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Design, development and performance evaluation of an on-farm evaporative cooler

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Abstract: The portable evaporative cooler was designed for storage of 50 kg fresh fruits having overall diamentions of 1220 x 860 x 787 to study the performance of an on-farm evaporative cooler with the effect of different filling materials viz., coconut coir, saw dust + gunny bag, ECC cool pad, *wala* sheet and gunny bag. Selection of filling material was based on the cost, water holding capacity, rate of evaporation of water from filled material and easy availability. Sapota (Cv. *Kalipatti*) fruits were stored in an on-farm evaporative cooler for 16 days. The effect of filling materials on Physiological weight loss (PLW), inside temperature, inside relative humidity and cooling efficiency of five filling materials were studied. The weight loss varied between 2.50 to 13.29, 14.96, 15.37, 15.36 and 15.20% in coconut coir, saw dust + gunny bag, ECC cool pad, *wala*sheet and gunny bag, respectively. The mechanical test such as cooling efficiency for each filling material was determined and it was recorded as 90%, 54%, 38%, 70% and 79% for coconut coir, saw dust + gunny bag, ECC cool pad, *wala*sheet and gunny bag respectively. Minimum inside temperature of 16.5 to 17.2^{0}C and maximum inside relative humidity of 97 to 90% was recorded in coconut coir of an on-farm evaporative cooler when ambient temperature was 27.66^{0}C and ambient relative humidity was 51%.The maximum storage life of 16 days was found in coconut coir. Coconut coir was performed better when compared with other filling material. It was most economical filing material over the other filling materials.

Keywords: Evaporative Cooler, Filling Material, Cooling Efficiency

1. Introduction

Much of the post-harvest losses of fruits and vegetables in developing countries is due to the lack of proper storage facilities. While refrigerated cool stores are the best method of preserving fruits and vegetables they are expensive to buy and run. Consequently, in developing countries there is an interest in simple low-cost alternatives, many of which depend on evaporative cooling which is simple and does not require any external power supply.

The basic principle relies on cooling by evaporation. When water evaporates it draws energy from its surroundings which produce a considerable cooling effect. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling. The efficiency of an evaporative cooler depends on the humidity of the surrounding air. Very dry air can absorb a lot of moisture so greater cooling occurs. In the extreme case of air that is totally saturated with water, no evaporation can take place and no cooling occurs. Generally, an evaporative cooler is made of a porous material that is fed with water. When ambient air drawn over the material the water evaporates into the air raising its humidity and at the same time reducing the temperature of the air. There are many different designs of an evaporative cooler. The design will depend on the materials available and the user’s requirements.

In principle, fresh commodities need proper postharvest management to reduce loss and maintain quality. However, at present there is no improvement over traditional postharvest handling methods of fruits and vegetables. The peasants have no storage facilities at their disposal and the fruits and vegetables they harvest are usually exposed to high temperatures and low relative humidity until wholesaler or retailers collect them. The trade also does not operate any intermediate storage for carrying oversupply to obtain better prices. No cooling facilities or packaging houses at any stage of product line from farm to consumer or exports market are currently available. As a result, nutritional loss and postharvest decay are found to be the serious issues. Reduced temperature decreases physiological, biochemical, and microbiological activities, which are the causes of quality deterioration (flavour, texture, colour, and nutritive value).

Evaporative cooling systems are commonly used in countries where the climate is hot and dry. Several studies have been devoted to the application of an evaporative cooling principles in the field of fruit and vegetables preservation mostly in India and the USA. The potential energy savings envisaged by replacing conventional refrigerated systems by evaporative systems. Evaporative cooling is an adiabatic cooling process whereby the air takes in moisture which is cooled while passing through a wet pad or across a wet surface showed that evaporative cooled storage is more energy efficient than a mechanical refrigeration system.

In developed countries, methods employed for extending shelf life and minimizing post-harvest losses of perishable produce include mechanical refrigeration, controlled atmospheres, hypobaric storage, and other sophisticated techniques. These techniques are highly capital intensive and for most developing countries, the required manpower is either lacking or inadequate. These cooling methods, except adiabatic cooling, are expensive for small scale peasant farmers, retailers and wholesalers, as they require electric power. Moreover, in the existing mechanical refrigerating systems, proper storage conditions are not often put into consideration as stored items (vegetables) were normally subjected to excessive chilling or freezing.

Low temperature and high relative humidity can be achieved by using less expensive methods of evaporative cooling [1]. Evaporative cooling has been reported for achieving a favorable environment in green houses [2] animations and the storage structure for fruit and vegetables [3] and [4]. The present study was therefore planned to design and develop a low cost, portable evaporative cooling system that could be utilized to store fruits and vegetables at their minimal storage temperature.

2. Materials and Methods

2.1. Design of Components

The portable prototype of an evaporative cooler was designed for storage of 50 kg fresh fruits having overall dimensions of 1220 x 860 x 787 mm. (Fig.1 and Fig. 2). The actual design realization was worked out based up on the literature reviewed and for simulation of results of filled material the designed prototype was used and was compared with the earlier studies.. The clearance between two layers of net was 50 mm. The container and inner frame clearance was 100 mm. The distance between two stakes of container was maintained 100 mm throughout the experiment .The clearance between two layers of net was filled with five filling materials viz., coconut coir, saw dust + gunny bag , ECC cool pad, *wala* sheet and gunny bag.

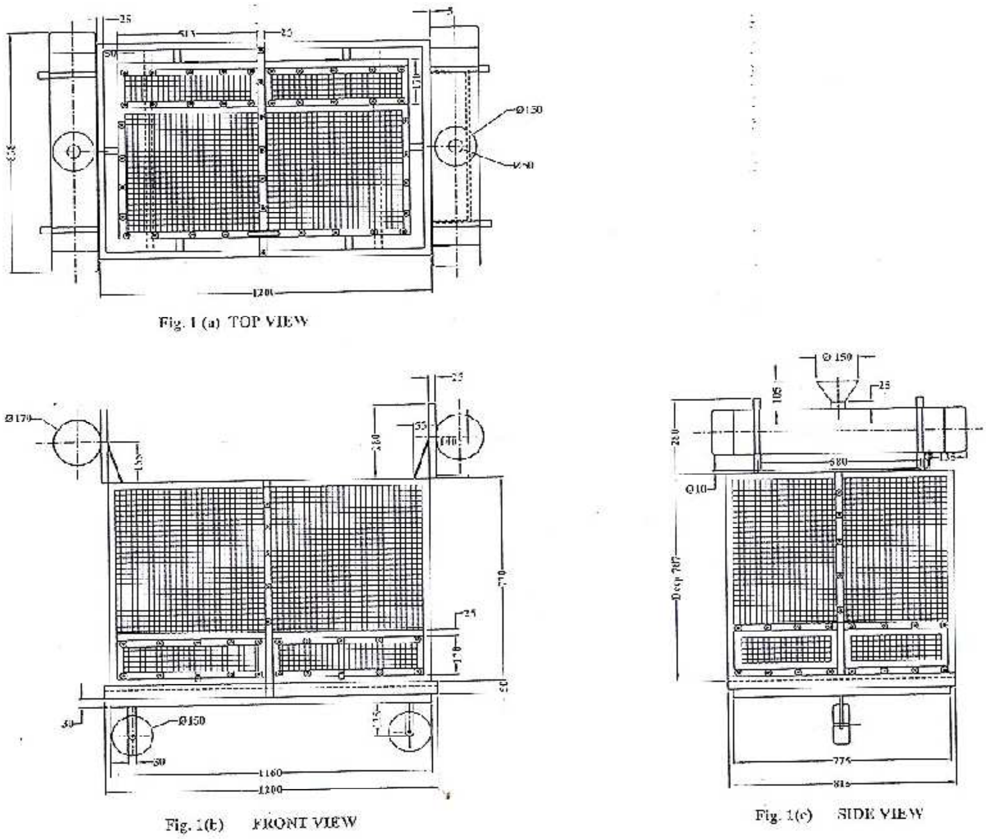

Figure 1. *Different views of an evaporative cooler.*

The water distribution was achieved though laterals of 12 mm diameter for trickling the water on the filled material sandwiched between two layers of net. The two water tanks made up of PVC pipe of 170 mm diameter and 910 mm in length of 20 liters capacity were used as reservoir to fulfill the requirement of water for storage. The water tanks were elevated to the height of 155 mm from top of evaporative cooler for natural circulation of water. The laterals were provided with drippers placed 150 mm apart from each other so as to trickle the water uniformly on filled material. For easy filling of pads inside the net gap a door of 170 x 513 mm with suitable handle was designed. The experiment was conducted in completely randomized design (CRD).

Figure 2. *Photographic view of evaporative cooler.*

2.2. Selection of Filling Material

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 filling material**.** This is dependent upon the air velocity, filling material thickness and the degree of saturation of the filling material which is a function of the water flow rate wetting the filling material[5]and [6]. Similar filling material**s** have been used by [7] and [8].

Table 1. *The on-farm evaporative cooler (OFEC) consists of following main parts and specifications.*

Particulars	Material	Size
Base	Galvanized iron sheet	1220 x 770 x 787(mm)
Outer frame	Mild steel	1180 x 820 x 800(mm)
Inner frame	Mild steel	1080 x 720 x 800(mm)
Door	Mild steel	980 x 650 x 50(mm)
Wheels (3 Nos.)	Caster wheel	6 inch. Dia.
Net	Galvanized iron	20 x 20(mm)
Lateral	PVC	12 mm dia.
Drippers	PVC	1 No./150 mm length of lateral
Water tank	PVC	2 nos. 170 mm dia.

The ambient and cabinet temperature was measured using digital thermometer and relative humidity by digital humidity –temperature meter. Products weight (preserved and unpreserved) was determined by digital weight balance 10.00, 14.00and18:00 hrs. The evaporative cooling system was tested over a period of 16days using 50 kg of sapota fruit. The chamber was tested for its suitability to reduce the temperature while maintaining the increased relative humidity. The experiment was carried out using the developed evaporating cooling system at no load condition for 7 days. The system was also used at loaded condition to preserve sapota fruit for the other 16daysfor storage of sapota fruits.. During the testing period, the thermometer was suspended in the chamber through a small hole in the cabinet to ascertain the variation of temperature in the chamber, while a control sample of 50 kg of sapota fruit spread on a tray were expose to the open air.

2.3. Cooling Efficiency

Analysis of the moist air properties is important to look at the suitability of a given modified air condition for fruit and vegetables storage in hot climate. Cooling efficiency is an index used to assess the performance of a direct evaporative cooler. Cooling efficiency in percentage can be defined as suggested by[8]and [9].

$$\eta = \frac{Td - Tc}{Td - Tw} x100 \tag{1}$$

where: *Td* and *Tw a*re the dry and wet bulb temperatures of the ambient air and *Tc* is the dry bulb temperature of the cooled air in ^{0}C.

2.4. Per Cent Loss in Weight (PLW)

Per cent loss in weight (PLW) was determined by weighing the sapota fruits after 4 days interval during storage with the equation used by[8]and[10].

$$(PLW) = \frac{W_1 - W_2}{W_1} \text{ x } 100 \tag{2}$$

where,

W_1: Weight of sample before storage

W_2: Weight of sample after storage

2.5. Statistical Analysis

Data analysis was performed using GLM procedure of SAS. Effects were considered significant in all statistical calculations (≤ 5). Graphs were plotted in MS Excel.

3. Results and Discussion

3.1. Effect of Filling Materials on Physiological Loss in Weight (PLW)

The effect of filling materials on physiological loss in weight (PLW) of sapota was found statistically significant in all filling materials used for evaporative cooler. The weight loss showed variation from 2.50 to 15.45% during storage. The weight loss found to be minimum (13.29%) in case of fruits stored in coconut coir on 16th day of storage whereas it was maximum (15.45%) in case of fruits stored at room temperature on 4th day of storage. The effect of filling materials on physiological loss in weight was plotted in Fig. 3. It was observed from Fig. 3 that the physiological loss in weight increased with increase in storage period for all filling materials. Similar trends were reported by [11] for potatoes stored in desert cooler and [12] for storage of eggplant under passive evaporative cooler.

It was observed from the data that the increase in physiological loss in weight was at faster rate in fruits stored at room temperature followed by ECC cool pad and saw dust + gunny bag respectively. Among all filling materials, coconut coir showed minimum weight loss. The increase in weight loss with storage period may be due to reduction in moisture content on respiration. The rate of respiration might have decreased due to low temperature. Similar results were reported by [13] for sapota and [14] for storage of mango in evaporative cooler.

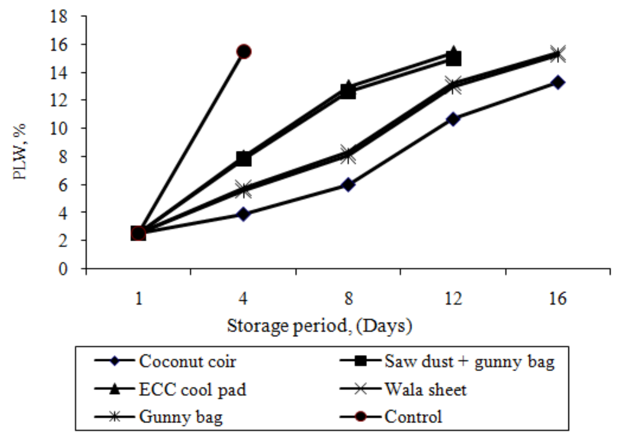

Fig 3. *Effect of filling materials on PLW.*

3.2. Effect of Filling Materials on Inside Temperature

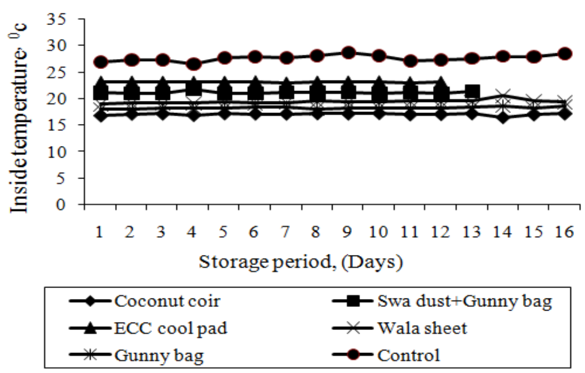

Fig 4. *Effect of filling materials on inside temperature.*

The effect of filling materials on inside temperature of on-farm evaporative cooler was found statistically significant in all filling materials. The data on effect of filling materials on inside temperature was plotted in Fig. 4. The average temperature obtained during storage period ranges from 16.5 to 23.3^{0}C throughout the storage period for all filling materials. Minimum temperature of 16.5 to 17.2^{0}C was obtained in coconut coir when ambient temperature was 26 to 29^{0}C. The higher (9.5 to 11.8^{0}C) temperature drop was obtained in case of coconut coir. Lower temperature drop was obtained in ECC cool pad followed by saw dust + gunny bag, *wala* sheet and gunny bag respectively.

Similar trend of inside temperature of the evaporative cooler have been reported by [8] for sapota fruit storage. Temperature drop of 20^{0}C was reported by [15] in acute summer for stored potatoes in cool chamber. Reference [16] reported temperature drop of 8 to 14^{0}C for fruits stored under low cost household evaporative cooler.

3.3. Effect of Filling Materials on Inside Relative Humidity

The effect of filling materials on relative humidity was found statistically significant in all filling materials. Relative humidity observed at atmospheric condition was 42 to 59% during storage. The data on effect of filling materials on inside relative humidity of evaporative cooler was plotted in Fig. 5.Inside relative humidity recorded for all of the filling material was ranging from 74 to 97%. Minimum relative humidity was recorded in ECC cool pad of evaporative cooler as compared to other. Whereas, maximum relative humidity (90 %) was recorded in coconut coir followed by gunny bag, *wala*sheet and saw dust + gunny bag of evaporative cooler. Same trend of inside relative humidity in the evaporative cooler have been reported by [8] for sapota fruit storage.

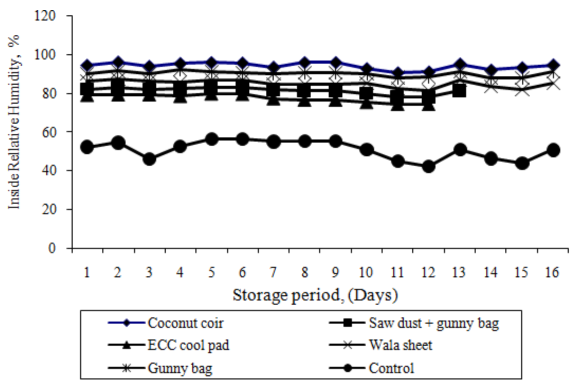

Fig 5. *Effect of filling materials on relative humidity.*

3.4. Effect of Filling Materials on Cooling Efficiency

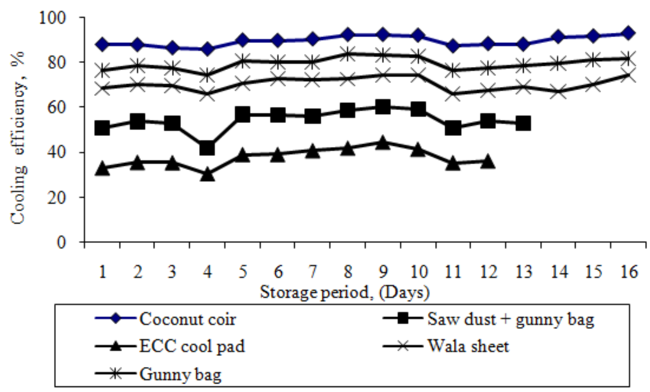

Fig 6. *Effect of filling materials on cooling efficiency.*

The effect of filling materials on cooling efficiency was found statistically significant in all filling materials. The data on effect of filling materials on cooling efficiency of evaporative cooler was plotted in Fig. 6.Maximum cooling efficiency was recorded in coconut coir followed by gunny bag and *wala* sheet. The highest cooling efficiency (90 %) was recorded in coconut coir. Minimum cooling efficiency was observed in ECC cool pad followed by saw dust + gunny bag. Cooling efficiency of ECC cool pad was ranging from 30.50 to 40.41%.

Similar results were reported by [17] for perishable products stored in evaporative cooling system and [18] for absorbent material stored in evaporative cooling.

4. Summary and Conclusion

Based on the results following conclusions could be drawn:

1. The percent weight loss (PLW) varied between 2.50 to 15.45%. Maximum weight loss was found in ECC cool pad whereas minimum (13.29%) was found in coconut coir. The PLW was found increased with increase in storage period for all the filling materials.
2. The maximum total storage life of 16 days was found in case of fruits stored in coconut coir withinthe acceptable range. Whereas, minimum storage life of 4 days found in control sample followed by 12 days in ECC cool pad.
3. Minimum inside temperature of 16.5 ^{0}C was recorded in coconut coir among all filling materials when average ambient temperature was 29^{0}C. The average temperature drop of 9.5 to 11.8 ^{0}C was found in case of coconut coir pad throughout the storage period.
4. Maximum inside relative humidity of 90% was recorded in coconut coir among all filling materials when average ambient relative humidity was 59%.
5. Highest cooling efficiency of 90% was recorded in coconut coir of an on-farm evaporative cooler followed by gunny bag 83%.
6. Coconut coir proved to be the best for increasing the shelf life (upto12days) of sapota fruits amongst all other filling material.
7. Coconut coir was found was found to be the most economical filling material amongst all other.

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