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# Development of Zero Energy Evaporative Cooling Storage Structure for Tribal Region of South Gujarat

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**Abstract:** Zero Energy Evaporative Cooling Storage Structure (ZEECSS) was designed and constructed with two different cooling pads i.e., gunny bags (GB) and small pieces of bricks (SPB) with the capacity of 50 kg to preserve yellowish red fresh tomatoes. In a no-load condition, an average temperature drop of 8±2°C and 9±2°C, with relative humidity varying from 87% to 88%, and cooling efficiency of 84% and 82% respectively was achieved in GB and SPB structure. Under loaded condition (with tomatoes stored in structure) average temperature drop of 10±2°C and 11±2°C, with relative humidity varying from 85% to 87%, and cooling efficiency measuring 88% and 91% was recorded respectively. A qualitative analysis of the stored tomatoes in terms of physiological loss in weight (% PLW), spoilage, shrinkage, total soluble solids (TSS), and pH indicated values of 16.25%, 22.06%, 4.67 cm, 4.34°Brix, and 4.68, respectively, for GB cooling pads, and 14.44%, 20.14%, 4.80 cm, 4.42°Brix, and 4.77, respectively, for SPB cooling pads on 14$^{th}$ day of storage. It was observed that the tomatoes could be stored for 14 days with 20±2% spoilage, compared to ambient conditions where rotting started on or after the 7$^{th}$ to 10$^{th}$ days, with spoilage reaching at 91.36% in next 2-3 days. Cost of structure had been calculated to be Rs. 7115, with 7 months payback period.

**Key words:** Zero energy, evaporative cooling, spoilage, efficiency, payback period.

Fruits and vegetables are highly perishable commodities that can't be kept for a long period due to their perishable nature. In developing countries, most of the post-harvest losses are incurred on fruits and vegetables due to the lack of adequate storage facilities. Tropical and subtropical vegetables like tomatoes faces greater storage and transportation challenges compared to several temperate fruits and vegetables, mainly because of their perishable nature. To preserve the harvested tomatoes in edible condition for a longer period, different kinds of storage and preservation techniques are employed. Tomatoes typically have a short shelf life of about one week (7 days) at ambient temperature. Therefore, it is important to attempt to extend their shelf life while retaining their nutritional value. Tomatoes are typically harvested when they are fresh and have high moisture content. The harvested fruits continue to undergo metabolic processes until it is consumed or begins to deteriorate. Preservation of perishable fruits and vegetables is of great importance because it allows delayed use and reduces wastage. To improve the shelf life of tomatoes, it is essential to select cooling technologies that balance low capital costs with high energy efficiency for storage. To encourage small scale farmers (SCF) to venture into horticultural production, cooling technologies should not only be of lower cost (Workneh and Woldetsadik, 2004; Workneh, 2007) but also should be made of appropriate locally available construction materials (Workneh and Woldetsadik, 2001). Small scale farmers have to often struggle to access different cooling technologies primarily due to their high prices (Baloyi, 2010). In developed countries, methods such as mechanical refrigeration, controlled atmospheres, hypobaric storage, and other sophisticated techniques are employed to extend shelf life and minimize post-harvest losses of perishable produce (Thompson *et al.*, 1998). However, maintaining low temperatures in tropical countries like India posed significant challenges. Conventional refrigeration systems are costly and also require electricity or fossil fuels, which may not be easily available in many villages and remote areas. To address this problem, a passive cool chamber, based on the principle of evaporative cooling, was developed for short term storage of fresh vegetables (Chaurasia *et al.*, 2005; Singh *et al.*, 2017). We aimed to further reduce temperature while increasing relative humidity to maintain optimal conditions for storing perishable crops like tomatoes for longer period using locally available material (Wills *et al.*, 1989; Thompson *et al.*, 1998; Basediya *et al.*, 2011). This led to development of zero energy evaporative cooling storage structure (ZEECSS) which along with its performance appraisal in the tribal region of south Gujarat is detailed in this paper.

## Material and Methods

### *Basic principle and theoretical consideration of developed ZEECSS (storage structure)*

The concept that evaporation cools its surroundings served as the foundation for constructing the evaporative cooling storage structure. A water distribution system caused water to drip steadily onto the cooling pad. As the water fell down and moved in to the pad, the warm, sensible heat-carrying air flowed through the wet pad and was converted into latent heat through evaporation. The evaporative cooling process require high temperatures, low humidity of the surrounding air, water spraying, and optimum air movement velocity. Based on the above principle, several points were considered for the development of the storage structure capable of holding 50 kg of fresh tomatoes (yellowish red, as per maturity indices). The structure incorporated a continuous water distribution system through PVC pipes, strategically placed to ensure air movement inside the storage unit. The selection of cooling media was based on calculations of water holding capacity, durability, and local availability, ensuring uniform wetting for proper water evaporation and optimized cooling conditions. Sturdy and non-corrosive construction materials were used to ensure the longevity of the storage structure. The rectangular shape of the storage unit maximized the surface area available for air circulation and storage of produce.

### *Fabrication and development work*

The Conceptual drawing and overall dimensions of ZEECSS is shown in Figure 1.

A. *Materials selection for the development of ZEECS structure*

i. Iron bar: A good quality MS material with a thickness of 4 mm was selected for its strengthening ability and capacity to sustain the structural load of the evaporative cooling storage structure.

ii. Wheel base arrangement: A 360°- wheel arrangement was provided at the base to allow for free movement of the storage structure according to the air wind velocity and sunny direction in the field, for achieving maximum cooling efficiency.

B. *Cooling Chamber*

i. Angle bar: The main frame of the evaporative cooling structure was constructed using angle bars, providing essential support to the entire storage structure and ensuring a strong strengthening effect.

ii. Mild iron sheet: Mild iron sheets, with low carbon content ranging from 0.04% to 0.30%, were used to resist the effects of corrosion.

*C. Cooling pad arrangement*

i. Galvanized iron wire mesh: A galvanized iron wire mesh with an aperture diameter of 5 mm was used as the active constructive body for holding the cooling pad, which could be adjusted with an annular space ranging from 5 to 15 cm.

*D. Water distribution system:*

i. Water tank reservoir: Serving as a water storage tank, water was supplied to the cooling pad area through a PVC pipe arrangement, relying on gravitational action.

ii. PVC pipe: A uniform water distribution system was implemented to the left, right, and back sides of the evaporative storage structure within the cooling pad area.

iii. Valve arrangement: Valve arrangements were incorporated to ensure proper water distribution throughout the cooling pad area and manage water requirements.

*E. Pull push arrangement:*

i. Iron bar: An iron bar was utilized to create a handle for pulling and pushing the storage structure, allowing for easy and convenient movement.

## *Development of the evaporative cooling system*

*A. Structural development*

An evaporative cooling system of 50 kg storage capacity was constructed for the preservation of on farm produces fresh yellowish red tomatoes. The evaporative cooling chambers consist of rectangular shaped cabinet with total storage space of 0.324 $m^3$ made of galvanized mild steel, cooling pad of 0.05 to 0.015 m adjustable annual space area for the incorporation of cooling pad made from the different materials linked to the cooling system from all three sides i.e., back side, left and right side of the storage structure.

The inverted pyramid structure provided for the air movement and spoilage control mechanism at the top of cabinet. The PVC pipe was used for supplying water to keep the cooling pad continuously wet to produce cooling effect by evaporation, as and when the system was set in operation, the dry air passes over the wet surface (cooling pad) and evaporated the soaked water away from the cooling pad from the upper side. When water evaporates, it draws energy from surroundings (storage chamber) which produce considerable cooling effect in the storage chamber.

*B. Theoretical design calculation of the experimental cooling storage structure*

The storage system is rectangular in shape and the design specifications for the system were done according to design given by with Zakari *et al.* (2016) in design and construction of an evaporative cooling system for the storage of fresh tomato as shown in Table 1.

*C. Water distribution system*

A 90 mm PVC pipe was used for uniform distribution of water from the water storage

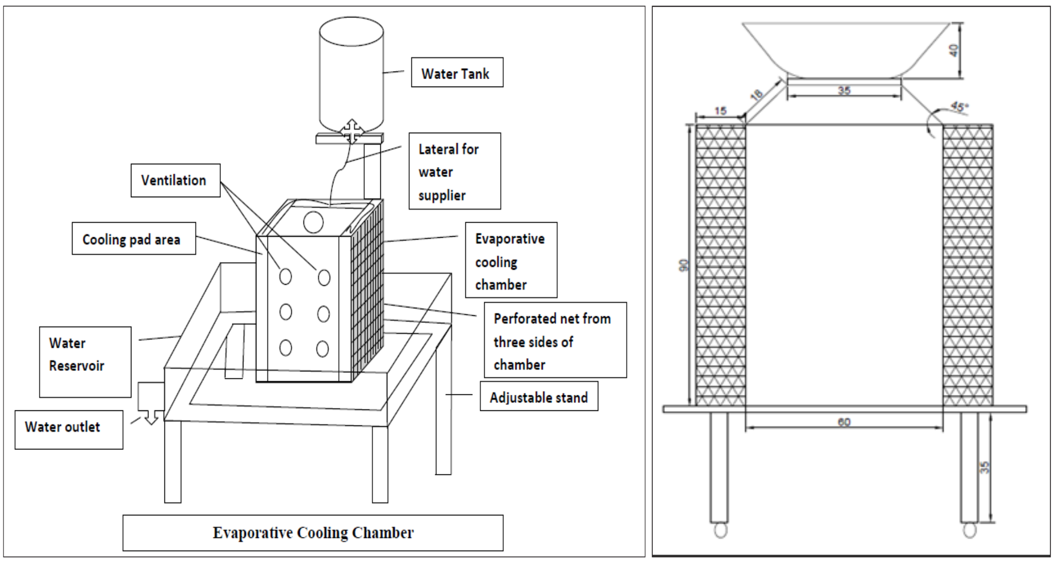


*Fig. 1. Conceptual drawing of zero energy evaporative cooling storage structure (ZEECSS).*

*Table 1. Design specification and calculations*

| Design specifications | Formulas | Calculations |
|---|---|---|
| Front and rear sides of the storage system | $A_r = H_r \times L_r$<br>$A_r$ = Area of rear side ($cm^2$)<br>$L_r$ = Length of rear side (cm)<br>$H_r$ = Height of rear side (cm) | $A_r = 0.9 \times 0.6$<br>$= 0.54\ m^2$ |
| Left, right hand and back sides of the storage system (pad area) | $A_l = H_l \times B_l$<br>$A_l$ = Area of left side of the storage system ($cm^2$)<br>$H_l$ = Length of left side (cm)<br>$B_l$ = Breadth of left side (cm) | $A_l = 0.6 \times 0.05$<br>$= 0.03\ m^2$<br>(All three area covered with the same dimensions) |
| Top of the storage system | $A_t = L_t \times B_t$<br>$A_t$ = Area of top ($cm^2$)<br>$L_t$ = Length of top (cm)<br>$B_t$ = Breadth of top (cm) | $A_t = 0.6 \times 0.6$<br>$= 0.36\ m^2$ |
| Bottom perforated sheet | $A_{wr} = L_{wr} \times B_{wr}$<br>$A_{wr}$ = Area of sheet ($cm^2$)<br>$L_{wr}$ = Length of sheet (cm)<br>$B_{wr}$ = Breadth of sheet (cm) | $A_{wr} = 0.9 \times 0.9$<br>$= 0.81 m^2$ |
| Volume of the storage system | $V_c = L_c \times B_c \times H_c$<br>$V_c$ = Volume of ZEECSS ($cm^3$)<br>$L_c$ = Length of ZEECSS (cm)<br>$B_c$ = Breadth of ZEECSS (cm)<br>$H_c$ = Height of ZEECSS (cm) | $V_c = 0.6 \times 0.6 \times 0.9$<br>$= 0.324\ m^3$ |
| Volume of reservoir | $V_r = \pi\, r^2 h$<br>$V_r$ = volume of reservoir ($cm^3$)<br>π = 3.14<br>$r$ = radius of reservoir (cm)<br>$h$ = height of reservoir (cm) | $V_r = 3.14 \times 0.19^2 \times 0.3$<br>$= 0.034\ m^3$<br>(Approx:35 L) |

tank of capacity about 35 L, surrounding the annular space of the evaporative cooling pad. Dripper of 4 mm diameter was spaced on PVC pipe to carry out uniform discharge through the cooling media twice daily.

*D. Storage cabin*

The main frame of the cabin was constructed with iron angle for the rigid support. The wall, roof and floor are constructed with iron angle and iron bar board which was white painted to reduce the effect of temperature difference. The interior of the cabin was divided into two sections by a wire mesh. The storage cabin of evaporative cooling system was made up of double jacket walls of wire mesh structure. The inside wall is a rectangular shaped (50 cm long x 50 cm wide x 80 cm deep) shaped with cooling media having partitions for storage of tomatoes. The outside wall was also a rectangular shaped (60 cm long x 60 cm wide x 90 cm deep) with a 5 to 15 cm adjustable gap with nut and long tread 15 cm screw separating it from the inside wall. The shelves dimensions were 450×450 mm and stand were constructed 350 mm height at the edges by 50 mm. The shelves were fixed in storage cabin. The overall dimension of the storage cabin was 600 × 600 × 900 mm.

*E. Cooling media selection as a cooling pad*

As part of the general requirements, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water from the cooling pad. This is dependent upon the air velocity, pad thickness and the degree of saturation of the pad, which is a function of the water flow rate wetting the cooling pad (Thakur and Dhingra, 1983; Wiersma, 1983). In this work, to obtain the higher storage efficiency of the storage structure, two cooling pad materials were utilized: gunny bag (GB) and small pieces of bricks (SPB), each with a thickness of 5 cm, as shown in Fig. 2. Gunny bags (GB) and small pieces of brick (SPB) had the density of 26.43 and 29.32 kg $m^{-3}$ and water holding capacity of 6.98 and 7.83 g $g^{-1}$, and absorbed 1.683 and 1.583 kg water, respectively.

The selection on the types of pads was used in the developed storage structure for its comparative analysis which was based on the porosity, water absorption evaporation rate of the material, high moisture content, high bulk density, local availability, desirable cost and

*Table 2. Total cost of zero energy evaporative cooling storage structure (ZEECSS)*

| Particulars | Dimensions (cm) | Materials cost (Rs.) |
|---|---|---|
| Iron bars for rectangular frame of ZEECSS with | 60×60×90 | 700 |
| Galvanized Iron 6 wire mesh (Wire net) for rectangular frame of ZEECSS to prepared adjustable frame | 60×60×90 | 1500 |
| GI bolt (8 No) and screw nut arrangement matching with the pad thickness in between 5cm to 15 cm in variation | 20×8 | 350 |
| Iron bar made roof arrangement to fixed water reservoir | 60×60×18 | 250 |
| Water reservoir plastic bucket with capacity | 35 lit. | 200 |
| Iron square rod for standing and supporting rectangular frame | 60×35 | 200 |
| Rotating wheel (Nos 4) movement of chamber accordingly | 360° angle | 800 |
| Door arrangement with door handle and lock arrangement | 90×60 | 100 |
| PVC pipe for watering arrangement in three sides to cool pads | 270 | 150 |
| PVC coupling, valve, L joints, U joints, T joints as per need for watering arrangement | Market availability | 250 |
| Gunny bags to prepare cooling pad (5 cm thickness) | 60×60×90 | 50 |
| Bricks to prepare small pieces of bricks cooling pad (5 cm thickness) | 60×60×90 | 50 |
| Color paint | 2.5 L | 200 |
| Labor cost for fabrication of cool chamber (ZEECSS) | 1 person | 350 |
| Total cost of developed zero energy evaporative cooling storage | | 5500 |

ease of construction for any unskilled farmer for its on-farm practice as reported (Manuwa, 1991; Igbeka and Olurin, 2009). The Total cost of ZEECSS is given in Table 2.

## *Experimental procedure and performance evaluation*

The experiment mainly consisted of performance evaluation of ZEECSS in terms of temperature drop; relative humidity and storage and their effect on shelf life along with different quality parameters of tomatoes such as size, shape, pH, TSS, shrinkage etc. The evaporative storage structure as shown in Fig. 2. was located on farm under the mid shadow and sunny area with proper wind direction selection to optimize the ambient air surrounded to storage structure.

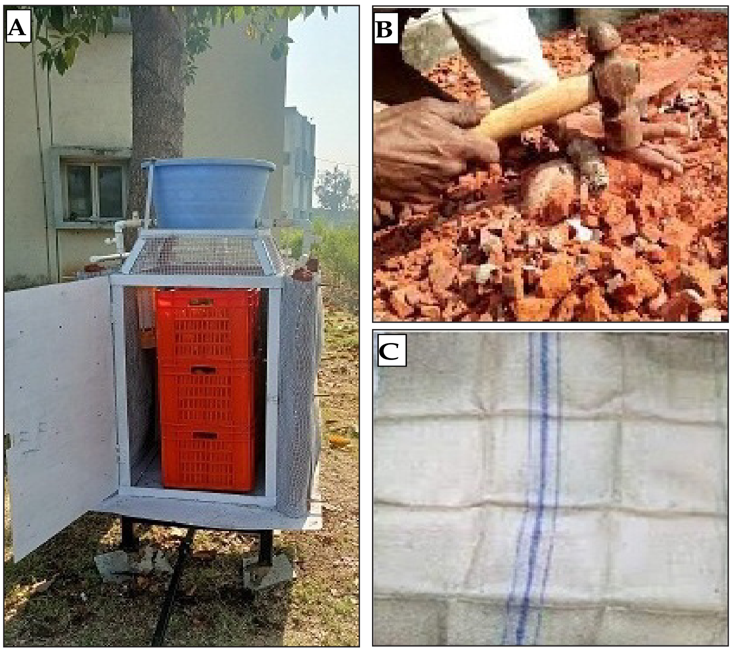


*Fig. 2. Developed zero energy evaporative cooling storage structure (A) and evaporative material viz. small pieces of bricks (B) and gunny bag (C).*

For comparative analysis two different cooling pads i.e., GB and SPB were wetted with continuous discharge of cleaned water from dripper with the uniform flow rate. Storage tank was filled regularly for the experiment as per the calculations of water requirement. Experimental tests were undertaken with evaporative storage structure under no load conditions (without tomatoes) and under loaded condition (with tomatoes) with installation of two different cooling pads i.e., GB and SPB. No load test was done to establish its transient response to variations in prevailing weather conditions in terms of temperature drop between the ambient temperature and the temperature found in evaporative storage structure chamber with different cooling pads and change in relative humidity before storage of tomatoes.

Load tests were conducted to determine the storage period and assess the enhancement of the shelf life of tomatoes inside the storage structure, indicated by the spoilage percentage and loss of weight over time. Tomatoes kept under ambient conditions in shade served as the control. Tomatoes kept both as control and in ZEECSS were observed daily, and their quantitative and qualitative changes were recorded. Additionally, changes in weather parameters in ZEECSS were periodically recorded. Fresh yellowish-red mature locally available tomatoes obtained from farmers' fields were used. Measurements of wet and dry bulb temperatures and relative humidity were taken at two-hour intervals for all tests conducted in a day, starting from 900 to 1700 hrs local time, both in ambient conditions and inside the storage structure. The tests were conducted during the hot summer season from mid-March to the first week of June. The developed evaporative storage structure was evaluated on the basis of temperature drop, change in relative humidity and cooling efficiency of structure.

*A. No-load test of the evaporative cooling system*

A no-load test was conducted of the storage structure to study the effect evaporation taking place to determine its cooling efficiency before being loaded with the agricultural produce i.e., tomatoes. Prior to the start of load test of tomato storage, the no load test was conducted to determine its transient reaction to changes in the prevailing meteorological conditions, namely in terms of change in temperature either it was decrease or increase from the ambient in the evaporative storage structure and change in relative humidity.

*Temperature and relative humidity measurement:* The temperature difference between the internal and external temperature was determined whether evaporation is effective for the system or not. Ambient wet and dry bulb temperatures were measured with the digital thermometers with a reading accuracy of ±0.10°C. The relative humidity was also monitored with a hygrometer with a reading accuracy of ±0.1%.

*Cooling efficiency:* Cooling efficiency of the developed storage structure was determine in two cases by changing the cooling pad (GB and SPB) to optimize the effectiveness of storage structure according to the change in the weather parameters and cooling pads. The following mathematical formula was used for determination of cooling efficiency of the developed storage structure (Harris, 1987 and Lertsatitthanakorn *et al.,* 2006).

$$S_E = \frac{T_1(db) - T_2(db)}{T_1(db) - T_1(wb)} \times 100$$

where,

$T_1$ (db) = dry bulb outdoor temperature, °C; $T_2$ (db) = dry bulb cooler temperature, °C; $T_1$ (wb) = wet bulb outdoor temperature, °C

*B. Load test of developed ZEECSS*

In load test, the evaporative cooling system was loaded with 50 kg tomatoes as per the capacity of the storage structure. The above-mentioned independent weather parameters were recorded. The quality assessment of the two produce like tomatoes were estimated to analyzed shelf life of the products under ambient condition and compared it with the with storage condition of evaporative cooling system by using two different cooling pads. Load tests were conducted to determine the shelf life of the tomato in the storage structure before spoilage. A control test in which the same product inside the evaporative cooler was exposed to open air conditions under a shade was used to evaluate the evaporative storage structure effectiveness in preservation of the tomato. Control test samples were weighed every day to determine the physiological loss in weight (PLW) and the change in colour while tomato in evaporative storage structure was examined every day to determine, physiological loss in weight (PLW), Change in total soluble solids (TSS) content, Spoilage percentage, shrinkage dimension, pH value and the color changes.

### *Quality Analysis*

*Physiological loss in weight (PLW):* The weight of tomatoes at regular intervals on a daily basis was recorded by altering the condition of both the cooling pads to optimize minimal changes in the physiological loss of weight for tomatoes, and it was compared with the tomatoes stored in ambient conditions.

*Change in total soluble solids:* Total soluble solid (TSS) in the tomato pulp was estimated by using Erma handheld refractometer. Determining the total soluble solids (TSS) in tomato pulp is a common practice to assess the fruit's sweetness and ripeness. The TSS measurement is usually expressed in terms of Brix, which represents the percentage of soluble sugars in the tomato pulp.

*Spoilage percentage:* The spoilage of the tomatoes inside evaporative cooling storage and ambient condition storage was studied according to the duration of the storage analysis. The spoilage percentage was calculated with the help of following equation.

$$Spoilage\ \% = \frac{\text{Wt. of the sample stored} - \text{Wt. of good quality sample}}{\text{Wt. of the sample stored}} \times 100$$

*Shrinkage dimensions:* The length, thickness and breadth of samples were measured as key for determining shrinkage using digital vernier caliper. The measure was done to determine the equivalent size of both the samples during storage. The equivalent size was determined on randomly selected samples on per day basis.

*pH Value:* The pH value in the tomato pulp was estimated by using pH meter during the storage study of fresh yellowish red tomatoes up to the specific period in the ambient condition and storage condition up to its overall maturity stage. Tomatoes are mildly acidic fruits, and the pH could vary slightly depending on the ripeness during storage. The pH level is essential for determining the safety and stability of tomatoes to enhance its shelf life

### *Techno-economic feasibility and payback period*

Cost economics was calculated to compare the cost of storage under ambient and storage structure ZEECSS with the fixed costs of the evaporative cooling storage structure. The fabrication and development and other costs (for development of storage structure) during the construction period were included in the cost component development. In the variable cost component, all the variable expenses such as tomato samples, maintenance cost, water and labor costs (for daily service and operation) were included for the effective cost analysis of the storage structure.

## Results and Discussion

### *Effect of cooling pads on weather parameters in no-load condition*

Temperature parameters such as wet bulb temperature and dry bulb temperature and relative humidity in evaporative cooling storage structure using both types of cooling pads were measured daily from 900 to 1700 hrs. During the study, it was observed that in case of GB cooling media, the maximum temperature drop occurred between 1200 to 1500 hrs and lowest between 900 to 1100 hrs in morning and 1600 to 1700 hrs in evening under no load conditions. The data was recorded for 5 days and repeated thrice (Fig. 3 and 4). It was observed that the average temperature drop was 8°C and 9°C with the relative humidity varying from 84 to 87% and 85 to 90% in case of GB and SPB respectively. In case of both the cooling pads, as the outside temperature increased, the temperature drop also increased. The inside temperature was found 23 to 28°C and relative humidity 84 to 90% which is favorable for storage of fresh tomatoes. The results clearly indicated that the ZEECSS could be effectively used as a short-term storage preservation practice as drop of 10±2°C below ambient is reported to be effective for cooling application (Anyanwu, 2004). Sharma and Mansuri (2017) reported highest average air-cooling efficiency for CELdek pad at 78.67%, compared to 73.82% for wood and 70.75% for *khas* pad material when these materials were used in all four sides in the ECSS. The findings showed that the evaporative cooling storage structure could increase relative humidity of 38

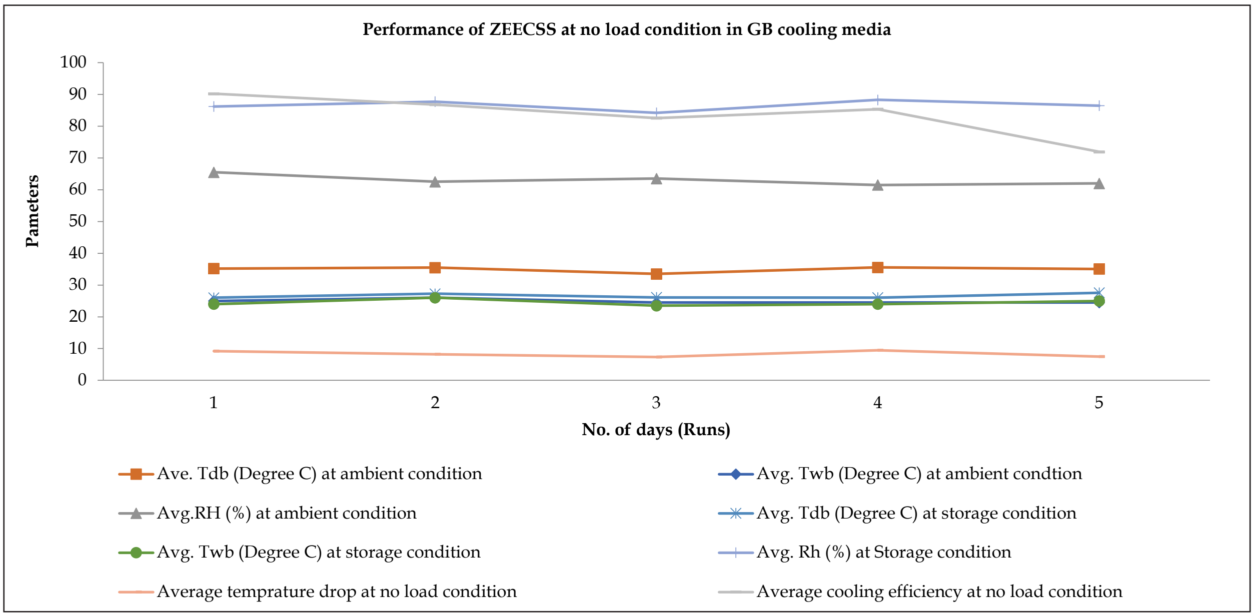


*Fig. 3. Performance of ZEECSS at no load condition with GB cooling media.*

to 78% under ambient condition to 88 to 92% and reduce maximum ambient temperature by 8 to 9°C.

*Effect of cooling pads on cooling efficiency during no load condition*

The cooling efficiency is the measure of useful effectiveness of evaporative cooling storage structure that indicates whether the cooling structure is viable for storage or not for agricultural produce as per change in whether parameters of atmospheric conditions like temperature and relative humidity. The data recorded on 5$^{th}$ day in case of gunny bag under no load condition is shown in Fig. 3 and for small pieces of bricks (SPB) shown in Figure 4. Average minimum and maximum cooling efficiency for GB pad was found 71.92% and 90.19% with the average cooling efficiency 83.36% likewise the average minimum and maximum cooling efficiency for SPB cooling pad was found 76.17% and 87.31 with the average cooling efficiency 81.50%. The results also showed that the in both the condition of cooling media, variation of cooling efficiency varied from 81.50 to 83.36%. The highest cooling efficiency in case of GB was found due to higher water holding capacity and uniform

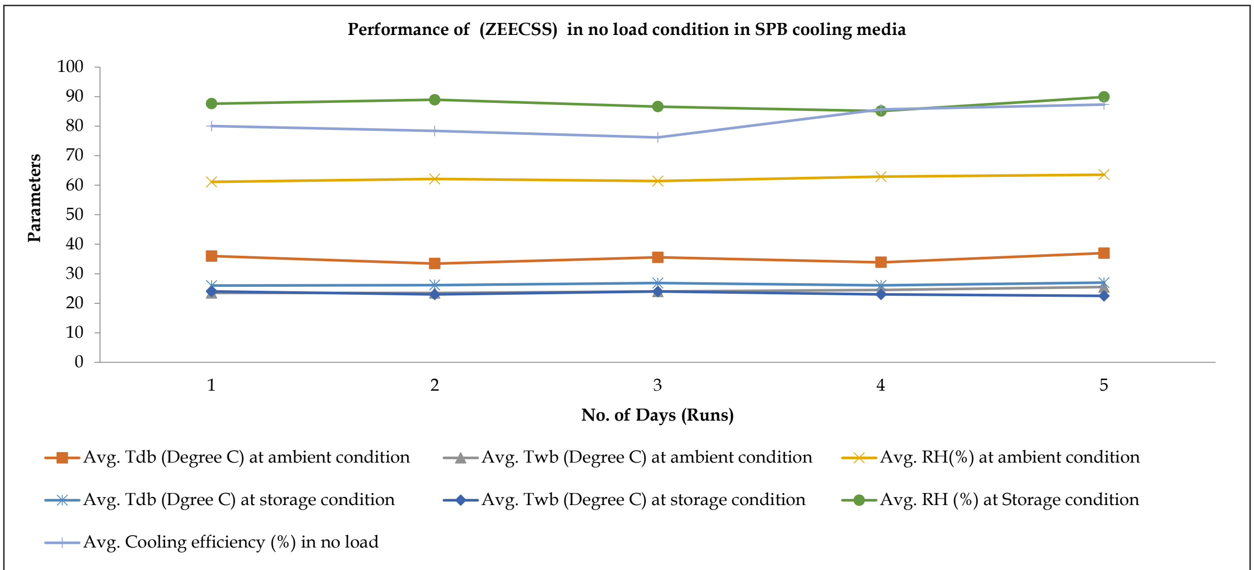


*Fig. 4. Performance of (ZEECSS) in no load condition with SPB cooling media.*

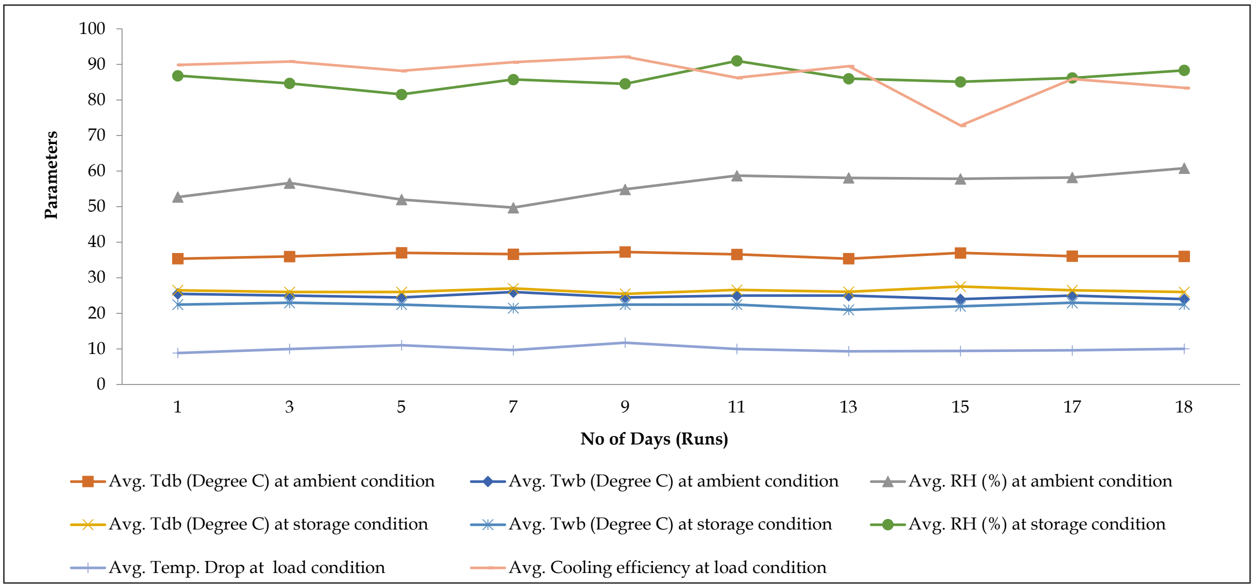


*Fig. 5. Performance of ZEECCS under loaded conditions with SPB media.*

water flow rate. The results also showed that the higher cooling efficiency was achieved at a higher temperature and low relative humidity, this agreed with the work of Chandegara, *et al.* (2016) on coconut husk chips cooling pad.

### *Effect of cooling pads on weather parameters under loaded conditions*

The Fig. 5 and Fig. 6 depicts that average highest temperature drop was 12°C and minimum 9°C with the average temperature drop up to 10°C in case of GB cooling pad during the study period of 18 days. The overall temperature drop was found 11°C in case of SPB. The relative humidity inside the evaporative cooling storage structure was in the range of 80 to 91% in GB and 81% to 94% in SPB while it was 52 to 62% for ambient condition. Average relative humidity inside the evaporative cooling storage structure was 88% and 91% in GB and SPB respectively. The observed weather parameters indicate favorable condition for storage, as it required high relative humidity and low temperature range to increase its shelf life.

### *Effect of cooling media on cooling efficiency in storage structure*

Experimental trials showed considerable effect of both GB and SPB cooling media in which the average minimum cooling efficiency was found 72.82% and average maximum

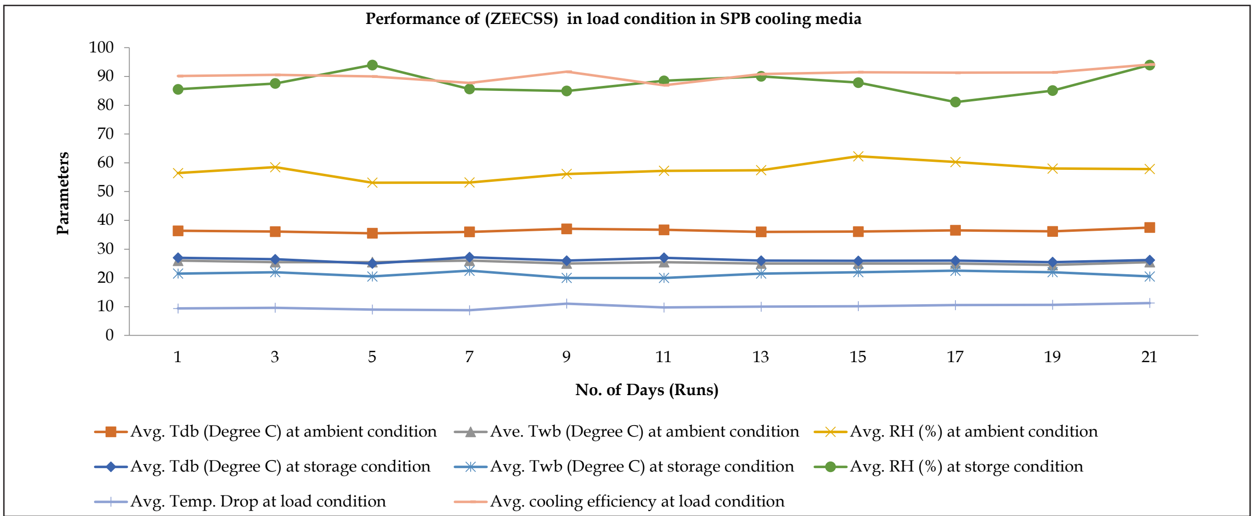


*Fig. 6. Performance of (ZEECSS) in load condition in SPB cooling media.*

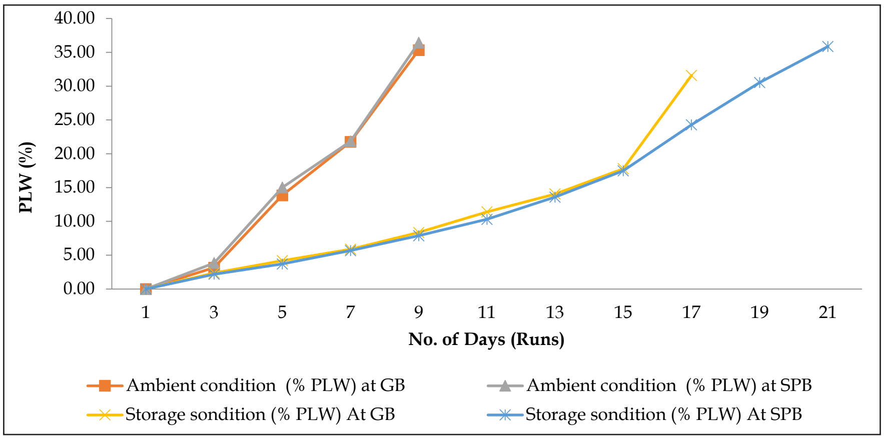


*Fig. 7. Comparison of physiological loss in weight under ambient and storage condition.*

cooling efficiency was found 92.17% with the average cooling efficiency 88% in case of GB for the storage period of 18 days. In case of SPB, the average minimum cooling efficiency was found 85.69% and average maximum cooling efficiency was found 94.15% with the average cooling efficiency 91.00% in the storage period of 21 days. The average cooling efficiency of SPB was more than the GB by the difference of 3%.

## *Physiological loss in weight (PLW)*

Change in physiological loss in weight (PLW %) of the stored tomatoes in storage structure was studied with the variation in GB and SPB and compared it with as storage in the ambient condition as shown in Figure 7. It was observed that the moisture loss from the stored tomatoes took place up to 18 and 21 days in case of GB and SPB respectively in comparison to ambient storage condition where the value was 10 days. The trend of physiological loss in weight increased with the increase in storage period in all three storage conditions but was found higher under ambient conditions. When gunny bags (GB) cooling media was used, physiological loss in weight was found 10.06% on 10$^{th}$ day and 16.25% on 14$^{th}$ day followed by 40.47% on 18 days. When small pieces of bricks (SPB) are used as a cooling media then the tomatoes, PLW losses were 9.01% on 10$^{th}$ day which increased to 14.44% on 14$^{th}$ day and 27.24% on 18$^{th}$ day. showed less loss occurred as compared with gunny bad and ambient condition. The results indicated superiority of SPB as a cooling material.

## *Spoilage percentage*

The spoilage increased gradually with storage period in all the three cases i.e ambient,

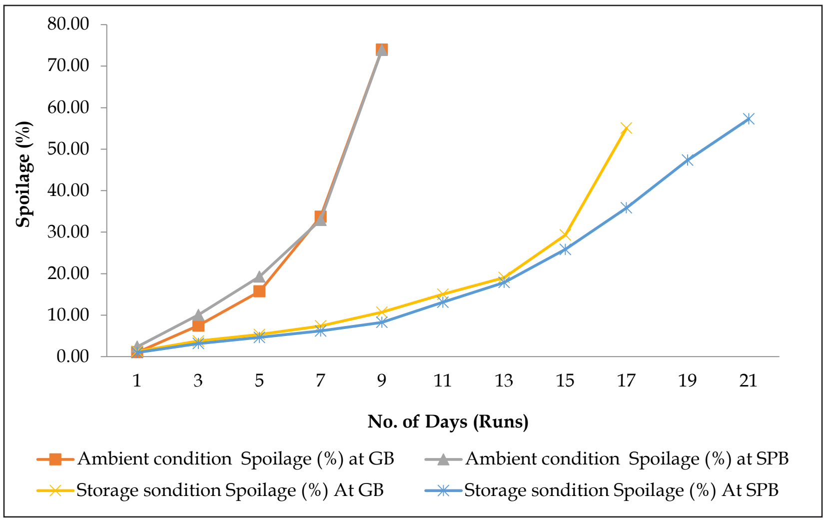


*Fig. 8. Comparison of spoilage (%) at ambient and storage condition.*

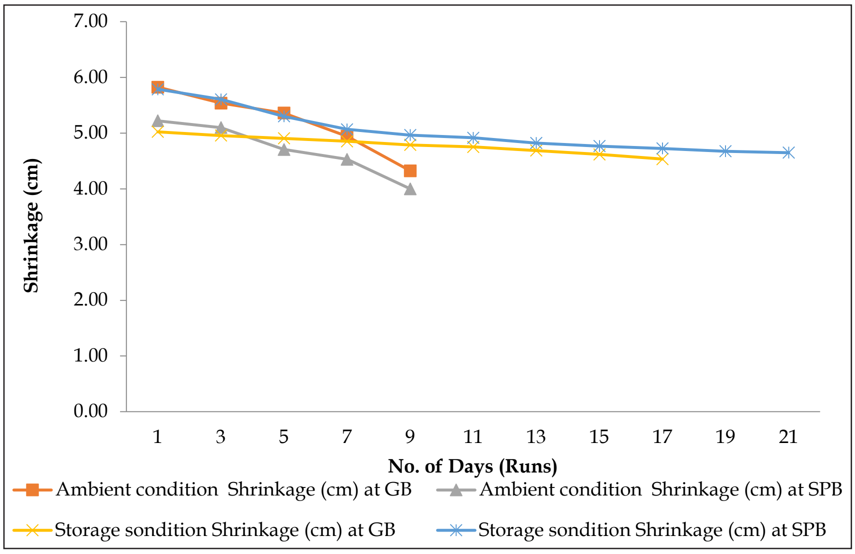


*Fig. 9. Comparison of shrinkage at ambient and storage condition.*

ZEECSS (GB) and ZEECSS (SPB) (Fig. 8). Under ambient condition about 90% tomatoes had spoiled by the 10 day. In contrast spoilage was only 12.93% on 10$^{th}$ day, 22.06% on 14$^{th}$ day and 65.03% on 18 days in GB while under SPB the spoilage was even lower (Fig. 8).

## *Shrinkage value*

Results of shrinkage in size are presented in Fig.9. Shrinkage also produced wrinkles. Shrinkage was about 30% on 10$^{th}$ day of storage under ambient conditions. When gunny bags cooling media was used, the shrinkage was about 5% on 10$^{th}$ day and about 10% on 18$^{th}$ day. When small pieces of bricks was used as a cooling media then the shrinkage dimension ranged from 15% on the 10$^{th}$ day to 20% on the 21$^{st}$ day. Results clearly showed that the quality of tomato under ZEECSS remained better.

## *Total Soluble Solids (TSS)*

The effect of both GB and SPB cooling media on the total soluble solids (TSS) for tomatoes is presented graphically in Figure 10 in storage study. It was observed that the TSS decreased with storage period in all the three situations. The total soluble solids (TSS) in ambient condition were found 5.51°Brix on 1$^{st}$ day and 2.45°Brix on 10$^{th}$ Day. In storage structure, GB cooling pad media affected the TSS value 6.17°Brix on 1$^{st}$ day and 3.70°Brix on 18 days but was 5.07°Brix on 10$^{th}$ day. Likewise SPB cooling pad affected the TSS value 5.78°Brix on 1$^{st}$ day, 3.12°Brix on 21$^{st}$ days and on 10$^{th}$ day it was only 4.79°Brix. When it was compared in all three condition the results of total soluble solids (TSS), the effect of GB has maintained better TSS value than SPB but the difference were marginal.

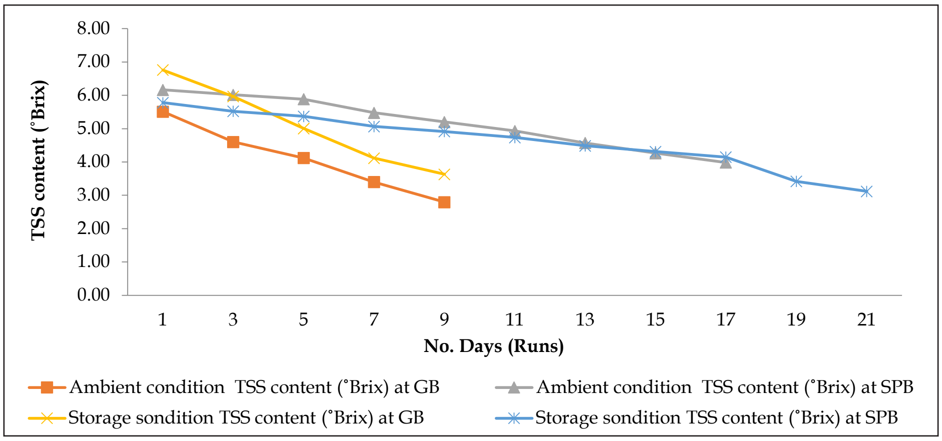


*Fig.10. Comparison of TSS content (˚Brix) at ambient and storage condition.*

*Table 3. Cost analysis of zero energy evaporative cooling storage structure (ZEECSS)*

| Particulars | Cost (Rs) |
|---|---|
| Ambient storage condition | |
| Total storage loss in 10 days: @ consider 1 ton of tomato at purchase cost Rs. 30 per kg. | 27000 |
| Loss per day (The tomato material spoilage @ 90% up to the storage of 10 days | 2700 |
| Net cost of loss in ambient storage (Rs./day/ton) | 2700 |
| Development cost of Zero energy evaporative cooling storage structure (ZEECSS) | 5500 |
| Fixed Cost | |
| (A) Depreciation of the Zero energy evaporative cooling storage structure (ZEECSS) | 495 |
| Assumptions: Life of Zero energy evaporative cooling storage (ZEECSS) (L) = 10 years | 10 |
| Salvage value (S) = 10% of capital cost of the ZEECSS | 550 |
| 12% on the Initial cost of Zero energy evaporative cooling storage structure (ZEECSS) | 0.12 |
| Average annual use (H) = 960 h.<br>(Note: Approximate working days @ 120 days in a year having working capacity of 8h/day in a year as the cooling storage structure woks from 9:00 to 17:00 ) | 960 |
| Depreciation cost:=(C-S)/(L×H) | 0.52 |
| (B) Interest on the investment on capital of ZEECSS in a year | 363 |
| Interest on the investment on capital of ZEECSS @ 12% per annum on price | 0.12 |
| Interest on the investment on capital of ZEECSS(I):I = (C+S)/2H×(12/100) | 0.38 |
| (C) Tax, Insurance, Shelter cost in a year | 110 |
| Tax, Insurance, Shelter cost @ 2% per annum (T): | 0.02 |
| Interest on the investment on capital of ZEECSS:T=(C/H)*2/100 | 0.12 |
| Total fixed cost in a year = (A)+(B)+(C) | 968 |
| Operating cost | |
| (D) Repair and maintenance cost in a year | 275 |
| Repair and maintenance cost/h @ 5% of Initial cost per annum (R) | 0.05 |
| Repair and maintenance cost/h @ 5% of Initial cost per annum ®:R=(C/H)*5/100 | 0.29 |
| (E) Labor requirement in a year : On the working operation on ZEECSS with full capacity @ wage rate 350 per man per day of 8 hour for 14 days on storage of tomatoes and maintenance | 4900 |
| Total operating cost of storage structure for 14 days of storage = (A)+(B) | 5175 |
| Total cost = Total fixed cost + Total operating cost | 6143.0 |
| Total fixed charges per day (Total fixed cost / no. of working days in the year) | 51.2 |
| Variable cost | |
| ZEECSS Storage condition | |
| Storage loss for 14 day consider 1 ton of tomato of Rs. 30 per kg @ 20.14% spoilage (%) | 6042 |
| Total storage loss Rs. per day as a Total variable cost Rs./day/ ton | 432 |
| Total cost of storage in ZEECSS/day/ton = (51.2+432) | 483 |
| Cost of Zero energy evaporative cooling storage structure (ZEECSS) = (2700/483) | 5.59 |
| Ratio of cost of ambient storage condition to ZEECSS storage condition | 5.59:1 |
| The saving amount by the use of ZEECSS storage (2700-483) | 2217 |
| Cost A: Developed equipment cost | 5500 |
| Cost B: 5500 + (495 (Depreciation) + 363 (Interest) + 110 (Tax & insurance)) =758 | 6468 |
| Cost $C_1$:6265 + (cost of family labour add during construction of equipment) | 6468 |
| Cost $C_2$:6261+10% (6261) @ 646.8 (other accessories) | 7115 |
| Payback period of ZEECSS | |
| The final cost of the developed equipment (Fixed cost) | 7115 |
| The production cost of Tomatoes @ 10 Rs. per kg for 1000 kg of tomatoes (Variable cost) | 10000 |
| Fixed cost + Variable cost | 17115 |
| The selling of Tomatoes @30 Rs. per kg for 1000 kg of tomatoes (Income) by use of ZZECSS | 30000 |
| Payback period of ZEECSS is = (16911/30000): year (7 Months) | 0.5705 |

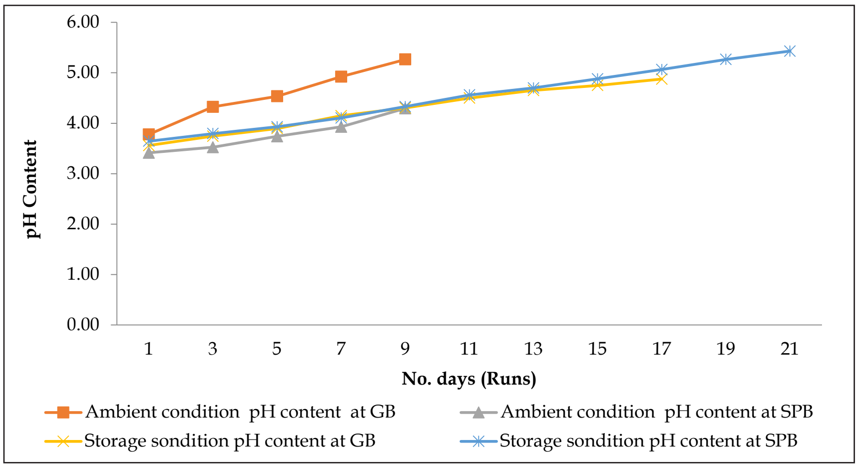


*Fig. 11. Comparison of pH at ambient and storage condition.*

### *Effect of cooling media on pH*

The effect of both cooling media GB and SPB on the pH value for tomatoes is presented graphically as shown in Figure 11. pH value gradually increased with storage in all the three situations viz. control and both cooling media GB & SPB. But the increase in pH in the tomatoes stored in cooling media was slower than stored under open conditions.

### *Cost analysis of developed ZEECSS*

The cost of the developed storage structure was estimated by adding the costs of different materials used during the fabrication of the storage structure. For effective cost analysis, some assumptions were made for calculation of storage of one ton of tomatoes as shown in Table 3. The current market flow rate of tomatoes was assumed as Rs. 30 $kg^{-1}$. The total cost of 1 ton of tomatoes calculated as Rs. 30000. According to the observed data, the 90% of tomatoes spoiled within 10 days under ambient condition (without the use of any type of storage structure) amounting to a loss of Rs. 2700 storage loss per day per ton. But this spoilage was reduced up to 20.14% for the storage period of 14 days with ZEECSS. The fixed cost of the developed ZEECSS was Rs. 5500. The depreciation cost along with the cost of interest on the capital investment as well as cost of insurance, taxes on machineries were considered in the fixed cost of storage structure. The variable and operating cost for storage of 14 days varies according to the repair and maintenance cost, operating labor charges and unavailability of storage loss cost used to found the total cost of storage Rs. 483 per day per ton with the saving of Rs. 2217 per day per ton. For the developed storage structure, deprecation cost, insurance cost, taxes consider at the 10% marginal cost was added to the final cost of the equipment as Rs. 7115. According to the markets flow of the tomatoes, the calculated cost of ZEECSS is a fixed cost and the production cost for the farmer is Rs.10 $kg^{-1}$ so that the variable cost for 1 ton of tomatoes is 10000 consider as a variable cost with the total amount Rs. 7115. The income generated to sell 1 ton of tomatoes @ 30 Rs. per kg (current flow market price) with Rs. 30000. So that the payback period of the equipment is 0.56 yrs or say 7 months.

## Conclusion

Zero energy evaporative cooling storage structure (ZEECSS) of 50 Kg capacity was designed and constructed for preservation of yellowish red on farm fresh tomatoes. The final cost of the storage structure was calculated as Rs. 7115 with the payback period up to 7 month. It was concluded that farmers, house holders and tomatoes processing entrepreneurs should adopt the use of Zero energy evaporative cooling storage structure (ZEECSS) system for preserving yellowish red fresh tomatoes to increases its shelf life up to 10 to 14 days according to the atmospheric conditions.

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