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Evaluation of an active evaporative cooling device for storage of fruits and vegetables

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Abstract: An active evaporative cooling device for storage of fruits and vegetables was evaluated. The cooling device was developed to improve the shelf life of fruits and vegetables. It consists of an inner wall (aluminum of 0.6 mm thickness), external wall (galvanized steel of 1mm thickness), one suction fan, water pump and three trays. The walls were lagged by polyurethane of 25 mm, and three trays. Water distribution network contains two water tanks of 20 litres capacity each, a polyvinyl chloride (PVC) pipe of 25 mm diameter for conveying water, a 0.5 hp pump for circulating water from the tank to the overhead reservoir and a floated switch for controlling the pump. Water is discharged from the overhead tank through a tap and drains through a jute bag which serves as a cooling pad material. As water drips through the pad, a suction fan of 38 cm swept depth set air in motion and blow through the wetted part. The cooler was evaluated with sweet orange, green tomatoes and red tomatoes for 7 days to determine firmness, colour changes and weight loss of the crops. Weight loss in the red and green tomatoes stored in the ambient was observed to be 47.20% and 5.14% respectively while it was 8.65% for red tomatoes stored in the cooler. Cumulative weight loss recorded in sweet oranges was 9.25% for ambient and 4.27% for the cooling device. The cooler reduced the ambient temperature of 29.5^{o}C to 22.8^{o}C and increased ambient relative humidity to 95.7%.

Keywords: evaporative cooling, storage, orange, tomato, post-harvest losses

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1 Introduction

Nigeria produces varieties of tropical and sub-tropical fruits and vegetables mainly for domestic consumption. Among some important fruits are banana, citrus, mangoes and pineapples with the principal vegetables as tomatoes and onions (Obetta et al., 2011). Citrus is one of the most important fruit crops grown all over the world. They are fat free, sodium free and cholesterol free and also very good source of fiber (Ndukwu, 2011). However, with all the surplus production of fruits and vegetable across the tropics, there are lots of problems associated with post-harvest activities of fruits and vegetables which result in rapid deterioration and scarcity during offseason. Short shelf-life of fruits and vegetables is one of the factors that reduce their economic value. Fruits and vegetables are exposed to contamination by microbes through contact with soil, dust and water and by handling at harvest or during post-harvest processing (Eni et al., 2010). Problems associated with poor postharvest operations had been a concern to farmers in the developing nations as food safety and quality demand increased (Kitinoja et al., 2010).

According to Manuel (2011), a large portion of all fresh produce is lost worldwide after harvest. It is estimated that a total of 20%-40% of all crops in developing countries is lost to postharvest losses. Losses are due to decay, mechanical damage, physiological disorders, and even to the action of several fruit flies, during harvest, storage and transport. Katsoulas et al. (2001) estimated that from 5% to 25% of fruit and vegetables leaving the farm gate is never consumed, but has to be thrown away. These losses result from

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deterioration of fruits and vegetables are accountable for by some factors as postulated by Olosunde (2006). Muhammad et al. (2012) disclosed that fruits and vegetables still continue their normal physiological activities during post-harvest process. Ripening is a physiological activity that takes place in fruit and it is associated with change in composition *i.e.* conversion of starch to sugar which gradually leads to spoilage or deterioration of the fruits. Improper handling of fruits and vegetables after harvest inflict injury which can be cracks, bruises, cuts or abrasion on the fruits and provides an attacking spot for micro-organisms to act which on the long run promotes rapid deterioration of the produce, makes the produce unattractive and also reduces its market value. An increase in evaporation decreases the moisture content of the produce and on the long run reducing its shelf life. According to Olosunde (2006), weight loss results from moisture loss via evaporation of water from the tissues when the fruits and vegetables are attempting to be in equilibrium with the environment which is usually at lower water activity.

In Nigeria, the deterioration rate of fruits is very high and detrimental to the income of fruit farmers and marketers across the country. Post-harvest losses of fruits and vegetables are estimated at 5%-20% in developed countries and 20%-50% in developing countries (Mashav, 2010). Nigeria post - harvest losses of fruits and vegetables amount to 35%-45% of the annual production (FAO, 2004). Postharvest loss includes food loss across the food supply chain from harvesting of crop until its consumption (Aulakh et al., 2013). Postharvest losses can broadly be categorized as weight loss due to spoilage, quality loss, nutritional loss, seed viability loss, and commercial loss (FAO, 2014).

The principle governing evaporative cooling system is the conversion of sensitive heat to latent heat. The outdoor air which is dry and warm is forced through the pores of the pad material that is wetted by water that is discharged and distributed by the overhead water tank or cooler reservoir. The air passing through the wetted pad is drawn by a suction fan from the environment. In other words, the surrounding air is set in motion by the suction fan and forced through the wetted pad. The sensible heat is a warm and dry air from the ambient that passes through the wetted pad and eventually changes to latent heat because of the occurrence of evaporation which results in the cooling of the chamber. The cooler was made of a rectangular shape so as to create a wider surface for circulation of air (Manuwa and Odey, 2012).

Several researchers have worked on evaporative systems. Redulla (1985) reported a drip evaporative cooler constructed from simple materials such as burlap and bamboo. Roy (1989) used baked bricks to construct a double wall evaporative cooling structure for storage of fruits and vegetables. Abdalla and Abdalla (1995) examined the suitability of using palm leaves as a wetted medium. Acedo (1997) developed two simple evaporative coolers with jute bag and rice husk as the cooling pad in the Philippines for cooling and storage of vegetables. These coolers were cumbersome, occupied space and they operated solely through the process of evaporation without the use of fan. Hence, there is a need for further research into substantial methods and technologies for improving the storage of fruits and vegetables in the tropics. This has led to the development of an active evaporative cooling system for the storage of citrus fruits with modification of the previous studies, in this study. The main objective of this study was to evaluate the performance of a prototype active evaporative cooling system for storing fruits and vegetables using citrus and tomato.

2 Materials and methods

2.1 Design principles

The principle governing evaporative cooling system is the conversion of sensitive heat to latent heat. The outdoor air which is dry and warm is forced through the pores of the pad material that is wetted by water that is discharged and distributed by the overhead water tank or cooler reservoir. The air passing through the wetted pad is drawn by a suction fan from the environment. In other words, the surrounding air is set in motion by the suction fan and forced through the wetted pad. The sensible heat is a warm and dry air from the ambient that passes through the wetted pad and eventually changes to latent heat because of the occurrence of evaporation which results in the cooling of the chamber. The cooler was made of a rectangular shape so as to create a wider

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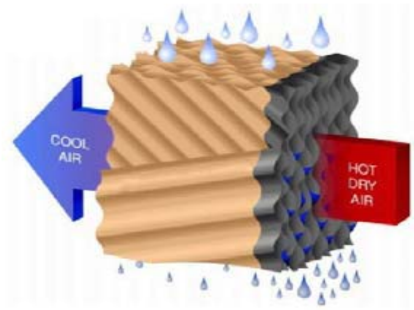


Figure 1 A pictorial representation of the process owing to temperature

2.2 Description of the evaporative cooling system

The cooler was made of metal sheets. The external wall was made of galvanized steel with dimensions 0.5 m long × 0.45 m wide × 0.9 m deep. The inner wall was made of aluminum with dimensions 0.45 m long × 0.425 m wide × 0.85 m deep. The inner and the outer walls were separated with polyurethane to provide lagging for the system to prevent exchange of heat between both walls. The outer wall was painted silver color to improve reflectivity and reduce rate of heat absorption. Jute was used as the wetted pad. One suction fan of 38 cm swept depth diameter was used to drive the ambient warm and dry air through the wetted pad into the controlled chamber. There were two water tanks each of 20 litres capacity, one below the cooler and the other above the cooler as overhead tank. A 0.5 hp electric pump lifts water from the bottom tank through a 25 cm diameter polyvinyl chloride (PVC) pipe to the overhead tank as water passing through the pad drains back to the bottom tank. The pad was held with wire mesh of 1 by 2 inch to allow air pass through the pad easily. The storage chamber has three trays. Each tray has dimensions 40 cm length × 35 cm breadth. The tray was made of 1 by 1 inch square pipe as the frame and a wire mesh of 1 by 2 inches. Figure 2 shows exploded view of the evaporative cooling system and fabricated evaporative cooling system, respectively.

(a) Exploded view (b) Fabricated cooling device (c) Evaporative cooling device loaded with tomatoes and oranges

Figure 2 Exploded view of the evaporative cooling system and fabricated cooling system

2.2.1 Cooling pad

The material used for this study was jute. The pad was framed with a square pipe of 2.5 cm by 2.5 cm and covered by a wire mesh of 2.5 cm by 5 cm. The pad was made with a thickness of 2 cm. it was placed right in front of the suction fans for direct flow of air through the wetted pad into the controlled chamber.

2.2.2 Water distribution

The system has two water tanks that stores water. The overhead tank drips water through a perforated 1” by 1” square pipe into the pad and drain down into the bottom tank through a trough. The water collected at the bottom water tank is then conveyed back to the overhead tank through a 1” diameter PVC pipe. This circulation continues for the system and the pump operation is controlled by a floater switch. The rate of water discharge from the overhead reservoir into the pad is regulated by a tap. Figure 3 shows the water circulation network for the cooling system.

Figure 3 Water circulation network for the evaporative cooling system

3 Experimental methods and procedures

The fabricated evaporative cooling system was evaluated with sweet orange, red tomatoes and green tomatoes at laboratory of the Agricultural and Biosystems Engineering Department, Landmark University, Omu Aran, to determine weight loss, cooling efficiency, color change and firmness. The stored crops were weighed for seven days of storage to evaluate performance of the cooler through the determination of the weight losses that occurred in the stored biological materials, and this was done through percentage weight estimate.

3.1 No-load test of the evaporating cooling system

A no-load test was carried out on the system to see the effect of the evaporation that is expected to take place whether the process is effective or not in determining its efficiency before loading the cooler with the agricultural produce for storage. The computation was done by measuring temperature and relative humidity difference between the inside (controlled atmosphere) and external (ambient) condition.

3.2 Temperature and humidity measurement

The temperature difference between the internal (controlled atmosphere) and external (ambient condition) temperatures indicates the effectiveness of the system. The temperature readings were taken using the dry and wet bulb thermometer. Relative humidity was obtained using the hygrometer (PCE-WB 20SD) and a data logger (OM-HL-SP) which has readings for both relative humidity and temperature.

The effectiveness of the jute pad is based on the cooling efficiency. The saturation efficiency (SE) of the cooler for the jute bag used was calculated using Equation (1) (Harris, 1995):

$$SE = \frac{\{T_1(\text{db}) - T_2(\text{db})\}}{\{T_1(\text{db}) - T_1(\text{wb})\}} \tag{1}$$

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.

3.3 Load test of the evaporative cooling system

Evaluation of the fabricated evaporative cooling was carried out at Soil and Water Laboratory of Agricultural and Biosystems Engineering Department, Landmark University. Sweet orange and tomatoes obtained from market were used for evaluation. Evaluation was conducted in two parts. In the first part, the cooler was operated under no load condition without crops to ascertain its conditions. Temperature readings of the cooler and the ambient were recorded using a thermometer. Relative Humidity (RH) readings of the cooler and the ambient relative humidity were taken using a hygrometer. The readings were taken three times in a day (8 am, 3pm and 9 pm) for two weeks. Second part of evaluation was load test to ascertain efficiency of the cooler when loaded was with crops. All procedures and all calculations were repeated and all observations were recorded.

3.4 Physiological weight loss

Physiological weight loss was determined by weighing five samples of sweet orange and tomato randomly sampled and labeled 1 to 5 to be used to measure physiological weight loss using a digital weighing scale (Constant 14192-1F model, China), and expressed as percentage weight loss using the following formula;

$$\text{Percentage Weight Loss} = \frac{W_1 - W_2}{W_1} \times 100$$

where, W_1 = Initial weight of sample (kg); W_2 = Weight of sample after storage (kg).

Firmness was measured using a fruit hardness tester (FTH-05 model, Guangzhou, China) fitted with a 3.5 mm probe. Five samples of sweet orange and tomato fruits were used for destructive analysis.

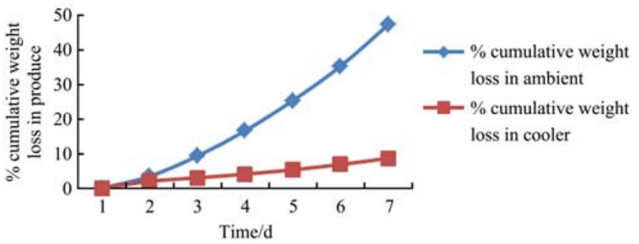
4 Results and discussion

4.1 Weight loss

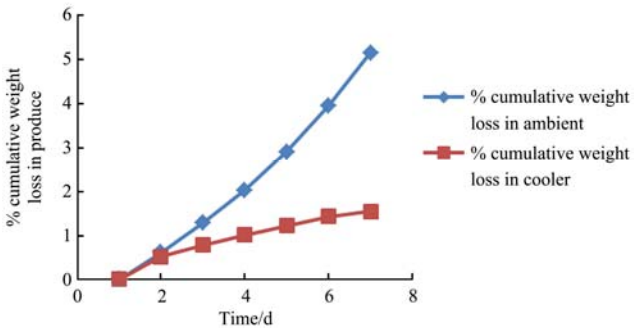
Figure 4(a) shows weight loss in red tomatoes. Weight loss in the red tomatoes stored in the ambient was observed to be 47.20% of the originally stored red tomatoes. While for the same quantity of red tomatoes stored in the cooler, just 8.65% of the originally stored produce was lost which was apparently insignificant. This also implies that release of ethylene which is known to be a ripening hormone was very rapid in tomatoes stored in the ambient condition which resulted into a drastic deterioration of red tomatoes in the ambient, but for the tomatoes in the cooler, release of ethylene was very slow which encouraged the shelf life extension of the tomatoes

(Ndukwu et al., 2013).

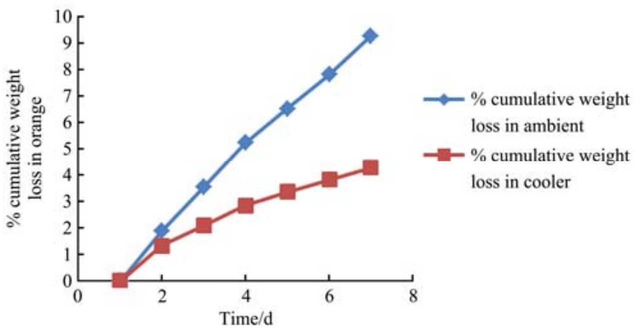
Figure 4(b) shows that the weight loss in green tomatoes stored in the ambient was 5.14% and 1.54% for the one stored inside the cooler. This apparently amount to 5:1 ratio of both storage weight losses incurred. Figure 4(c) shows the effects of both environments (ambient and cooler) on the sweet oranges kept for seven days. Cumulative weight loss incurred after seven days of evaluation was 9.25% for ambient and 4.27% respectively for the cooler.



(a) Percentage weight loss in red tomatoes.



(b) Percentage weight loss in green tomatoes



(c) Percentage weight loss in sweet orange

Figure 4 Percentage weight losses in red tomatoes, green tomatoes and oranges

4.2 Colour changes

The initial colour of the crops were bright before storage but during the evaluation process the colour of the tomatoes and oranges stored outside began to change some days after storage. In the ambient, the green tomatoes began to change colour after the fourth day, the red tomatoes became totally red and started getting deteriorated on the third day. The sweet orange had gradual and slightly noticed changes in colour. After the seven days of evaluation, the red tomatoes kept in the ambient already got deteriorated and was virtually useless, the green tomatoes got ripen and the sweet orange had change almost totally yellow. While in the cooler, the red tomatoes stored maintained its colour for the seven days, the green tomatoes were still green in colour but only one was slight getting ripen but minimal compared to the one kept in the ambient. And the orange was of little or change in colour.

4.3 Firmness

Firmness was determined by feeling. It was tested with the freshness of the fruits by observing the surrounded skin of the fruits in terms of its softness during the storage period. The firmness of the various fruits and vegetable stored both in the cooler and the ambient after storage are presented in Figure 5, Figure 6 and Figure 7 below. On the seventh day, it was observed that sweet orange in the ambient had shrink, red tomatoes decayed and virtually lost firmness while the green tomatoes were a bit firm. However, for the produce stored in the cooler, red and green tomatoes were firm compared to those kept outside in the ambient. Shrinkage rate for sweet orange was very slow compared to the ones stored in the ambient.

(a) Red tomatoes in ambient

(b) Red tomatoes in cooler

Figure 5 Photographs of red tomatoes stored in ambient and inside the storage device

(a) Green tomatoes in ambient

(b) Green tomatoes in cooler

Figure 6 Photographs of green tomatoes in ambient and inside the cooler

(a) Orange in ambient (b) Orange in cooler

Figure 7 Photographs of orange in ambient and inside the cooler

5 Conclusion

An active evaporative cooling device was fabricated to evaluate with tomatoes and sweet orange. The cooler dropped the temperature of the ambient of 29.5^{o}C to 22.8^{o}C and increased the relative humidity from 64.69% to 95.70%. The cooler is a very simple to operate system that stored fruits and vegetables for a short period of time without rapid deterioration. The cooler was able to store already ripen red tomatoes without deteriorating for seven days. This shows that this technology is worth adopting to reduce rate of post-harvest losses in fruits and vegetables and also improving the commercial values of agricultural produce. This will also encourage more cultivation of fruits and vegetable and will eventually result in geometric increase in income generation from agricultural produce.

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