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**Dare Ibiyeye,
Oluwatoyin Olunloyo,
Adeniyi Aderemi,
Tolulope Bamigboye,
Haastrup Nathaniel**

DEVELOPMENT AND PERFORMANCE EVALUATION OF A DOUBLE CHAMBER EVAPORATIVE COOLING SYSTEM FOR STORAGE OF VEGETABLES

The object of research is a double chamber evaporative cooling system for the storage of vegetables with one chamber filled River sand, the other Sawdust as absorbents and Ambient chamber storage conditions being the third treatment (control). Amaranthus was used as the test crop. The structure was developed both internally and externally using six (6) inches concrete blocks and plastered with cemented mortar.

460 g each of Garden fresh vegetables (Amaranthus) were collected and kept chambers of the evaporative cooling system and ambient chamber conditions (control), then, replicated twice respectively. Change in quality (weight reduction, withering, change in colour), temperature change, relative humility and cooling effectiveness were the parameter assessed during the experiment and were subjected to analysis of variance (ANOVA) using Duncan's Multiply Test at 5 % level of significance. The experiment was conducted and analyzed at Crop Production Department of the Federal College of Forestry (Jericho Ibadan, Nigeria). The study revealed there were no significant difference between relative humidity (%), absorbent cooling efficiency (%) for absorbent materials in the evaporative cooling chambers were (89.90 %, 89.30 % and 75.80 %) and (88.50 %, 82.50 % and 80.40 %) for day 10 and 15 River Sand (RS), sawdust (SD) and Control (Cont.) respectively. While, Control had moderately highest temperature reading at day 13 (30 °C), followed by Sawdust (28.90 °C) and River Sand (27.80 °C). However, vegetables kept in the ambient chamber were observed to rot faster than those in the double chamber of the evaporative cooling system. Complete deterioration occurred at day 5 for ambient chamber conditions. The quality of the vegetables kept in double evaporative cooling chamber using river sand performed best in the storage of Amaranthus.

This research hereby recommended that evaporative cooling chambers filled with river sand and constant water supplied to keep the absorbent moist should be utilized for storage of Amaranths and other vegetables in an evaporative cooling system. Further studies should vary the use of different porous absorbent. Also, cooling fans should also be incorporated to the storage system to enhance cooling efficiency.

Keywords: *evaporative cooling system, Amaranthus, performance assessment, river sand, sawdust, ambient conditions.*

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1. Introduction

An increase in atmospheric temperature around fruits and vegetables increases their process of dehydration [1]. High ambient temperature accelerates the process of dehydration in fruits and vegetables, which lead to reduction in its water content, decrease in shelf-life and consequent spoilage in due course of time. To enhance shelf life of fruits and vegetables, conventional methods of air conditioning and refrigeration are costly and require electricity [1].

Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. It occurs when air that is not too humid passes over a wet surface; the faster the rate of evaporation the greater the cooling. Evaporative systems take advantage of the reduction in temperature resulting from the evaporation of mostly water to air [2].

Over the years, several variety of evaporative cooling systems were designed and developed making use of direct or indirect evaporative cooling methods, which have been discovered to be temporary functional for field storage of vegetables in the tropics [2, 3].

Evaporative cooling is an effective and low-cost operation involving lowering temperature and intensifying the relative humidity of an inclusion and in far reaching ways tested in other to increase or improve horticultural produce shelf life [1, 4]; and which are essentially important for continuous freshness of farm produce [5]. Evaporative cooling is eco-friendly which uses the method of air conditioning for its operations by using induced processes of heat and mass transfer in which water and air are working fluids [6]. However, these structures provide economical, power saving, environmentally benign (not be in need of ozone-damaging gas as in an active systems) and practically absorbent cooling system [7].

Direct cooling systems involve evaporation of water into air to cool it, simultaneously humidifying the surrounding. Indirect cooling utilizes air to air heat exchangers to remove heat from primary air stream requiring building up moisture [8].

Amaranthus cruentus L. is a leafy vegetable cultivated regularly in Nigeria and other West African countries. It serves as an alternative primary source of vitamins and proteins of animal origin from which are recognized to be out of reach of most peasants [9]. Amaranth is considered as one of the most commonly produced and consumed indigenous vegetables on African continent [5]. However, vegetable and Fruits farmers are not adequately compensated for their labour over their produce, which resulted from inadequate storage facilities, poor mode of transportation, and perishability nature of the crops which also often results in considerable economic damages [10]. However, vegetables are usually harvested garden fresh, utilized as greens in slaws or boiled, steamed, blanched, fried in oil, and variegated with nourishment, cucurbits, sea food, palm oil or groundnut. Prepared fresh and severed as side dish, with soups or as condiment in sauces and food for baby and others [5, 11].

It is therefore necessary to preserve Amaranths under most favourable conditions to decrease its perishability, increase shelf life and keep its freshness. An evaporative cooling facility has been used to store Amaranthus favourably using various evaporative materials, with diverse outcomes. Chronically demanded of Amaranthus, there is need to develop a cost effective evaporative absorbents material is essential for vegetable storage [12].

Hence, *the object of research* is a double chamber evaporative cooling system for the storage of vegetables with one chamber filled River sand, the other Sawdust as absorbents and Ambient chamber storage conditions being the third treatment (control). *Thy aim of research is* developing and evaluating the performance of a double chamber evaporative cooling system for the storage of vegetables with one chamber filled River sand, the other Sawdust as absorbents and Ambient chamber storage conditions being the third treatment (control). Amaranthus was used as the test crop and contrasting performance of two different evaporative absorbents (river sand and sawdust) used to store freshly harvested Amaranthus.

2. Materials and Methods

The experiment was conducted at the Teaching and Research farm (crop section) Federal College of Forestry (latitude 07^0 23^1 N longitude 03^0 51^1 E), Ibadan, Oyo state Nigeria. Annual rainfall is 1250 mm having a dual mode seasons, wet season about 8 months, between April and November, and a brief dry spell which starting mostly in second half of August. The minimum and maximum mean daily temperatures is 21.9 °C and of 35.5 °C respectively [13].

2.1. Evaporative cooling facility design. Design considerations of the double chamber evaporative system include the following: Temperature changes, Relative humility, Change in quality and cooling effectiveness of the system.

2.1.1. Material selection. Considering that the designed cooling facility is to assist peasant farmers to lower the cost of erecting storage facilities. Materials used were obtained locally with the mind of most economical available. They were therefore hand-picked on basis of availability, cost, and durability amongst others.

2.1.2. Dimensions. The double chamber of the evaporative storage system is $740\times240\times400$ mm^3 each, having a total volume of 1.72 m^3 collectivity.

2.1.3. Development of evaporative cooling system. Floor and foundation of cooling system was constructed over one layer of boulders arranged closely together in a rectangular layout, then covered with sand (Fig. 1). The internal and external walls of the cooling facility were constructed using fifty (50) six inch (6″) hollow cement blocks. The space in the middle of inner outer walls measures 120 mm. The inner part of the structure was divided into four (4) minor chambers $740\times240\times400$ mm^3 two each to form single double chamber and a three quarter (3/4) inch pipes were used to build water outlet at the bottom part of the structure. The cavities were filled with river sand in one chamber and sawdust in the other. Palm tree branches and bamboo sticks were employed to construct a shack over the facility so as to increase efficient chilling of the system. Thermometer was set down in each chamber to observe the temperature changes. Wooden plank was fitted to the chamber to serve as doors (inlet) as well as cover. These wooden doors were perforated and fitted with mosquito nets prevent entrance on insects and other contaminant and also allow free movement of air off and on of chambers. Load test was not implemented on the structure before packing chambers with test crop (Amaranthus). Freshly harvested samples Amaranthus were stored in the cooling chamber and the while the camber cavity containing river sand was watered continuously with flow of water.

Fig. 1. Evaporative cooling chamber with water reservoir

2.1.4. System cooling chamber assessment. The system was evaluated using Amaranthus as a test produce (Fig. 2).

The following parameters were evaluated: Relative humidity, weight and physical observation (wilting and colour change) and temperature changes.

1. *Weights:* changes in weights were recorded within two days interval to ascertain the amount of loss weights using

Camry High Precision Electronic Scale (ISO 9001:2008 Certified by SGS).

2. *Physiological weight loss:* Variations in weights of samples kept in cooling system chambers and ambient chamber conditions were observed daily and recorded using a sensitive scale.

Fig. 2. Amaranthus before storage

The experiment spanned over 10 days test period; after which percentage weight loss were calculated as shown below:

$$\% \ W = \frac{W_i - W_n}{W_i}, \quad (1)$$

where $\% \ W$ – percentage weight; W_i – original weight; W_n – new weight.

3. *Relative Humidity (RH):* Atmospheric Relative Humidity was resolved using the psychometric chart.

4. *Temperature:* Temperature readings were taken 5 times daily using wet and dry bulb thermometer (7 and 10) am and (1, 4, and 7) pm to monitor and ascertain temperature changes of the systems' cooling chambers.

5. *Cooling efficiency (load test):* showed the level at which dry bulb temperature of cooled air measures up to wet bulb temperature of the ambient air and was determined as followed:

$$\tau = \frac{T_a - T_1}{T_a - T_{wb}} \cdot 100 \ \%, \quad (2)$$

where T_a – ambient air dry bulb temperature; T_1 – cooled air dry bulb temperature; T_{wb} – ambient air wet bulb temperature.

2.1.5. Cooling system performance assessment. Performance assessment of the system was assessed using Amaranthus as a test produce.

The following parameters were assessed: Weight and physical observation (wilting and colour change), temperature and relative humidity [2].

Temperature readings were taken 3 hourly 5 times daily, (7 and 10) am and (1, 4, 7) pm to observe and ascertain the temperature changes in the cooling chambers using a thermometer.

Records of the changes in Relative humidity were also observed every 3 hours daily (7 and 10) am and (1, 4 and 7) pm to monitor and determine the humidity of the chambers utilizing hygrometer.

Cooling efficiency (for load test) indicate the length by which dry bulb temperature of cooled air measures up to wet bulb temperature of ambient chamber air.

Key:

- River Sand (RS) – T_1;
- Sawdust (SD) – T_2;
- Control (Cont.) – T_3.

2.2. Colour change assessment of test produce. Both Amaranthus kept under ambient chamber conditions and ones kept in the double chamber evaporative cooling system were evaluated for colour change visually.

2.2.1. Wilting. Amaranthus kept in chambers of the double evaporative system and in ambient chamber were noted and classified under wilting points making use of an adaptation of the Likert Scale where:

1 – Fresh (No wilting);
2 – Slight wilting;
3 – Moderate wilting;
4 – Severe wilting;
5 – Extreme wilting (Limp).

2.2.2. Statistical analysis. Data collected were put through Analysis Of Variance (ANOVA), level of significance; means were separated using Least Significant Difference (LSD) at 5 percent level of significance ($F_{pr.} \leq 5$). Treatments were replicated twice.

3. Results and Discussion

The experiment was conducted over a period of period of 15 days, and data were collected were noted. Table 1 revealed that observation for effect of absorbent materials (Sawdust and River Sand) on mean daily temperature were not significantly different in the treatments in all the days under observation, except for day 13 which recorded highest temperature (30 °C) for control (Cont.), followed by Sawdust SD 28.90 °C and River Sand RS 27.80 °C. This signifies that increase in temperature increases the rate of deterioration in produce. This is in accordance with [11] who suggested increase in temperature in or around fruits decrease their respiration rate.

Table 2 shows that there was no significant difference among the treatments in all the days except in day 5 for effect of the absorbent materials on the mean of daily cooling efficiency (%). However, at day 15 the highest mean was recorded in RS with the mean value of 88.50 % followed by SD with the mean value of 82.50 %. Cont. showed the lowest mean value of 80.40 %. RS has constantly the highest cooling efficiency except for Days 1, 2 and 6.

Table 3 revealed at day 10, river sand RS (89.90 %) recorded highest Relative Humidity of the mean of daily humidity (%), followed by sawdust SD (89.30 %) and Control. Cont. had (75.80 %) for the absorbents in the system chambers, while, ambient chamber air conditions fluctuated between (46 and 90) %. It should be noted that highest relative humidity readings were recorded between of 7 pm and 7 am daily, while, the lowest relative humidity was recorded during the afternoons. The relative humidity recordings in one of the chambers of the evaporative cooling system filled with (River Sand) varied between (48 and 87) %, although, the chamber filled with (Sawdust) reached between (48 and 90) % relative humility, which however line up in a similar pattern as the relative humidity under ambient chamber conditions.

Table 4 showed a significant difference in all the days of observations in the experiment for effect absorbents on the means daily weight loss of the Amaranths. It was observed the Amaranths lost weights during the experiment regardless of the chamber they were kept in. It was observed that RS had the highest mean weights in percentage (178.00 %) followed by SD with the mean weight (121.00 %) and Cont. the least in performance with the mean weight value (71.50 %). This corresponds with the work of [9] who postulated that fruits and vegetables generally lose weight during storage.

Table 1

Effect of Mean Daily Temperature on Absorbents, °C

Trt. Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RS	18.20^{a}	28.20^{a}	34.30^{a}	27.10^{a}	28.30^{a}	28.10^{a}	27.60^{a}	27.80^{a}	27.70^{a}	28.00^{a}	28.30^{a}	28.20^{a}	27.90^{a}	28.20^{a}	26.90^{a}
SD	17.30^{a}	27.60^{a}	27.90^{a}	37.90^{a}	28.10^{a}	28.00^{a}	27.50^{a}	27.90^{a}	27.50^{a}	33.90^{a}	28.10^{a}	28.20^{a}	27.80^{ab}	27.60^{a}	27.40^{a}
Cont.	17.20^{a}	28.90^{a}	29.70^{a}	29.40^{a}	28.50^{a}	28.20^{a}	28.10^{a}	29.00^{a}	28.80^{a}	29.10^{a}	28.90^{a}	27.00^{a}	30.00^{a}	28.10^{a}	28.90^{a}

Notes: means with the same alphabets are not significantly different at 5 % level of significance; Trt. – Temperature; SD – Sawdust; RS – River Sand; Cont. – Control

Table 2

Effect of Mean of Daily Cooling efficiency of Absorbents, %

Trt. Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RS	36.79^{a}	60.60^{a}	77.85^{a}	79.91^{a}	88.66^{b}	81.16^{a}	79.01^{a}	83.08^{a}	79.64^{a}	80.72^{a}	85.40^{a}	88.20^{a}	79.60^{a}	87.40^{a}	88.50^{a}
SD	40.00^{a}	66.66^{a}	73.75^{a}	42.50^{a}	30.64^{a}	85.64^{a}	65.80^{a}	80.81^{a}	65.27^{a}	77.91^{a}	83.60^{a}	85.70^{a}	71.20^{a}	78.00^{a}	82.50^{a}
Cont.	51.75^{a}	44.16^{a}	71.85^{a}	72.50^{a}	61.77^{ab}	73.66^{a}	46.03^{a}	82.07^{a}	71.53^{a}	74.58^{a}	76.20^{a}	67.76^{a}	75.90^{a}	65.40^{a}	80.40^{a}

Notes: means with the same alphabets are not significantly different at 5 % level of significance; Trt. – Temperature; SD – Sawdust; RS – River Sand; Cont. – Control

Table 3

Effect of Mean of Daily Humidity on Absorbents, %

Trt. Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RS	48.50^{a}	81.20^{a}	79.80^{ab}	86.70^{a}	84.60^{b}	84.50^{b}	82.80^{a}	85.90^{b}	85.10^{b}	89.90^{b}	87.00^{ab}	81.20^{a}	76.00^{ab}	81.20^{a}	81.20^{ab}
SD	48.20^{a}	86.90^{b}	84.40^{ab}	83.10^{a}	82.10^{b}	86.10^{b}	81.00^{a}	85.20^{b}	86.80^{b}	89.30^{b}	82.80^{ab}	86.90^{b}	86.90^{b}	81.50^{a}	85.00^{ab}
Cont.	46.50^{a}	85.20^{a}	73.60^{ab}	86.00^{a}	84.50^{b}	83.60^{b}	78.70^{a}	77.60^{b}	79.90^{b}	75.80^{a}	85.20^{ab}	87.50^{b}	86.50^{a}	76.70^{a}	86.90^{ab}

Notes: means with the same alphabets are not significantly different at 5 % level of significance; Trt. – Temperature; SD – Sawdust; RS – River Sand; Cont. – Control

Table 4

Effect absorbents on mean daily weight, %

Trt. Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RS	460.00^{a}	460.00^{a}	460.00^{b}	453.50^{b}	413.30^{b}	403.70^{b}	381.80^{b}	331.40^{b}	315.00^{a}	299.10^{a}	283.10^{b}	244.50^{a}	210.00^{a}	198.40^{a}	178.00^{a}
SD	460.00^{a}	460.00^{c}	458.90^{c}	451.50^{c}	401.40^{b}	399.10^{c}	372.50^{c}	322.30^{b}	305.60^{a}	296.20^{a}	231.80^{a}	201.30^{a}	172.90^{a}	145.50^{b}	121.80^{b}
Cont.	460.00^{a}	421.90^{a}	373.50^{a}	310.40^{a}	300.20^{a}	278.70^{a}	245.60^{a}	215.50^{a}	200.00^{a}	193.60^{a}	161.80^{a}	121.60^{a}	105.70^{a}	89.00^{a}	71.50^{a}

Notes: means with the same alphabets are not significantly different at 5 % level of significance; Trt. – Temperature; SD – Sawdust; RS – River Sand; Cont. – Control

3.1. Wilting. Table 5 showed that evaporative absorbent (River Sand) chamber performed best as an absorbent employed compared with absorbent (Sawdust) chamber and ambient chamber conditions. The Amaranths wilted slower in the double chamber cooling system than under ambient chamber conditions and temperature.

Table 5

Amaranth Wilting in Chambers

Days	Room temperature	Evaporative cooling chamber (River sand)	Evaporative cooling chamber (Sawdust)
1	1	1	1
2	1	1	1
3	1	1	1
4	2	1	1
5	2	1	1
6	2	1	1
7	2	1	1
8	3	1	2
9	3	2	2
10	3	2	3
11	4	2	3
12	4	3	4
13	5	3	4
14	5	4	5
15	5	4	5

Notes: 1 – No wilting; 2 – Slight wilting; 3 – Moderately wilting; 4 – Severe wilting; 5 – Extreme wilting

3.2. Rate of absorption of absorbents. Table 6 revealed that River Sand absorbed water faster than Sawdust as an absorbent in an evaporative cooling system; this indicates that river is a better evaporative absorbent compared with sawdust.

Table 6

Absorption Rate of River sand and Sawdust as Evaporative Absolvents

Sample	Weight, g	Absorption rate, lt/hr
River sand	410	16.67
Sawdust	410	15

3.3. Recommendations. It is recommended based on this experiment that permeable media should be developed and utilized as storage Amaranths and other vegetables in an evaporative cooling system. Further studies should vary the use of different porous absorbents with respect to availability, porosity, durability, and cost.

Fig. 3. Ambient storage of Amranthus at day 9

Fig. 4. Amaranthus stored in evaporative cooling chamber (River sand) day 10

Fig. 5. Amaranthus stored at evaporative cooling chamber (Sawdust) day 11

3.4. Discussion. The study revealed that Amaranthus kept in the cooling chambers held onto its colour up till day 9 (Fig. 3).

Colour changes were observed from day 10 with the initial dark green colour changing to lighter shade of green, subsequently yellowish (Fig. 4).

However, rotting of the Amaranths began in day 11 in the cooling chambers as it was observed from the experiment the leaves of Amaranthus appearing moist and brownish spotted with colours black (Fig. 5).

However, changes in colour of Amaranthus kept in ambient chamber was evident on day 5 of storage period with Amaranthus initially appearing green in colour, then began to change yellowish then to it turned dark brown.

Based on the results from the experiment, the development of the research will include further studies vary the use of different absorbent (natural) materials such as wool and cotton, and the felts made from them, straw and peanut peel with respect to availability, cost, and durability among others. Comparison can also be made between vegetables storage under bagged and un-bagged conditions placed in the developed double chamber evaporative cooling system for storage of vegetables.

4. Conclusions

From the research done, it is possible to conclude that it was inferred that evaporative cooling system chambers filled with river sand as an absorbent with water constantly running through the absorbent performed best in the storage of Amaranths, since the shelf life of the Amaranths were lengthened compared to the Amaranths stored under ambient chamber conditions together with sawdust utilizes as evaporative absorbents in the evaporative cooling system. This study showed that the storage of perishable Amaranth (leafy vegetables) in evaporative cooling chamber decreased the rate of wilting, yellowing and eventual drying up of vegetables. Vegetable kept in the evaporative cooling chamber (River sand) as the absolvent appear to still be sellable for up to day 6, whilst, Amaranths in the other evaporative cooling chamber (sawdust) lasted day 5 before any changes occurred as compared to those kept under the ambient chamber condition which already began to wilt at day 3.

Conflict of interest

The author declares that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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✉***Dare Ibiyeye,*** *Lecturer, Department of Crop Production Technology, Federal College of Forestry, Jericho Ibadan, Nigeria, ORCID: https://orcid.org/0000-0003-3418-1308, e-mail: mcdare005@gmail.com*

Oluwatoyin Olunloyo, *Lecturer, Department of Crop Production Technology, Federal College of Forestry, Jericho Ibadan, Nigeria, ORCID: https://orcid.org/0000-0003-4518-6104*

Adeniyi Aderemi, *Lecturer, Department of Agricultural Technology, Federal College of Forestry, Jericho Ibadan, Nigeria, ORCID: https://orcid.org/0000-0001-9615-866X*

Tolulope Bamigboye, *Lecturer, Department of Crop Production Technology, Federal College of Forestry, Jericho Ibadan, Nigeria, ORCID: https://orcid.org/0000-0003-4851-5356*

Haastrup Nathaniel, *Senior Research Fellow, Department of Forest Conservation and Protection, Forestry Research Institute of Nigeria, Jericho Ibadan, Nigeria, ORCID: https://orcid.org/0000-0002-3835-7078*

✉*Correspondent author*