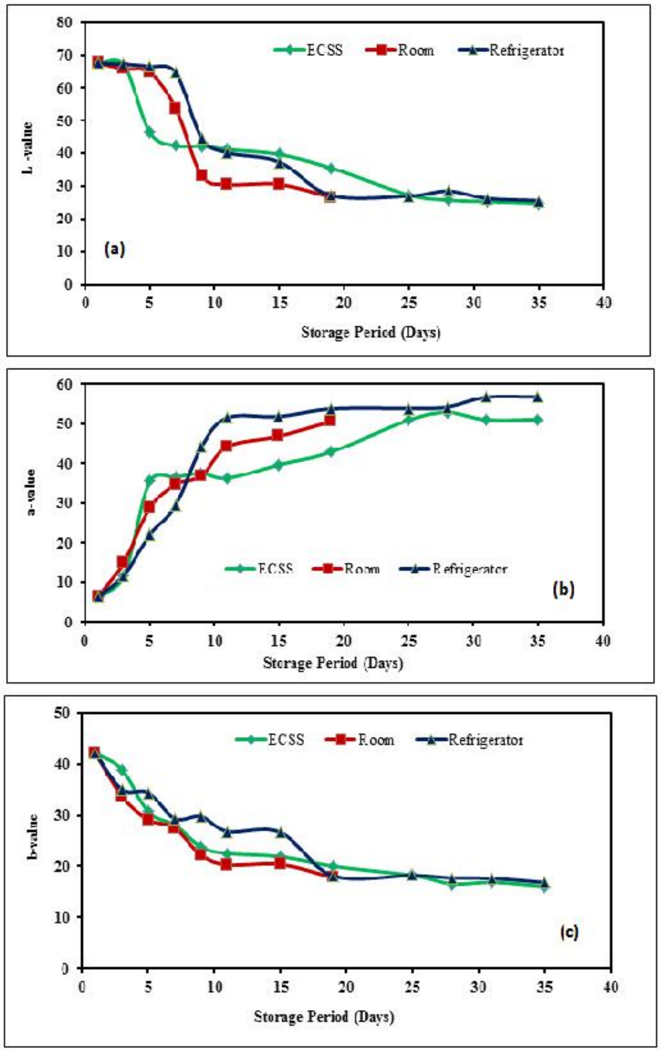

Fig. 6 : Variation of (a) L, (b) a, and (c) b values of tomatoes with time

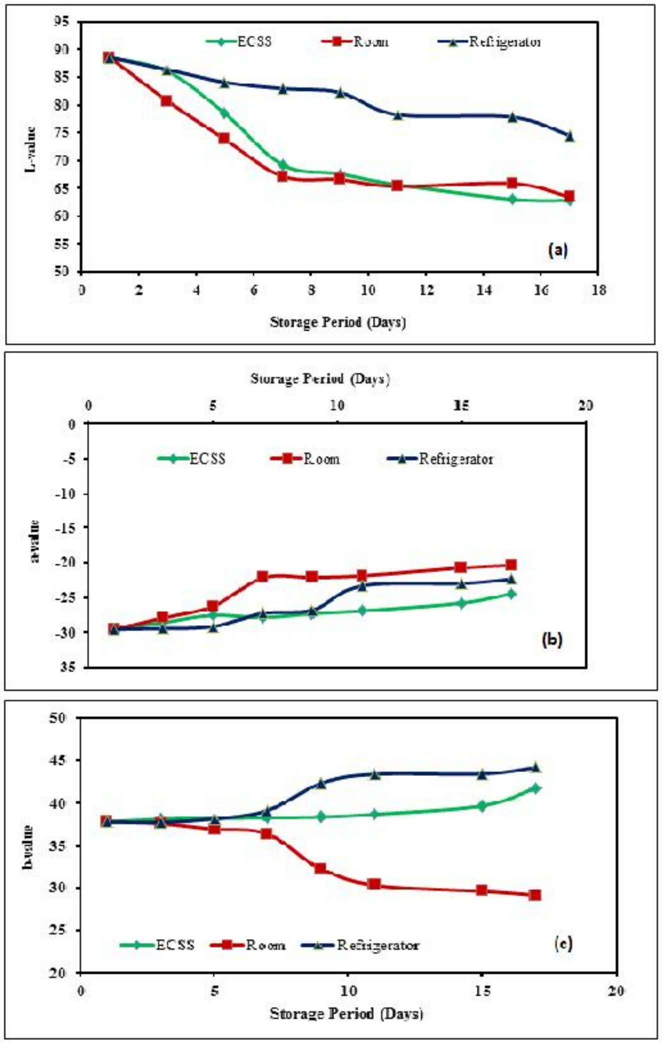

Fig. 7 : Variation of (a) L, (b) a and (c) b values of grapes with time

room temperature and 0.99 in refrigerator. From this, it can be inferred that the overall ripening of tomatoes and grapes in terms of colour change is fastest at room temperature and relatively slower in case of evaporative cooling storage structure and the slowest in refrigerator.

Cost estimation of the evaporative cooling storage structure:

In this study, an attempt was made to compute the total cost involved in operation of the evaporative cooling storage structure. It involves the cost of materials used for its construction along with the fabrication cost. The unit-wise cost of materials used for the development of the evaporative cooling storage structure is given in Table 1. The cost of fabrication is Rs. 550. From the Table 1, it can be seen that the total cost associated with the evaporative cooling storage structure is only Rs. 1926. Since, no extra energy is required to operate the evaporative cooler, its overall costis much lower than that is generally required in case of a refrigerator.

Conclusion:

In this study, an attempt was made to develop and analyze the performance of a low- cost evaporative cooling storage structure for perishable commodities. The main aim of this study was to provide useful means to reduce the post-harvest losses as well as the handling charges. A double-wall evaporative cooling storage structure was developed using locally available and low-cost materials such as rice husk and sawdust keeping in mind the properties required for evaporative cooling. The temperature and relative humidity outside and inside the evaporative cooler was measured for 3 days under no load condition. The experiment was conducted upto 40 days with tomatoes and grapes stored inside the evaporative cooler in two different bamboo stacks. The performance evaluation of the evaporative cooler was carried out by means of cooling efficiency. The percentage loss of weight of commodities, their moisture content and colour changes were measured at every 2 days interval. The total cost involved in the operation of the evaporative cooler was also assessed. The comparison of the performance of evaporative cooler was made in comparison to that of refrigerator and room temperature.

Based on the study, the following conclusions were drawn:

The temperature inside the evaporative cooler varied from 19-25°C with a drop of 10-12ºC from the ambient conditions. The relative humidity increased to 80-99 per cent inside the evaporative cooler providing an optimum condition for perishable commodities.

The cooling efficiency of the evaporative cooler ranged between 70-95 per cent. It reached its maximum values at times of the day when ambient temperature was highest and relative humidity was lowest justifying the principle of evaporative cooling.

The percentage loss of weight of tomatoes and grapes were 7.7 per cent and 4.65 per cent, respectively on the 35th day and 19th day, respectively. The moisture of tomatoes and grapes attained its maximum values (97.44% and 86.21%) on the 35th and 19th day, respectively.

Visible changes in the colour of the tomatoes and grapes were seen with some spots on the surface on the

Table 1 : Cost evaluation of evaporative cooling storage structure

Materials used	Unit price (Rs.)	Units used	Cost for ECSS (Rs.)
Sawdust (kg)	1	6	6
Rice husk (kg)	1	18	18
Wood (pieces)	50	11	550
Plastic net (m)	80	8	640
Nails (kg)	100	0.5	50
Wire (pieces)	6	2	12
Polythene sheet (m)	50	2	100
Total material cost			1376
Cost of fabrication			550
Total			1926

35th day and 19th day, respectively. The total cost involved with the evaporative cooler was only Rs. 1926 including the fabrication cost, which is way too less in comparison to that of a refrigerator.

Tomatoes and grapes were in good and edible conditions till the 31st day and 19th day, respectively.

Due to their shorter shelf-life, perishable commodities do not stay fresh after harvest. The only way to increase their shelf life is to provide optimum temperature and relative humidity. Higher cost of devices used to maintain the temperature and relative humidity at an optimum level makes their use limited to rich households and large-scale industries only. The evaporative cooling storage structure developed in this study proves to be an efficient and feasible device in monetary terms for the farmers. This type of structure is a unique one and can be adopted by farmers world-wide.

LITERATURE CITED

Abdul, A.K. (1989). Postharvest losses during processing and preservation of fruits and vegetables. A Ph.D. Thesis, University of Punjab Pakistan.

Adetuyi, F.O., Ayileye, T.A. and Dada, I.B.O. (2008). Comparative study of quality changes in shea butter coated pawpaw *Carica papaya* fruit during storage. *Pakistan J. Nutr.,* **7** (5) : 658-662.

Anonymous (2010). Area and production estimates for horticulture crops for 09-10. National Horticultural Board (NHB), India. *www.nhb.gov.in*

Anonymous (1985). *Zero energy cool chamber.* Research Bulletin No. 43, IARI, New Delhi, India.

Anyanwu, E.E. (2004). Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. *Energy Conversion Management,* **45** (13): 2187 - 2195.

Basedia, A.L., Samuel, D.V. K. and Beera, V. (2013). Evaporative cooling system for storage of fruits and vegetables - A review. *J. Food Sci. & Technol.,* **50** (3): 429-442.

Bhardwaj, R.L. and Sen, N.L. (2003). Zero energy cool-chamber storage of mandarin (*Citrus reticulatablanco*) Nagpur Santra. *J. Food Sci. & Technol.,***40** (6) : 669-672.

Boyette, M.D., Wilson, L.G. and Estes, E.A. (2010). *Postharvest handling and cooling of fresh fruits, vegetables and flowers for small farms.* Leaflets 800-804. North Carolina Cooperative Extension.

Camargo, J.R. (2008). Evaporative cooling: water for thermal comfort. An Interdisciplinary. *J. Appl. Sci.,* **3** : 51-61.

Chandra, P., Shrivastava, R. and Dash, S.K. (1999). Thermal behaviour of a fruits and vegetables storage structure. *J. Institution Engineers,* (AG-1), **80** (1) : 5.

Chopra, S., Baboo, B., Alesksha, Kudo, S.K. and Oberoi, H.S. (2003). *An effective on farm storage structure for tomatoes*. Proceedings of the International Seminar on Downsizing Technology for Rural Development held at RRL, Bhubaneswar, Orissa, India, October 7-9, pp. 591-598.

Chouksey, R.G. (1985). Design of passive ventilated and evaporatively cooled storage structures for potato and other semi perishables. In: *Proc. Silver Jubilee Convention of ISAE held at Bhopal*, India, October 29-31, 45-51.

Dadhich, S.M., Dadhich, H. and Verma, R.C. (2008). Comparative study on storage of fruits and vegetables in evaporative cool chamber and in ambient. *Internat. J. Food Engg.,* **4** (1): 1-11.

Datta, S., Sahgal, P.N., Subrahmaniyam, S., Dhingra, S.C. and Kishore, V.V.N. (1987). Design and operating characteristics of evaporative cooling systems. *Internat. J. Refrigeration,* **10** (4) : 205-208.

FAO (1983). FAO *production Yearbook,* vol. **34**. FAO, Rome.

FAO (1986). Improvement of post-harvest fresh fruits and vegetables handling- A manual. Bangkok.

FAO (1995). *FAO Yearbook 1995.* FAO Statistics Series No. 132. FAO, Rome.

Franco, A., Valera, D.L. and Peña, A. (2014). Energy efficiency in greenhouse evaporative cooling techniques: Cooling Boxes versus Cellulose Pads. *Energies,* **7**: 1427-1447.

Ganesan, M., Balasubramanian, K. and Bhavani, R.V. (2004). Studies on the application of different levels of water on zero energy cool chamber with reference to shelf- life of brinjal. *J. Indian Institute Sci.,* **84**:107-111.

Habibunnisa, E.A., Aror, E. and Narasimham, P. (1988). Extension of storage life of the fungicidal waxol dip treated apples and orange under evaporative cooling storage conditions, *J. Food Sci. & Technol.,***25**(2): 75-77.

Horisawa, S., Sunagawa, M., Tamai, Y., Matsuoka, Y., Miura, T. and Terazawa, M. (1999). Biodegradation of nonlignocellulosic substances II: physical and chemical properties of sawdust before and after use as artificial soil. *J. Wood Sci.,* **45** : 492–497.

Ihekoronye, A.I. and Ngoddy, P.O. (1985). *Tropical fruits and vegetables. Integrated Food Science and Technology* *for the Tropics*, Macmillan Publications. Ltd. London and Basingstoke, 293-311.

Jadhav, R.T., Yadav, A.N., Ghag, K.S. and Gavnang, M.R. (2010). Comparative study on low cost evaporative cooling systems for storage of tomato. *Internat. J. Agric. Engg.*, **3** (2) : 199-204.

Jain, D. (2007). Development and testing of two-stage evaporative cooler. *Build Environment*, **42**(7): 2549-2554.

Jany, M.N.H., Sarker, C., Mazumder, M.A.R. and Shikder, M.F.H. (2008). Effect of storage conditions on quality and shelf life of selected winter vegetables. *J. Bangladesh Agric. Univ.*, **6** (2) : 391-400.

Jha, S.N. and Aleksha Kudos, S.K. (2006). Determination of physical properties of pads for maximizing cooling in evaporative cooled store. *J. Agric. Engg.*, **43**(4): 92-97.

Jha, S.N. (2008). Development of pilot scale evaporative cooled storage structures for fruits and vegetables in hot and dry region. *J. Food Sci. & Technol*, **42**(2): 148-151.

Katsoulas, N, Baille, A. and Kittas, C. (2001). Effect of misting on transpiration and conductance of a greenhouse rose canopy. *Agric. & Forest Meteorol.*, **106**: 233-247.

Lertsatitthanakorn, C., Rerngwongwitaya, S. and Soponronnarit, S. (2006). Field experiments and economic evaluation of an evaporative cooling system in a silkworm rearing house. *Biosystems Engineering*, **93**(2): 213-219.

Liberty, J.T., Ugwuishiwu, B.O., Pukuma, S.A. and Odo, C.E. (2013). Principles and application of evaporative cooling systems for fruits and vegetables preservation. *Internat. J. Curr. Engg. &Technol.*, **3** (3) : 1000-1006.

Metin, D., Karaca, C. and Yýldýz, Y. (2009). Performance characteristics of a pad evaporative cooling system in a broiler house in a Mediterranean climate. *Biosystems Engineering*, **103** (1): 100-104.

Mogaji, T.S. and Fapetu, O.P. (2011). Deveplopment of an evaporative cooling system for the preservation of fresh vegetables. *African J. Food Sci.*, **5**(4): 255-266.

Mordi, J.I. and Olorunda, A.O. (2003). Effect of evaporative cooler environment on the visual qualities and storage life of fresh tomatoes. *J. Food Sci. & Technol.*, **40**(6): 587-591.

Ndukwu, M.C. (2011). Development of a low cost mud evaporative cooler for preservation of fruits and vegetables. *Agric. Engg. Internat. CIGR J.*, **13**(1): 1-8.

Ndukwu, M.C, Manuwa, S.I., Olukunle, O.J. and Oluwalana, I.B. (2013). Development of an active evaporative cooling system for short-term storage of fruits and vegetable in a tropical climate. *Agric. Engg. Internat. CIGR J.*, **15**(4): 307-313.

Odesola, I.F. and Onyebuchi, O. (2009). A review of porous evaporative cooling for the preservation of fruits and vegetables. *Pacific J. Sci. & Technol.*, **10**(2): 935-941.

Olosunde, W.A., Igbeka, J.C. and Olurin, T.O. (2009). Performance evaluation of absorbent materials in evaporative cooling system for the storage of fruits and vegetables. *Internat. J. Food Engg.*, **5**(3): 1-14.

Rayaguru, K., Khan, M.K. and Sahoo, N.R. (2010). Water use optimization in zero energy cool chambers forshort term storage of fruits and vegetables in coastal area. *J. Food Sci. & Technol.*, **47**(4) : 437-441.

Roy, K.S. and Khurdiya, D.S. (1982). Keep vegetables fresh in summer. *Indian Horticulture*, **27**(1): 5-6.

Salunkhe, D.K. and Kadam, S.S. (1995). *Handbook of fruit Sciences and Technology.* New York: Dekker.

Sisman, C.B., Gezer, E. and Kocaman, I. (2011). Effects of organic waste (rice husk) on the concrete properties for farm buildings. *Bulgarian J. Agric. Sci.*, **17**(1): 40-48.

Sunmonu, M., Falua, K.J. and David, A.O. (2014). Development of a low-cost refrigerator for fruits and vegetables storage. Internat. *J. Basic & Appl. Sci.*, **2**(3): 85-93.

Umbarkar, S.P., Bonde, R.S. and Kolase, M.N. (1991). Evaporatively cooled storage structures for oranges (*Citrus reticulatu*). *Agric. Engg. Today*, **1** (1) : 26-32.

Vala, K.V. and Joshi, D.C. (2010). Evaporatively cooled transportation system for perishable commodities. *J. Agric. Engg.*, **47** (1): 27-33.

Vala, K.V., Kumpavat, M.T. and Nema, A. (2016). Comparative performance evaluation of evaporative cooling local pad materials with commercial pads. *Internat. J. Engg. Trends & Technol.*, **39** (4) : 198-203.

Zhang, Y., Ghaly, A.E. and Li, B. (2012). Physical properties of rice residues as affected by variety and climatic and cultivation conditionsin three continents. *American J. Appl. Sci.*, **9** (11): 1757-1768.

■ WEBLIOGRAPHY

http://www.engineeringtoolbox.com. (Accessed on: 16 September 2014).

Received : *18.08.2019;* **Revised :** *21.09.2019;* **Accepted :** *28.09.2019*