



Development and Evaluation of an evaporating cooling system for agricultural products

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Abstract: Evaporative cooler works on the principle of cooling resulting from evaporation of water from the agricultural product. The cooling achieved by this device also results in high relative humidity of the air in the cooling chamber from which the evaporation takes place relative to ambient air. A proper storage of farm produce is needed in order to extend the shelf life of the farm produce. To have a proper storage there is need in controlling both the temperature and relative humidity of the storage area. The essence of storage is important because not all the harvested farm produce is used immediately after harvest; this minimizes spoilage of farm produce and enhances their life span. The evaporative cooling system reduces the storage temperature and also increases the relative humidity within normal level of storage. The cooling system is an enclosed system and air is allowed to pass only through the pad and also a suction fan centrally located which draws in air through the pad. Water drips into the jute pad at a constant rate through a water distribution system. The materials used are: Suction fan, pad end, water reservoir, pipe network, battery, water pump, spinach, okro and melon leaf. This paper reviews the evaluation of the effect of absorbent materials on an active evaporative cooling system for the storage of fruits and vegetables.

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Introduction

An evaporative cooler is a device that cools air through the evaporation of water which otherwise lowers the temperature of air. Evaporative cooling utilizes the heat and humidity in the air by eliminating humid moisture on the plant's leaves while other wet surfaces in the room start to naturally evaporate rapidly at the triggering of an evaporative cooling system. Vegetables and fruits are important sources of minerals, protein, carbohydrates and vitamins, which are needed for normal healthy growth. The major problem during storage is what happens to the quality parameters and physical characteristics such as: color, texture, freshness; which affects the price of the produce. In order to extend the shelf life of these products, fruits need to be properly stored which requires controlling both the temperature and relative humidity of the storage area.

Evaporative cooling is especially well suited for climates where the air is hot and humidity is low. In dry arid climates, the installation and operating cost of an evaporative cooler can be much lower than that of refrigerative air conditioning, often by 80% or so. However, evaporative cooling, vapor-compression and air conditioning are sometimes used in combination to yield optimal cooling results. Some evaporative coolers may also serve as humidifiers in the heating

season. Even in regions that are mostly arid, short periods of high humidity may prevent evaporative cooling from being an effective cooling strategy.

The most abundant constituent of fruits and vegetables is water which may be up to 80% when fruits and vegetables are in their fresh form such as cucumber, lettuce and melon which contains about 95% water, this is why vegetables are generally classified as perishable crops. After harvest these crops begin to shrivel, wither or rot away rapidly, particularly under hot tropical conditions mainly causing loss of moisture, changes in composition and pathological attack. The environment for safe and prolonged storage of perishable commodities must therefore be one of high humidity and low temperature to retard moisture loss, reparatory process and inhibit activities of microbes (pathogens) which are the most destructive activity during storage of vegetables crops. Adequate storage of fruit and vegetables prolong their usefulness, check market gluts, provide a wider availability of fruit and vegetables throughout the year, help in orderly marketing, increase the financial gain to the producer and reduce subsequent losses. Some methods of preservation of raw and processed fruits and vegetables include: storage in ventilated shed, storage at low temperatures,

use of evaporative coolant system, waxing and chemical treatment. However, refrigeration is very popular but it has been observed that several fruits and vegetables like banana, plantain and mango cannot be stored in the domestic refrigerator for a long period of time as they are susceptible to chilling injury. Moreover, costs and power availability of refrigerators are beyond the reach of low income farmers in the rural communities. Although, development of storage technology for fruit and vegetable crops shows considerable benefit in terms of extended shelf life and quality of produce, but lack of capital may force the farmer to ignore the use of high storage technology, even when available and effectively managed.

There are inadequate storage facilities for crops in Nigeria (Aremu *et al.*, 2015a), Losses of fruit and vegetable occur at different stages from the field to ultimate consumer and depend on the degree of peristaltic of the produce. Fresh fruits and vegetables deteriorate easily when stored under ambient condition, mainly due to physiological and microbial activities, which are accelerated at high temperature and low relative humidity of the storage environment. In evaporative cooling system, the latent heat of evaporation is used to carry heat away from an object and cool it. FAO (2003) has advocated a strong system based on the evaporative cooling for the storage of fruits and vegetable, which is simple, relatively efficient and of low running cost. This was aimed at increasing the shelf life of the farm produce and improving the quality of market produce to yield higher earning and improve the living standard of the farmers.

The result of this study will provide the basis of developing appropriate storage for the selected fruits and vegetables and reduce the menace of deterioration, the success of the study will enhance the shelf life of the fruits and vegetable, boost the economy of the country and improve farmer standard of living.

In ensuring food security for the entire populace, it very essential to improve the storage and processing facilities for perishable crops to reduce wastage (Ogunlade *et al.* 2019). The choice of packaging material in storage and absorbent materials in evaporative cooler affects the longevity of stored products (Aremu *et al.*, 2015b; Jaiyeoba *et al.*, 2017a and b). Olosunde *et al.* 2009 evaluated the performance of absorbent materials in evaporative cooling systems for storage of banana, tomato and okro and reported that jute fiber used as an absorbent has overall advantage over hessian fiber and cotton waste; Zakari *et al.* (2016) designed and constructed an evaporative cooling system for storage of fresh tomato and discovered that tomatoes can be stored for an average of five days without any meaningful changes in product characteristics as compared to

detrimental changes in these properties after 3 days in ambient conditions; however, Ogbuagu *et al.* (2017) was able to store tomatoes, garden eggs and carrots for ten days with the use of composite-padded evaporative cooling bin. Literature review showed that information on the development and evaluation of an evaporative cooler for crops like spinach and mallow leaf is very scanty hence this study aimed at development and evaluation of an active evaporative cooling for the storage of spinach, mallow leaf and okra using jute pad as absorbent.

Methodology

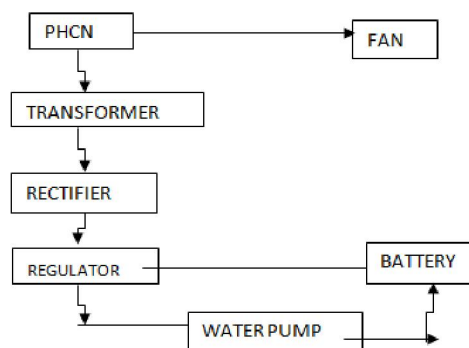


Figure 1: The arrangement of cooling components

Design Principle: The design of the evaporative cooler was based on the principle of evaporation which causes a cooling effect to its surrounding. The system is an enclosed system and air is allowed to pass only through the pad, and a suction fan, centrally located which draws in air through the pad. Water drips into the jute pad at a constant rate through a water distribution system. As the water drips into the pad the suction fan draws warm air through the wetted pad. During this process the warm air which is the sensible heat passes through the wetted pad which is now changed to latent heat due to the evaporation that has occurred as a result of the water being evaporated which causes the cooling within the enclosure to achieve a temperature difference of about 10°C. The systematic arrangement of the cooling system is presented in Figure 1. The applied voltage is 220 alternating current which powers the cooling system, the transformer helps in stepping down the voltage to 12 volts alternating current, the rectifier help converts alternating current to direct current electricity, the regulator stabilizes current at 12 volts, the battery serves as back up incase the electricity is not available while the water pump transmits the water from the bottom tank to the top tank in a cyclic form, the pump used is an horse power with 10-12 volts and the fan blows the water dripped on the jute pad to the bottom

tank back to the top tank which blows fresh air to the vegetables in the cooler.

Operation of the Evaporating Cooling System:

The cooling system has two storage tanks (buckets) of 60 liters each at the top and bottom of the cabin. Water is poured into the bottom tank in which the pump is placed so as to transmit the water to the top tank with the aid of a pipe being connected to both ends. As soon as the water get to the bucket at the top, the water distribution pipe is connected to it and the pipes is perforated so that the water drops on the absorbent material (jute pad). Then, the fan blows directly on it and cools the stored products. The water being dripped on the jute pad returns to the bottom bucket and get recycled to the top bucket continuously for four hours, when the water at the bottom tank is low that the pump needs sufficient flow of water. The whole body was painted white colour so as to deflect heat in contact with the cooling system. The products get cooled and fresh due to adequate movement of air from the fan to the cooling pad. The temperature was monitored by measuring the ambient temperature and the temperature inside the chamber and the difference was recorded. The Relative humidity was also obtained using a digital thermo-hygrometer.

Experimental Methods and Procedures

a. **No-Load Test:** A no load test was conducted on the system to determine the effectiveness before being loaded with the agricultural produce, this was computed by measuring temperature difference and the relative humidity of the evaporative cooler.

b. **Heat Load Test of the evaporative cooler:** The air passing through the pad was designed to remove the heat load from the evaporative cooler. This was achieved in three major ways:

i. Measurement of heat gained by conductance through the walls, roofs, floor and cooler: The wall, roofs, floor and cooler contribute to the heat load by conduction in the cooler. The heat transfer was calculated by multiplying the area of each component of the cooler such as the roof, floor, and walls by their appropriate conductivity value, reciprocal of insulation thickness. The temperature difference between the external and internal temperature was measured. The total heat load was then calculated using Equation 1:

$$Q = KA \frac{dT}{dt} \quad (1)$$

Where: Q is the heat transfer by conduction, A is the Total area of the various components, d_T = Temperature difference between internal and external temperature and d_i is the insulation thickness.

ii. Measurement of Respiration heat load from the produce: The heat generated from the produce is directly proportional to the mass of the produce and the storage temperature as presented in Equation 2:

$$Q_r = M_p \times P_r \quad (2)$$

Where: Q_r is the respiration heat (V/hr), M_p is the mass of produce (g), P_r is the rate of respiration heat production (W/kg/hr).

iii. Field heat of the produce: this is measured as the heat picked up by the produce on the field and it is directly proportional to the mass of the produce and the storage temperature as shown in Equation 3:

$$Q_f = (M_p \cdot C_p) \alpha \frac{T}{t_c} \quad (3)$$

Where: Q_f is the Field heat picked by produce (W), C_p is the Specific heat capacity of produce (KJ/Kg°C), t_c is the cooling time in seconds, for fruits to equal 12hrs (Rastvoski, 1981), T is the infiltration of air (Heat transfer from cracks and door opening during cooling). (Rastvoski, 1981, FAO/SIDA, 1986) disclosed that the heat is estimated from 10 to 20 % of the total heat load from other sources.

c. **Load test of the Evaporative cooling System:** freshly harvested spinach, okro and mallow were procured from the market, they were cleaned and sorted and loaded in the evaporative cooler. The quality assessment of the was estimated by determining the following:

i. Physiological weight loss: The weight of the produce after every 24 hours was estimated and compared to their initial weight. The change in the weight of the samples both stored in the ambient and the cooler was estimated for a total of nine days after which the percentage weight loss was estimated using the Equation 4:

$$PWL = \frac{O_w - N_w}{O_w} \times 100\% \quad (4)$$

Where: PWL is the Percentage Weight loss (%), O_w is the Original Weight (g) and N_w is the New weight (g)

ii. **Colour Changes:** The change in the colour of the produce was noted both in the cooler and in the ambient temperature. The colour changes were discovered based on the physical appearance of the vegetables.

Results And Discussions

Some basic physical properties of the pad was investigated and presented in Table 1 while the temperature and the relative humidity values are presented in Table 2. The changes in the temperature of the Evaporative Cooler with storage days and differences between ambient and evaporative cooler relative humidity is presented in Figures 1 and 2 respectively.

Table 1: Pad Materials and Jute Pad

Pad Materials	Jute Pad
Density (kg/m ³)	98.41
Water Holding Capacity (g/g)	1.48
Amount of Water Absorbed (kg)	9.21

Table 2: Temperature and Relative Humidity Readings

Days	Ambient Temperature (°c)	Ambient Humidity (%)	Relative (Inside) Humidity (%)	Temperature Inside the Cooling Chamber in Two Hours Interval (°c)	
				Before	After
1	30.3	42	70	22.1	20.5
2	34.2	38	72	24.8	22.4
3	36.1	45	77	26.4	24.1
4	35.6	43	75	26.7	25.2
5	37.4	39	70	24.2	22
6	35.5	41	73	28.4	23.3
7	34.3	38	70	22.8	21.1
8	33.1	42	75	23.6	22
9	32.3	44	74	23	22.8
10	33.2	43	70	24.2	23.1

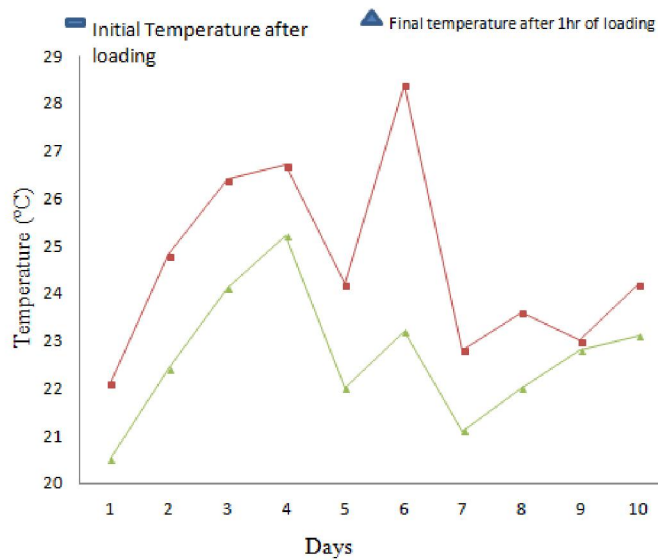


Fig 1: Changes in Temperature of the Evaporative Cooler

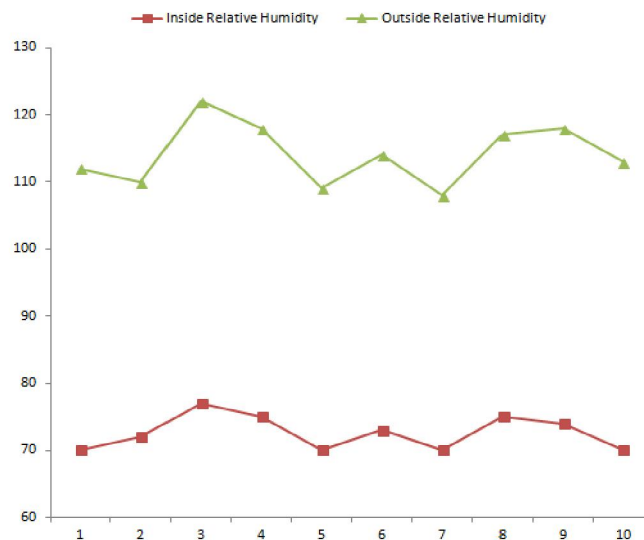


Fig 2: Differences between Ambient and Evaporative Cooler Relative Humidity

Quality Of Stored Products:

The colour changes noticed with the product stored in the ambient was most evident. The colour changed from green colour and some parts turned to light green and later to yellow. The stored products in the ambient started changing its colour on the 3rd day of the experiment run until there was a total change on the 5th day while the stored samples inside the evaporative cooler retained their colour with little significant change within the test period till 10 days for the three stored products. The change in the firmness was much noticed in the okro because of its shape. The okro stored in the cooler still retained its firmness but those stored in the ambient have started to lose their firmness after the 4th day and after the 7th day most of the okro has started to rotting.

Conclusion

The study provided an alternative source of storage for the selected products (spinach, mallow leaf and okro) using an insulated padded evaporative cooler. Cooled dry air was passed into the storage chamber where the vegetables are stored to remove the effects of the heat load of the store thereby providing a favourable condition for the preservation of the vegetables. The percentage weight loss of the vegetables was much in the ambient compared to those stored in the cooler and the colour changes noticed in the vegetables stored in the ambient was greater compared to the ones stored in the cooler. Different types of absorbent material could be used as the cooler pad to enable the fan blow directly to the products.

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