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Design and Development of a Solar PV Based Evaporative Cooled Transit Storage Unit for Horticultural Products

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Authors' contributions

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

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ABSTRACT

Adequate cold storage facility for Horticultural products is critical due to their perishable nature. Green energy based evaporative cooling storage unit is a sustainable and efficient solution for small scale farmers and vegetable vendors in hot and dry climates who need to store their produce. Solar power operated evaporative cooling structures are low cost and efficient in reducing ambient temperature and increasing relative humidity, which increases the shelf-life of vegetables. A green energy-based evaporative cooling transit storage unit of 0.63m^3 capacity was designed and fabricated. The transit unit was designed and operated as a a tricycle. Two suction fans (15.6W), submersible water pump (12W) and LED light (2.88Wp) were powered through two 100-Wp solar

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panels. Two batteries, 7Ah each were also used to store energy. The storage unit was made up of MS sheets of 1.2mm thick while a side of the system was made up of GI wire mesh with honeycomb pad. To test the performance of the developed unit tomato, spinach and radish were used. Results revealed that there was a significant difference (P=0.05) in PLW, firmness, TSS, and colour values of the vegetables when stored inside the unit compared to vegetables stored in ambient condition. The ambient temperature during the study was 32.2-43.4°C and RH was 21.1-46%. The drop-in temperature was 7.8 to 14.8°C as compared to ambient conditions, while RH in the cooling chamber increased considerably to 84%. The average cooling efficiency obtained was 84.12%. The shelf life of stored vegetables inside the unit was 2-5 days higher than those kept under ambient conditions.

Keywords: Transit storage; evaporative cooling; green energy; perishables; low-cost storage.

1. INTRODUCTION

One of the critical factors contributing to food insecurity is post-harvest losses [1]. Post-harvest losses of fruits and vegetables result in food scarcity, which is exacerbated by population growth [2]. Due to population growth and social development, world food demand is expected to double by 2050 [3]. The status of global food security is alarming, and protection against losses caused by lack of proper cold storage facilities, wastage of perishable agricultural commodities due to improper handling and storage, especially in a hot climate, can play a critical role in improving food security worldwide [4]. Vegetables are mostly grown by small and marginal farmers. They lack a proper system for safe transit from farm to market and finally to consumers. Produce is delivered to its end users through a poor resource links, specifically in urban and semi-urban areas. The important concern is to keep commodities in acceptable state till the destination is reached. In contrast to the developing countries, the agricultural supply chain is unbroken in post-harvest production in developed countries. In contrast, in developing countries storage options and access to basic cold storage structures are a major lag to marginal farmers and the situation becomes worse for small farmers. Availability of limited technology and infrastructure compels them for distress sale, leading to loss in income and profit subsequently. Despite their hard work, their livelihood conditions remain stagnant and lack betterment. Furthermore, if farmers and vendors are unable to maintain the product quality, then further investment or processing for increasing self-life will be questionable. To address these problems, several efforts have been made leading to the development of motorized vegetable and refrigerated vehicles. Refrigerated storage is accepted as one of the best systems for storing vegetables in fresh form, but it is energy intensive and requires high capital investment. Therefore, it is not recommended for on-farm short duration storage. The high cost and dependency on commercial energy sources makes it infeasible for the use in fields [5]. Some of the vegetables like banana, capsicum and tomato are also prone to chilling injury when stored in a refrigeration system [6]. Acedo [7] constructed an evaporative cooler with wood, GI sheet, and wire mesh having sawdust, charcoal or rice hull-wall insulation and observed that it maintained more than 90% RH and temperature at 3-6°C lower than the room temperature. Venu [8] developed a pushcart with a low energy storage system for vegetable vending. The basic structure was almirah cooler and made out of 600 mm x 600 mm x 600 mm mild steel structure with storage capacity of 30-45 kg of vegetables. The maximum ambient temperature during the study was 38ºC and humidity was 35-45%. It was observed that the temperature inside the structure was 8-10ºC lower than the ambient and 40-45% increase in humidity. The results showed that the shelf life of beans, carrot, okra, tomato, amaranths were increased to 11, 12, 10, 12 and 5 days respectively in comparison to shelf life of 2, 3, 2, 4 and 2 days respectively observed under the ambient condition. Olosunde et al. [9] developed a solar powered evaporative cooling storage system (SPECSS) to improve the shelf life of fruits and vegetables for small-holder farmers in rural Nigeria where an electrical power distribution network is almost non-existent. The SPECSS chamber temperature depression and relative humidity from ambient conditions varied from 7.8 to 15.4°C and from 44 to 96.8%, respectively. The shelf lives of tomatoes, mangoes, bananas and carrots stored inside the SPECSS chamber were 21, 14, 17 and 28 days, respectively, when compared to 6, 5, 5 and 8 days for the ambient storage [10]. An evaporative cooled vegetable vending cart was developed at Indian Agricultural Research Institute (IARI), New Delhi to ameliorate the economy of poor vegetable vendors [11]. However, the developed cart had problems of high-water consumption, higher weight, no control over environmental threats (dust, micro-organisms), and poor operator comfort. Therefore, an effort has been made to design and develop green energy based evaporative cooled storage units, a sustainable and efficient solution for small farmers and vegetable vendors who need to store their produce in hot and dry climates. These units use renewable sources of energy such as solar power to provide electricity for the storage unit and use an evaporative cooling system and display unit for perishables that allows direct access and viewing of the items while maintaining their freshness.

2. MATERIALS AND METHODS

2.1 Functional Design

The vegetable transit storage unit was developed in ICAR-IARI, New Delhi. The evaporative cooling vegetable transit storage unit consists of a storage cabin, honeycomb cooling pad, suction fan, solar panel, battery, control panels, water distribution mechanism and transit unit. The water distribution mechanism includes a submersible water pump, pipes, and a water collection tank. The pads were installed on three sides of the cabin, and the suction fan on one side of the storage cabin. A water tank was mounted at the bottom of the cooler from which water distributed onto the pad through a lateral small pipe placed on top of the pad. Excess water from the pad was also collected in the same water tank. The submersible pump re-circulates water. The solar panel power was used to run the exhaust fan and the submersible pump and also charges the battery. The purpose of the battery was to power the fan and pump in the absence of sunlight. The isometric view of the vegetable transit storage unit is shown in Fig. 1.

2.2 Structural Design

The structural components of vegetable transit storage unis were designed on the basis of functional and operational requirements. The different dimensions and view of the vegetable transit storage unit is shown in Fig. 2.

2.2.1 Platform, roof cover and storage capacity of structure

The polycarbonate compact sheet of 6-mm thickness with UV protection was fitted to the main frame which acted as a platform. PC sheets have good impact strength, high temperature resistance, and are unbreakable along with UV protection. The solar panels were used as a roof cover. A suitable frame was fabricated and solar modules fitted to cover the top frame to protect the operator from harsh sunlight and also provide shade to the storage unit. The storage chamber with storage capacity 0.63 m^3 was fabricated with overall dimensions 1.25 x 0.84 x 0.60 m. The shape of the cooling chamber was cuboid. Pad-holders were fabricated to make the coolers versatile, effective and with provision to change the pad.

2.2.2 Heat load on transit storage unit

The cooled and humidified air from the pad was required to remove the total heat load of the evaporative cooler. The most important parameters determining the design of cooling processes and equipment are the processing time and the heat load.

$$\text{Total heat load, } Q_{total} = Q + Q_c + Q_g + Q_a \quad (1)$$

Where,

Q = heat gain of storage unit
Q_c = Specific heat generated by product load
Q_g = Latent heat generated by product load
Q_a = Heat load due to air infiltration

Heat gain is mainly through storage chamber floor, roof, and side walls. Thus the heat gain of storage unit, is calculated by formula $Q = U\,A\,(T_o - T_i)$, specific heat generated by product load used $formula, Q_c = m\,c_{pm}\,(T_1 - T_2)$, latent heat generated by product load is calculated by $Q_g = m\,h_g$ and Q_a is the heat load due to air infiltration taken as 4100 kJ/day. Thus, total heat load obtained was 230W. Based on calculation Ton of refrigeration (TOR) 0.064 is the required cooling capacity storage unit.

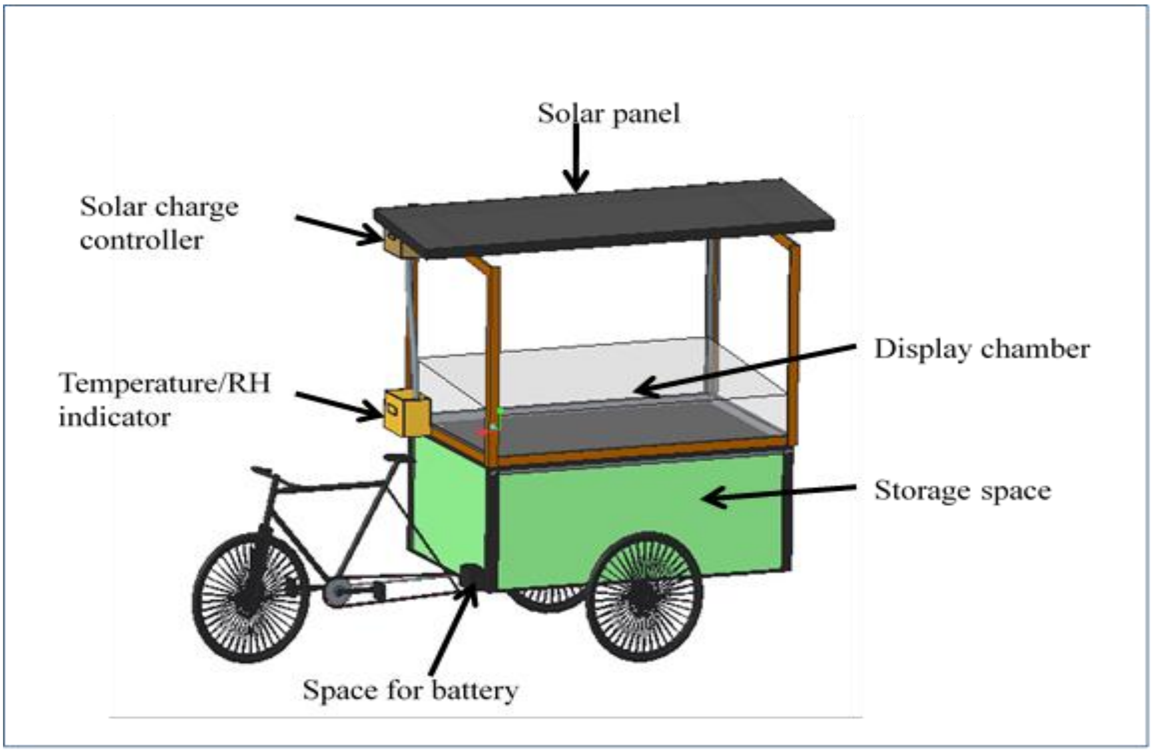

Fig. 1. Isometric view of transit storage unit

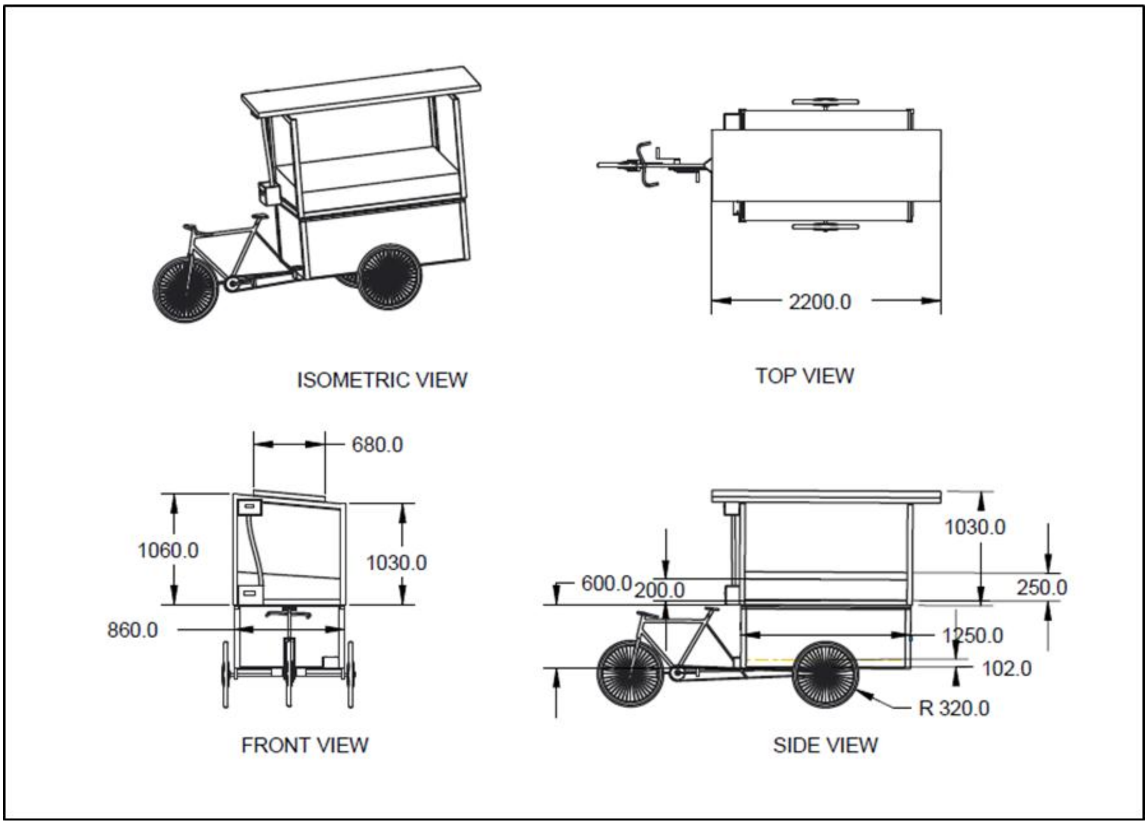

Fig. 2. Dimensions and view of the transit storage unit
**All the dimensions in mm*

2.2.3 Selection of cooling pad material

The efficiency of an evaporative cooling system depends on the water holding capacity of the cooling pad, exposed area of pad, rate and amount of evaporation of water from the cooling pad [9,12]. In this work, a honey comb pad made up of high polymer material and the spatial crossing linking was used. Honeycomb type of cooling pad of one-inch thickness was selected for an efficient performance of the evaporative cooling system as it had good water holding capacity, high moisture content, and high durability. These pads were expensive but, when properly maintained, do an excellent job of cooling air [13]. The amount of evaporated water increases by increasing the inlet air velocity and thickness of pads. On the other hand, effectiveness and humidity variation decreased with increasing inlet air velocity [14]. Adequate pad surface area is needed to maximize the operating efficiency, along with an adequate water supply and distribution system. The pad area needed depends upon several factors including the type of pad material used and requirement of cooling capacity. The pads should be continuous along the entire length of the wall. Water holding capacity of pad was calculated using formula given by Venu [8].

$$\text{Water holding capacity (\%)} = \frac{\textit{Initial mass} - \textit{Final mass}}{\textit{Initial mass}} \times 100 \quad (2)$$

2.2.4 Water requirement and recirculation system of water

The water circulation network consists of a water collection tank, water circulating pipes, water pump, and water recirculation system arrangement. Evaporative cooler manufacturers recommend water flow rates to the evaporative cooler ranging from 4-6 l/min for each meter length of the distribution pad for coolers up to 6-feet high to work satisfactorily [13]. The water recirculation system in the developed transit storage unit consists of a small submersible, direct current water pump, water tank and pipes. The system was designed to recirculate the water by the pump. The water to be recirculated is supplied to the bottom tank passing through the pad by gravity and collected in the bottom tank. The pump delivers the water through a vertical pipe with a diameter of 15 mm onto the cooling pad at a height of 60 mm. The pipe perforated with a 3 mm-diameter hole was used through which the water drips onto the pad. So, as per the requirement, a submersible water pump with 12V DC (voltage ratings), 1 A (Current), and 12 W (power ratings) along with a discharge capacity of 16.3 lit/min, which can lift water up to 130 centimetres was selected.

2.2.5 Selection of suction fan

Air movement in storage chamber either natural or artificially, is an important factor that influences the rate of evaporation. The evaporative cooling system cannot function well without exhausting the air from the conditioned area to the outside. Evaporation of water from the wet surface increases the humidity inside the chamber. This humid air needs to be removed from the chamber in order to maintain the rate of evaporation otherwise it gets saturated and decreases the rate of evaporation. The fan capacity was determined based on equation given by Bartok [15] and Zakari et al. [16].

$$\text{Fan Capacity} = 8 \text{ cfm /ft}^2 \times \text{floor area in ft}^2 \quad (3)$$

So, two suction fans with 130 cfm (fan capacity), 12V DC (voltage ratings), 1.3 A (Current), 15.6 W (power ratings) were installed.

2.2.6 Selection of power source and battery sizing

The main components for the solar PV system were PV modules, solar charge controller, battery bank, loads (applications). For selection of the solar power source specification of two suction fans and water pump were considered. The electric current produced by SPV panels during daylight hours charges the batteries, and the batteries in turn supply power to the system. A solar charge controller was installed to provide constant power during low light periods and night. To calculate total watt per day for each appliance's equation given by Leonics [17], Mansuri [18] and Olosunde et al. [9] were used.

Required current = (Average total load)/(system voltage x battery charging efficiency x hours of insolation per day) (4)

Required voltage =(system voltage+(system voltage × temp correction factor)) × constant power factor (5)

Selection of battery depends upon number of appliances used, amount of power they take, the level of discharge before recycling and the temperature of the area where the batteries are stored. So as per requirement two 12 V, 7 Ah batteries were installed.

Fig. 3. Developed transit evaporative cooled storage unit

2.3 Performance Evaluation of the Developed Vegetable Transit Storage Unit

Performance evaluation was done considering variation in temperature and relative humidity, the experiments were conducted in the premises of, the Division of Agricultural engineering, ICAR-Indian Agricultural Research Institute, New Delhi.

2.3.1 Measurement of temperature, relative humidity inside and outside the storage unit

The temperature and relative humidity inside and outside the storage unit was measured with the help of Hygro-Thermometer (Temperature range -30 to 80°C and humidity range of 0-100%), DHT 11 sensor with operating temperature between 0^oC to 50^oC with accuracy $\pm$ 1^oC and Relative Humidity range 10-99% with accuracy $\pm$ 2%. The psychometric relationship was used to determine the wet-bulb temperature values with the help of measured dry bulb temperature and relative humidity values.

2.3.2 Cooling efficiency of evaporative cooling storage unit

The cooling efficiency was used as an index for evaluating the performance of direct evaporative cooling media. Equation (6) given by Huang et al. [19] and Chineye et al. [12] was used to calculate the cooling efficiency.

$$l = \frac{\text{Tdb}-\text{Ts}}{\text{Tdb}-\text{Twb}}. \quad (6)$$

Where, T_{db}= ambient dry bulb temperature (^0C); T_{wb} = ambient wet bulb temperature (^0C); T_s = dry bulb temperature of cooler storage space (^0C);

2.3.3 Statistical experiment and quality assessment of the vegetables stored inside storage unit

In order to determine quality of vegetables inside storage unit, three crops namely tomato, spinach and radish were stored in ambient condition and inside the developed storage structure. The parameters measured for stored commodity was physiological weight, colour change, total soluble solids and firmness. The physiological weight was calculated to find the percent weight loss of the vegetables. Initial and final weight of vegetables were measured by weighing balance with 0.01gram accuracy. Surface color of vegetables was measured by using Hunter colorimeter, Colour Tec-PCM^{TM} Colorimeter (Accuracy Micro sensors 30 mm, Tokyo, Japan). The firmness was measured by using a texture analyzer (TA-XTplus of Stable Micro Systems, Ltd., Surrey, UK). The TSS was determined by hand refractometer (Model Misco) with a range of 0 to 32 °Brix and a resolution of 0.2 °Brix. The performance efficiency of the cooler for the storage of tomatoes, radish and spinach was evaluated. The experimental data were analysed using factorial completely randomized design (CRD). The statistical package SAS was used to analyse the experimental data.

3. RESULTS AND DISCUSSION

3.1 Properties of Cooling Pad materials

Basic physical properties of the cooling pad material and water holding capacity were studied and their respective values are summarized and presented in Table 1.

To determine water holding capacity of pad first noted down the initial weight of pad then, dipped the pad in a container containing water for 12h.

After 12h final weight was measured. The water holding capacity of the honey comb pad was found as 3.03 g/g, which shows that the saturated honey comb pad will hold a quantity of water that is 3.03 times the mass of its sample.

Table 1. Properties of cooling pad materials

Parameter	Value
Mass of saturated Pad material (g)	43.62
Mass of Pad material (g)	10.8
Mass of water absorbed (g)	32.82
Water holding capacity (g/g)	3.03

3.2 Specifications of Selected Material According to Design of Transit Storage Unit

The materials selected for the evaporative cooling transit storage of capacity 0.63m^3 according to the design values are presented in Table 2.

Table 2. Specifications of material selected according to design of transit storage unit

Sr. No	Material selected	Specification
1.	Two Solar Modules	100 Wp, Vmp -17 V, Imp -5.88
2.	Two suction fans	15.6 W, 12V DC
3.	One water Pump	12 W DC
4.	LED light	2.88 W
5.	Battery	12V, 7Ah
6.	Solar charge controller	20 A, 12V
7.	Pad Material	Honey Comb Pad
8.	M.S. Sheet	1.2 mm thick
9.	G.I Wire mesh	3 mm dia.

3.3 Temperature and Relative Humidity at Ambient and Inside the Developed Unit

For the experimental site, the ambient air-dry bulb temperature ranged from 32.2 – 43.4^{o}C with an average of 38.6^{o}C and the ambient relative humidity ranged from 21.1 – 46% with an average of 27.2% during the experimental period of 5 days. The storage unit temperature was maintained at 25.3 -27.6°C. The ambient wet bulb temperature ranged from 21.79 – 25.4°C. The temperature and relative humidity profiles indicated that the higher the relative humidity of the ambient condition, lesser was the cooling effect in the evaporative cooling chamber. At 10:00 AM, the dry bulb temperature difference between ambient and storage structure was low because of high relative humidity while the temperature difference increased during the period 2.00 PM - 4:00 PM because of reduction in RH value. The temperature inside the evaporative cooling storage unit reduced at the same time there was an increment in relative humidity. It is clear from Fig. 4 that the cooling chamber could drop the ambient temperature very close to its wet bulb temperature. Minimum temperature drop was 7.8^{o}C while maximum temperature drop was 14.8^{o}C.

The relative humidity inside the evaporative cooled storage unit was found to vary from 76% to 84% which shows the maximum possible level of saturation of air by humidification. The relative humidity inside the evaporative cooling unit remained about 38-55% higher than outside of the chamber. Similar findings have been reported by Ndukwu and Manuwa [20].

3.4 Cooling Efficiency

The cooling efficiency during 10:00 AM to 6:00 PM was calculated for 5 days. As shown in Fig. 5, the cooling efficiency of the pad media ranged from 71%–90.9% with an average of 84.12%. The curve of cooling efficiency revealed that the higher cooling efficiency was achieved at the higher temperature and lower relative humidity of ambient air in the afternoon during 2.00 PM – 4.00 PM when the solar intensity was highest. This is a desirable effect, because more cooling is required in the afternoon due to the high solar load.

3.5 Effect on Quality of Vegetables Stored Inside Transit Storage Unit Compared to Ambient Condition

Efficiency of the evaporative cooling transit storage unit in order to store vegetables in good storage condition was evaluated and was compared with ambient condition storage. The results on the observation of typical 5 consecutive days in month of May were recorded. During storage, change in physiological loss in weight, firmness, colour and TSS properties was analysed. Temperature and relative humidity of evaporative cooling transit storage unit, as well as for the condition outside the unit were measured, during the period 10:00 AM to 6:00 PM at an interval of one hour. Results show that the temperature and relative humidity remain almost constant in the evaporative cooling transit storage unit throughout the day despite changes in temperature and relative humidity values outside the storage unit.

3.5.1 Physiological Loss in Weight (PLW)

The total weight of vegetables decreased due to physiological stress and loss in moisture content when stored for a long period. The weight of the vegetables was recorded before putting them in storage units. After storage, the change in weight was noted on the 2nd, 3rd, 4th, and 5th days. The loss in weight of vegetables in the evaporative cooling chamber as well as in ambient storage was observed and is presented in Fig. 6. The PLW of tomato at 5th day was found to be 3.31% inside the storage unit, while it was, 9.24% in the ambient condition. Similarly, in case of radish 11.99% weight loss was observed inside the storage unit and 23.07% in ambient condition. PLW of Spinach after the 4th day was found as 15.84% and 31.60% inside the storage unit and in ambient condition respectively.

The analysis of variance of the results showed that, there was a significant difference (P = 0.05) in PLW (%) between the evaporative cooled transit storage unit and in ambient storage condition (Table 4). It was found that the weight loss was minimum when the commodities were stored in the evaporative cool chamber while it was maximum in the ambient storage.

3.5.2 Change in firmness

The change in firmness is an important parameter, as it is associated with the stage of maturity and it is an important quality from a consumer's point of view. The firmness of vegetables decreased when stored for a longer period. The firmness of vegetables stored inside the storage unit and in ambient condition was recorded for 5 days. Initially the firmness was 6.19 N for tomato, 2.1 N for spinach, and 19.17 N for radish (Fig. 7). During storage, change in firmness was observed on the 2nd, 3rd, 4th, and 5th day.

After the 5th day of storage the firmness was 4.64 N for tomato, and 15.37 N for radish. Spinach firmness after the 4th day was 3.77 N. But in ambient storage conditions for 5 days, the firmness was 3.94 N for tomato, 11.23 N for radish. Spinach firmness was 5.47 N after the 4th day. The analysis of variance of the results showed that there was a significant difference (P = 0.05) observed in firmness (N) between the evaporative cooling transit storage unit and ambient storage (Table 4). It was found that the difference in initial and final firmness of vegetables was highest in case of ambient storage condition while the low difference was found in evaporative cooled storage units.

3.5.3 Change in colour

The change in colour is also associated with the stage of maturity. The colour of vegetables was recorded before putting them in the storing units. The L* value of tomato and radish decreased slightly which indicates that lightness of tomato and radish decreased. The increase in a* value of tomato indicates increase in redness of tomato, while the decrease in b* value indicates a decrease in yellowness of tomato. But a* value of radish did not change drastically, whereas b* value increased, and this revealed a decrease in whiteness and increase in yellowness of radish. For the spinach, increment in b* and L* values was observed because of the increase in yellowness of the spinach, while a decrease in a* value showed a decrease in greenness. The change in L*, a* and b* values from the initial values had lesser difference, when stored in evaporative cooling transit storage unit but had higher difference from initial value when stored in ambient (Table 3).

3.5.4 Total soluble solids

Total soluble solids of vegetables is the indicator of product maturity and sugar content. Results of TSS revealed that, TSS increased as the storage period increased. In ambient conditions TSS increased from 4 to 4.73° brix for tomato, 4 to 6.8° brix for radish and 4 to 7.87° brix for spinach. In case of vegetables stored inside evaporative cooled storage unit, TSS was increased from 4 to 4.33° brix for tomato, 4 to 5.7° brix for radish and 4 to 6.3°brix for spinach. The difference in the initial and final TSS of vegetables was found to be highest in case of ambient storage condition, while it was the lowest in evaporative cooling storage unit. The analysis of variance of the results showed that there was a significant difference (P = 0.05) in TSS of tomato and spinach between the evaporative cooled transit storage unit and in ambient storage condition (Table 5).

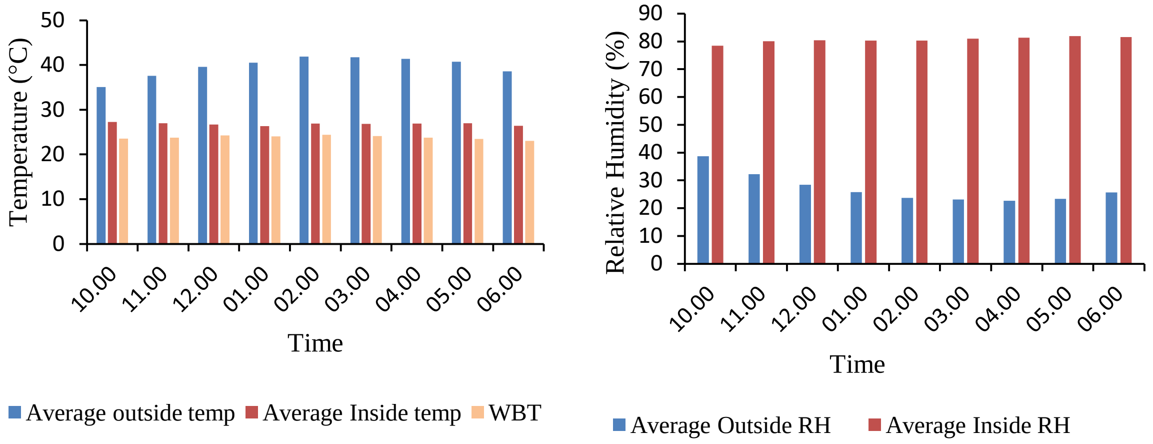

Fig. 4. Average ambient and inside storage unit periodic variation in temperature and relative humidity for the system at loaded condition for 5 days

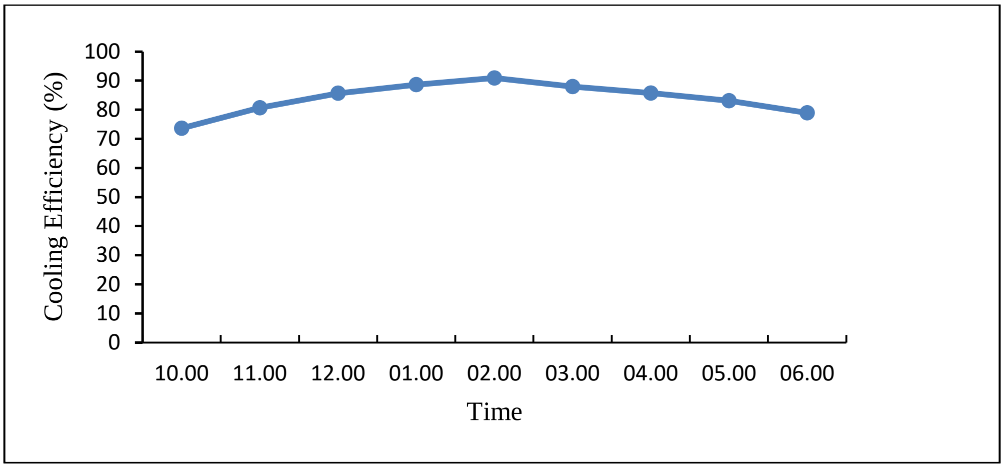

Fig. 5. Hourly variation in cooler efficiency for the evaporative cooled transit storage unit

Table 3. Change in colour of vegetables stored in the evaporative cooling storage unit and in the ambient

		Nature of storage					
Crop	**days**	**Inside storage unit**			**Ambient (outside)**		
		L*	**a***	**b***	**L***	**a***	**b***
Tomato	1st day	30.39	13.22	21.12	30.37	13.30	21.03
	2nd day	29.16	13.76	20.89	29.15	14.57	19.41
	3rd day	28.73	14.21	18.73	28.52	15.18	17.34
	4th day	28.31	14.55	17.56	27.70	15.86	16.68
	5th day	28.26	15.32	15.90	27.88	16.36	16.16
Radish (with leaves)	1st day	47.20	2.21	14.35	47.25	2.38	14.23
	2ndday	46.89	2.36	14.70	46.22	2.75	15.89
	3rd day	46.27	2.38	15.04	45.11	3.07	16.78
	4th day	45.71	2.46	15.47	44.69	3.39	18.10
	5th day	45.01	2.73	15.80	43.51	3.61	18.67
Spinach	1st day	27.58	-5.35	18.39	27.42	-5.33	18.47
	2ndday	28.20	-4.78	19.52	29.99	-3.88	21.32
	3rd day	29.25	-4.27	20.12	31.94	-2.96	21.78
	4th day	29.90	-3.93	20.88	32.71	-2.44	22.63

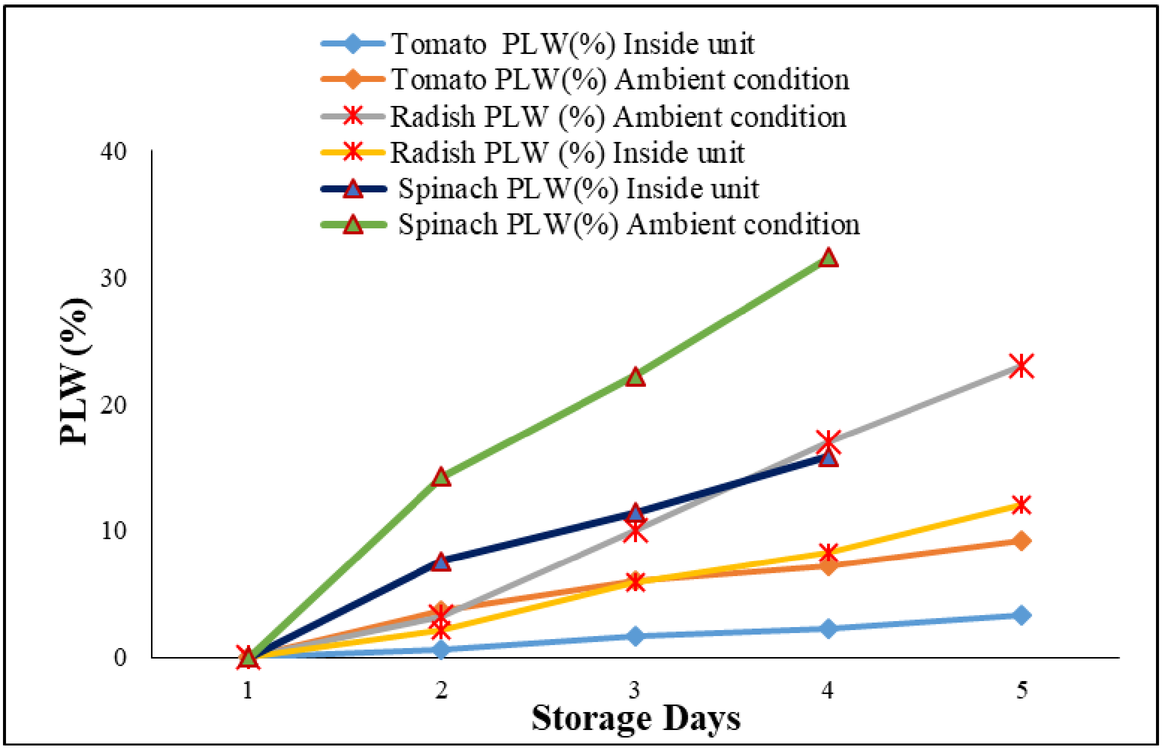

Fig. 6. Physiological weight loss of produce stored in the solar powered evaporative cooling transit storage unit compared with the produce stored under ambient conditions

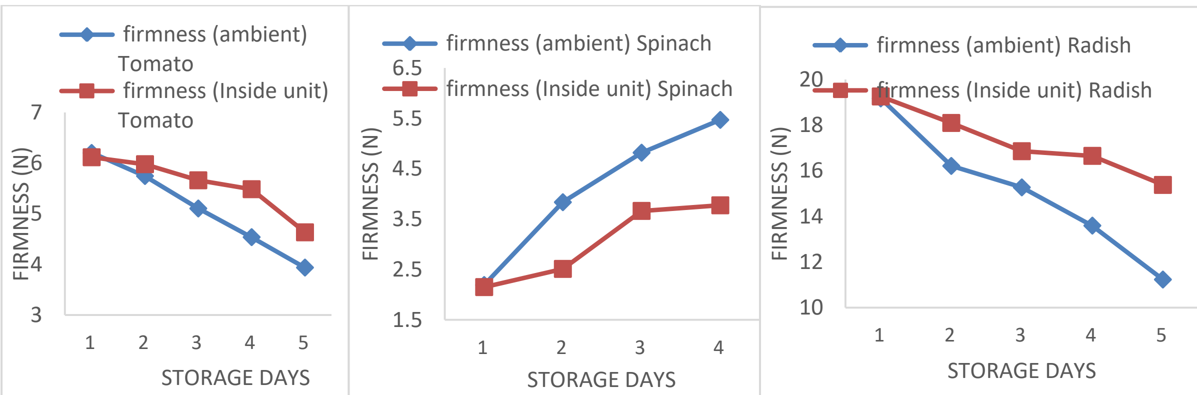

Fig. 7. Firmness of produce stored in the solar powered evaporative cooled transit storage unit compared with the produce stored under ambient condition

Table 4. Analysis of effect on PLW (%) and firmness (N) of product stored inside the storage unit

Sr. No	Product	Storage condition	PLW (%)	Pr> F	Firmness (%)	Pr> F
1	Tomato	Inside unit Ambient	3.62[b] 9.51[a]	<0.0001	4.63[a] 3.70[b]	0.0055
2	Radish	Inside unit Ambient	10.55[b] 23.37[a]	<0.0001	16.52[a] 11.46[b]	<0.0001
3	Spinach	Inside unit Ambient	15.96[b] 32.06[a]	<0.0001	3.77[b] 5.61[a]	0.0055

**Means with the different letter are significantly different*

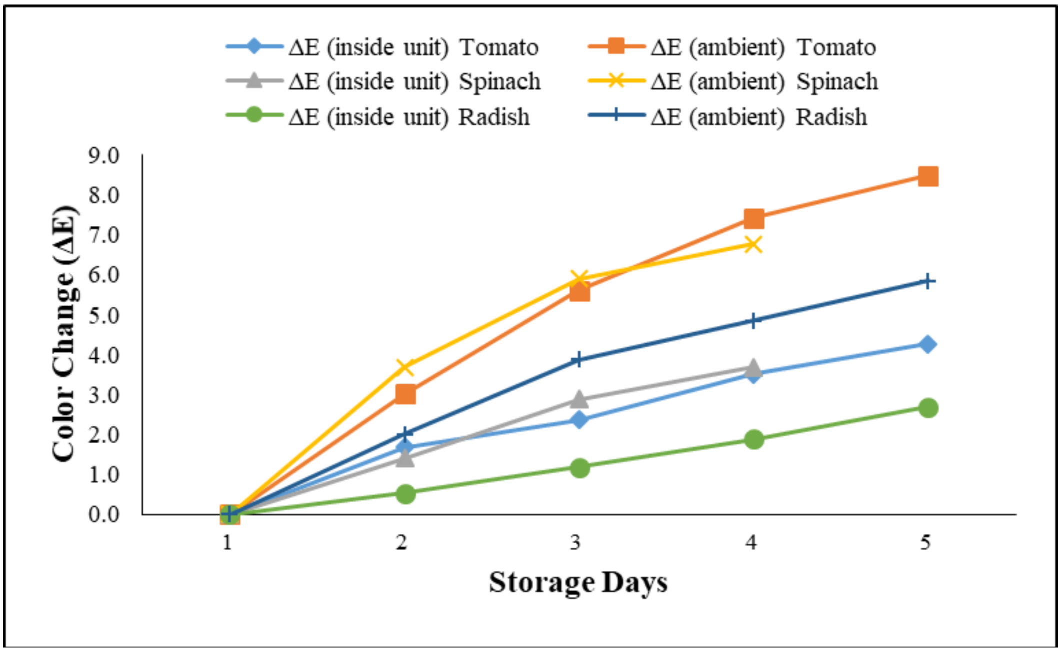

Fig. 8. Colour change of produce stored in the solar powered evaporative cooled transit storage unit compared with the produce stored under ambient condition

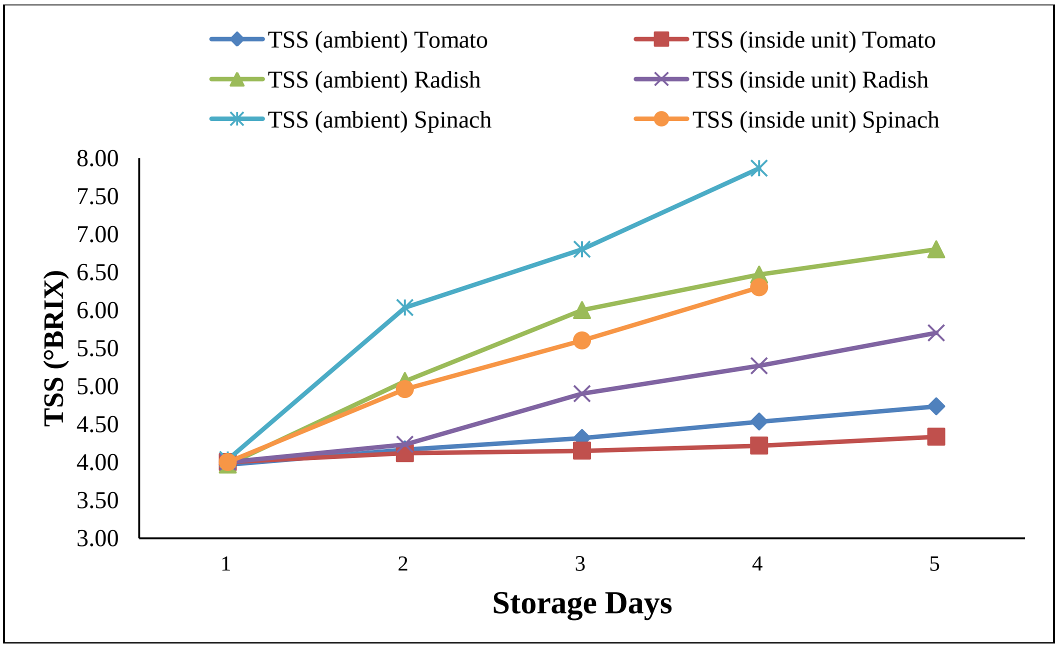

Fig. 9. TSS of produce stored in the solar powered evaporative cooling transit storage unit compared with the produce stored under ambient condition

3.6 Shelf Life of Fruits and Vegetables

The Shelf life of fruits and vegetables was decided on the basis of change in physiological loss in weight during storage in evaporative cooling storage units and in ambient condition. The weight of the produce after each day of storage was measured and compared with their initial weight. The difference in the weight was measured by storing the produce both in the storage unit and in the ambient condition. When the collected produce losses were more than 10% of its fresh weight, it started wilting and soon became unusable. The Shelf life of stored vegetables is shown in Table 6.

Table 5. Analysis of effect on colour change (ΔE) and TSS (°Brix) of product stored inside storage unit

Sr. No	Product	Storage condition	Colour change (ΔE)	Pr> F	TSS (°Brix)	Pr> F
1	Tomato	Inside unit	4.39[b]	<0.0001	4.33[b]	<0.0001
		Ambient	8.34[a]		4.73[a]	
2	Radish	Inside unit	2.77[b]	<0.0001	5.7[a]	0.002
		Ambient	5.82[a]		5.8[a]	
3	Spinach	Inside unit	3.67[b]	<0.0001	4.21[b]	<0.0001
		Ambient	6.68[a]		7.85[a]	

**Means with the different letter are significantly different*

Table 6. Change in shelf-life (in days) of vegetables store inside the storage unit Vs in ambient condition

S.No.	Produce	Shelf-life (days)	
		In inside unit	In room condition
1	Spinach	3	2
2	Tomato	13*	6
3	Radish	5	3

**days calculated from regression analysis as PLW (%) measured only till 5th day of storage*

The shelf life of all the vegetables increased by more than two days when it was stored in the evaporative cooled storage unit compared to ambient conditions. This could be due to the fact that the storage unit had maintained the low temperature and high relative humidity which increased storage life of vegetables. A similar result was obtained by Mansuri (2015). The cost of a green energy-based vegetable transit storage unit was computed by taking into consideration fixed cost and variable cost**.** The cost of the transit storage unit was Rs. 25000. It is economical as it can be recovered by increasing the shelf life of the vegetables stored inside the evaporative cooled vegetable transit storage unit.

4. CONCLUSION

Post-harvest losses of horticultural products are a significant challenge to food security. Addressing this challenge requires an approach to the reduction of losses through innovative solutions such as green energy-based storage units and transportation infrastructure. By harnessing renewable energy sources, uninterrupted power supply can be provided to the storage unit, ensuring that the produce remains fresh and in good condition, thereby reducing wastage and increasing income for the farmers and vendors. Two 100-Wp solar panels power rating were found sufficient to run an evaporative cooling system with two suction fans (15.6W), water pump (12W), and LED light (2.88W) for 0.63m^3 storage capacity. The temperature drop was 7.8 to 14.8°C as compared to ambient temperature 32.2 – 43.4^{o}C and relative humidity 21.1-46%. Relative humidity in the cooling chamber increased considerably to 84%. The average efficiency of a storage unit with honeycomb pad material range was from 71%–90.9% with an average of 84.12%. The analysis of variance results revealed that there was significant difference between evaporative cooling storage unit and ambient storage condition for PLW and firmness of tomato, spinach and radish. The shelf life of vegetables stored in evaporative cooling units was 2-5 days more than ambient condition. The cost of the developed transit storage unit was approximately Rs. 25000. Evaporative cooling transit storage unit is easy to operate, efficient, affordable, provides a basic cold storage and transportation facility especially for the farmers and venders in developing nations enabling them to deliver fresher produce, reduce waste, and better meet customer demands.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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