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DEVELOPMENT OF WIND OPERATED PASSIVE EVAPORATIVE COOLING STRUCTURES FOR STORAGE OF TOMATOES

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Abstract
A Wind operated passive evaporative cooler was developed. Two cooling chambers were made with clay container (cylindrical and square shapes). These two containers were separately inserted inside bigger clay pot inter- spaced with clay soil of 7 cm (to form pot-in-pot and wall-in wall) with the outside structure wrapped with jute sack. The soil and the jute sacks were wetted with salt solution. Five blades were constructed inside the cooling chambers with aluminium material which were connected with a shaft to a vane located on a wooden cover outside the cooling chamber. The vanes (made of aluminium) were to be powered by the wind which in turn rotates the blades inside the cooling chamber. The total volume of 40500cm^3 and storage capacity of 31500cm^3 were recorded for the square structures while total volume of 31792.5cm^3 and storage capacity of 24727.5cm^3 were recorded for the cylindrical structures. During the test period, the average temperatures of 27.07^{o}C, 27.09^{o}C and 33.6^{o}C were obtained for the pot-in-pot (cylindrical), wall-in-wall (square) and the ambient respectively. The average relative humidity of 92.27%, 91.99% and 69.41% were obtained for the pot-in-pot (cylindrical), wall-in-wall (square) and the ambient respectively. The average minimum and maximum wind speed recorded for the month of October was 2.5m/s and 2.6m/s respectively

Keywords: Wind, evaporative, passive, fruits, tomatoes, cylindrical, square, aluminium

1. Introduction

Fruits in their natural and fresh form are highly perishable. Once ripe, either before or after harvest, tends to deteriorate. In order to extend their shelf life, they need to be properly stored. Proper storage means controlling both the temperature and relative humidity of the storage environment (Susan and Durward, 1995). Owing to lack of information on appropriate post harvest storage techniques, it is estimated that about 20-30% of total fruits are lost after harvesting (Kader, 1987). About 23% of most perishable fruits and vegetables are lost during their journey through the agricultural food chain due to spoilage, physiological decay, water loss, and mechanical damage (FAO, 2011 ; Stuart, 2009).. These losses have been estimated at about 40 to 50% in the tropics (FAO, 1995).

Renewable energy flows involve natural phenomena such as sunlight, wind, tides and geothermal heat, which are renewable (naturally replenished) (IEA, 2002). As wind turbines and wind vanes depend on power from wind to function effectively, wind energy can as well be used to drive fans in evaporative cooling structures so that the conditioned air and space air can be evenly distributed in the storage chamber. The wind energy can be used to remedy the fluctuations or near-absence of electricity supply in this part of the country (Medugu and Malgwi, 2005).

However, because refrigerator is rather complex, energy intensive and expensive to purchase and maintain, its application for fresh perishable crops storage is thus not feasible under the prevailing socio-economic status of the rural remote areas. This therefore necessitates the need to develop an alternative, inexpensive, an easy to operate and maintain cooling system that does not need electricity for preserving the various types of fruits and vegetables produced by several small scale farmers. Consequently, in developing countries, there is an interest in simple low cost alternatives, many of which depends on evaporative cooling which is simple and does not require any external supply (FAO, 1994)

Evaporative cooler works on the principle of cooling resulting from evaporation of water from the surface (FAO, 1995). 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 the ambient air. The atmosphere in the chamber therefore becomes more conducive for fruits and vegetables storage (NSPRI, 1990).

The aim of this study was to improve fruits and vegetable storability by developing a wind operated passive evaporative cooling structures for the storage of fruits.

2. Materials and Methods

2.1 Design Calculations

2.1.1 Capacity of the Square Cooling Chamber

Each cooling chamber had a length of 45 cm, breadth of 30 cm and height of 45 cm so the volume of each cooling chamber was calculated from the relation:

$$volume = length\ x\ breadth\ x\ height \quad (1)$$

The length of the shaft from the top of the cooling chamber to where the blades were attached was 10 cm, meaning the chamber can be filled with fruit up to this length from the bottom of the cooling chamber.

Actual capacity for fruit storage was 31500 cm^3

Assuming a tomato radius of 3 cm, volume of one tomato fruit is calculated from the relation:

$$volume\ of\ fruit = \frac{4\pi r^3}{3} = 113.04 cm^3 \quad (2)$$

The square box design should be able to hold approximately; 31500/ 113.04 number of tomatoes totaling up to 279 fruits.

2.1.2 Capacity of the Cylindrical Cooling Chamber

Each cylindrical cooling chamber has a diameter of 30 cm and length of 45 cm so the volume of each cooling chamber is calculated from the relation;

$$V = \pi r^2 \text{h} \quad (3)$$

where: r and h is the radius and height of the cooling chamber respectively

Volume = 31792.5cm^3

The length of the shaft from the top of the cooling chamber to where the blades were attached was 10cm, meaning the chamber was filled with fruit up to this length from the bottom of the cooling chamber.

Actual capacity for fruit storage = 24727.5 cm^3

From equation 2 above, volume of tomato was calculated as 113.04 cm^3. Therefore cylindrical design should be able to hold approximately 24727.5/ 113.04 number of tomatoes totaling up to 218 fruits.

2.1.3 Design for Fan Blade Velocity

The longitude, latitude and altitude of Gidan Kwano (Minna, Niger State, Nigeria) is 6.26^{o}E, 879', 9.02^{o}N, 056' and 256.4m respectively. Using high a sensitivity global positioning system, the minimum and maximum wind speeds of 2.5m/s and 2.6m/s respectively were recorded in the month of October (since the wind speed is highest in the month of October to drive the vanes) when the experiment was carried out. However, an average speed of 2.55m/s was adopted for this design. The vanes on top of the cooling chambers will rotate with the speed of the wind. The higher the wind speed, the more the vanes rotate. Hence, the blades in the cooling chamber will rotate and circulate air radially and evenly on the stored tomatoes. Taking the radius to be 1.5m, the blade rotation was found to be 12 rpm and the angular velocity was 1.699 rad/s. With this conversion, the rotation of the vanes (rad/s) was compared with the wind velocity (also in radians/seconds). The tip speed is the speed of the wind because it gives an idea of how much power is generated by the wind. The fan was made of five blades and it was made to rotate with the speed of the wind to move the air radially. The blades were attached by means of a screw to the long shaft (about 10 cm) that connects to the vanes as shown in Figures 1 and 2.

2.1.4 Amount of Air Moved in One Revolution

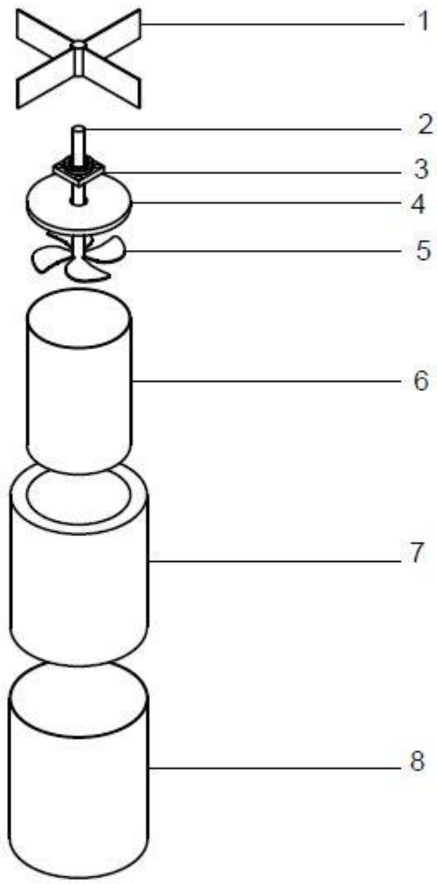
The air flow rate was calculated using the expression given by Tony (2001) and Maxwell *et al.* (2012 as

$$\boldsymbol{Q} = \left(\frac{\boldsymbol{\pi D^2}}{\boldsymbol{4}}\right) \boldsymbol{L} \left(\frac{m^3}{s}\right) \quad (5)$$

where: Q is volumetric flow rate (m^3/s), D is diameter (m), L is length (m).
Q was obtained as 104.49 cm^3/s.

2.1.5 Distance Travelled in One Second

Let the average number of revolutions per minute of the fan be rpm. Dividing this by 60 yielded the fan's revolution per seconds (rps). Multiplying the rps by the circumference (π r) gave the meters travelled in one second by the blade.
N was obtained as 54 rps, where N is the distance travelled per second (m/s).



LEGEND	
KEY	DESCRIPTION
1	Wind Vane
2	Shaft
3	Bearing
4	Cover
5	Fan
6	Inner Chamber
7	Clay soil lagging
8	Outer Chamber

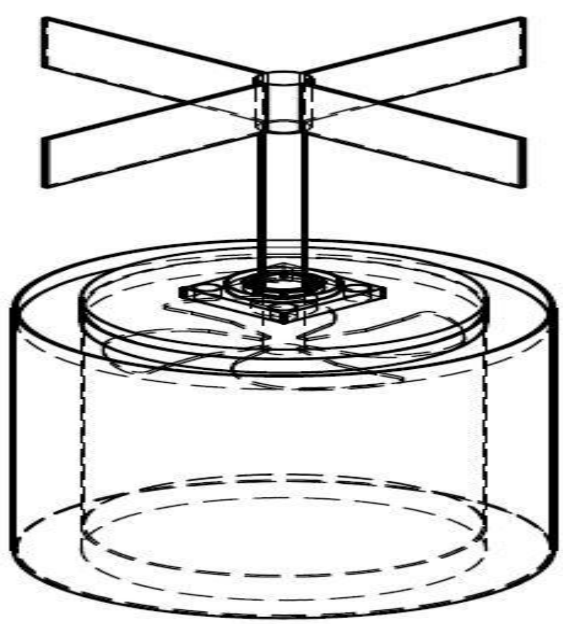
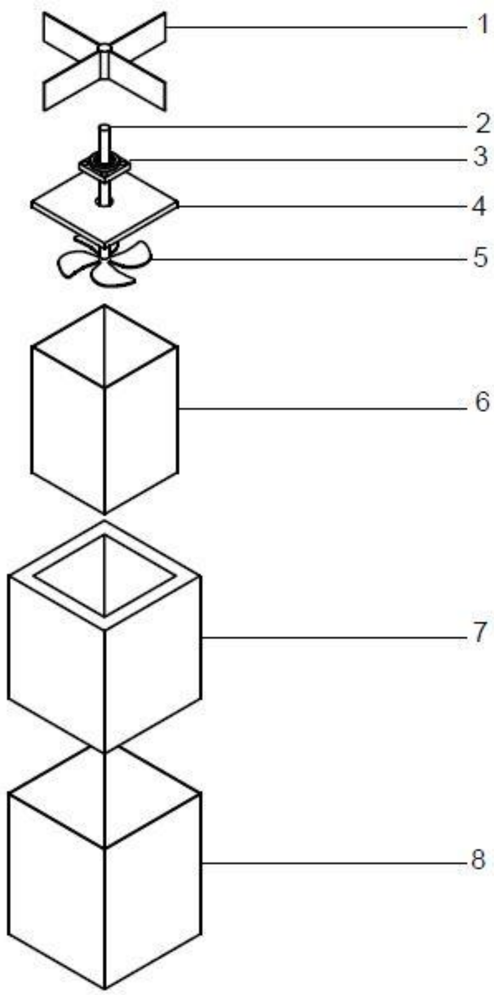


Figure 1: Exploded and Isometric Views of Cylindrical Wind Operated Evaporative Cooling Structure



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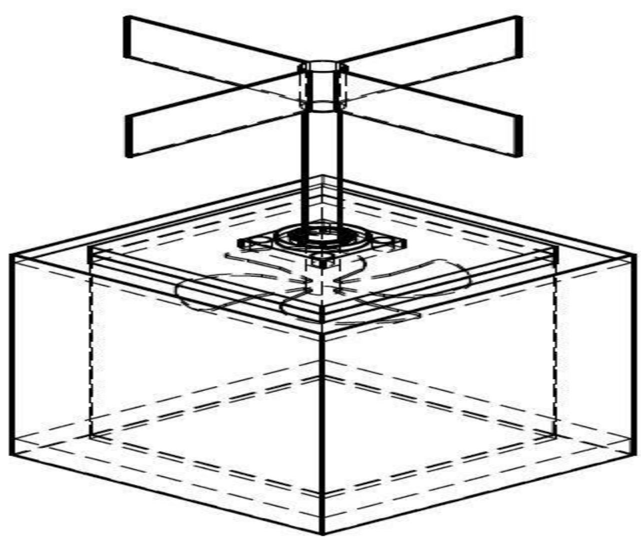


Figure 2: Exploded and Isometric View of Square Wind Operated Evaporative Cooling Structure

2.1.6 Power in the Wind

For known swept area of the blades and the wind speed, the theoretical power available in the wind was calculated from the relation given by Tony (2001) and Maxwell *et al.* (2012) as:

$$P = \frac{1\rho A v^2}{2} \qquad (6)$$

Where: P is the wind power, (Watt), ρ is the air or wind density= 1.293kg/m^3, A is swept area of the impeller fan obtained as 7.065m^2, V is the wind speed, (m/s).

P was obtained as 29.7W. The power in the wind using maximum and minimum wind speed of 2.5m/s and 2.6m/s were 28.55 W and 30.88 W respectively.

2.1.7 Fan Pressure

Fan pressure was calculated from the relation due to Tony (2001) and Maxwell *et al*. (2012):

$$\mathrm{pw} = \mathrm{PQ\ X\ number\ of\ blades} \qquad (7)$$

where: $pw\ is\ the\ wind\ power\ (watts),$ P is the fan pressure $\mathrm{N/m^2}$, Q is the discharge (m^3/s). When Fan pressure was 0.05685N/m^2, 0.05465N/$m^2$and 0.05911N/m^2, the wind power was 29.70Watts, 28.55 Watts and 30.88 Watts respectively.

2.2 Description of the Passive Evaporative Cooler and Its Principle of Operation

Two cooling chambers were made with clay container (round and rectangular shapes). These two containers were separately inserted inside a bigger clay pot inter- spaced with clay soil of 7 cm(to form pot-in-pot and wall-in wall) as shown in Figures1 and 2 with the outside structure wrapped with jute sack. The soil and the jute sacks were constantly wetted with salt solution (NaCl) at interval of between 2 to 4 hours depending on the rate of evaporation to keep the soil in moist condition. The salt solution was used to reduce the growth of microorganisms present in the soil. Fan with five blades were constructed inside the cooling chambers with aluminium material which were connected with a shaft to a vane located on a wooden cover outside the cooling chamber. The vanes (made of aluminium) were powered by the wind.

2.3 Collection of Fresh Fruits

The experiment was carried out at Federal University of Technology Gidankwano Campus in Minna, Niger state, Nigeria and the matured green samples of tomatoes (globe varieties) were sourced from Garatu Market. About 280 and 220 pieces of tomatoes were used for the square and cylindrical structure respectively as calculated above. The mature green samples of tomatoes were stored inside the two types of passive evaporative cooling structures for a period of 16 days.

2.4 Testing the Performance of the Evaporative Cooling System

2.4.1 Determination of temperature and relative humidity

The temperature and relative humidity of stored tomatoes in the two structures were taken daily using a digital thermometer and a relative humidity measuring instrument at 8.00am, 12 noon and 6.00pm and their average taken and compared with the average ambient temperature. The wind operated passive evaporative cooling structures were tested with mature green tomato fruits for a period of sixteen days.

3. Results and Discussion

The storage chambers for the two structures recorded lower temperature when compared with the ambient. The temperature and relative humidity in the storage structures as well as the ambient is as presented in Figures 3 and 4 below. The temperatures in the evaporative coolers were lower than that obtained for the ambient for stored tomatoes while the relative humidity was observed to be higher. This may be attributed to the cooling effect of the evaporative cooler. The results showed a temperature reduction of between 5^{o}C - 6^{o}C against the ambient and an increase in relative humidity of between 15-17% against the ambient for both structures for stored tomatoes. This is in line with the temperature reduction of up to 10^{o}C and increase in relative humidity of the air from 40% of the ambient to 92% of the storage chamber reported by Dzivama *et al*. (2006). Reduction in temperature in the structures was enhanced by wetting the jute sacks and evaporation of water from soil around the structures. This agreed with the findings of Thompson (1988). Also reduction in the temperature may be as a result of the shade provided for the evaporative cooling structures as well as the wooden covers (Roy and Khudiya, 1986). This is also in line with the temperature reduction of between 8^{o}C to 12.5^{o}C reported by Babarinsa (2006). Also, higher values of relative humidity of above 90% were noticed in the structures as a result of higher volumes of water applied at interval on the surface of the soil. The higher value may also be attributed to the higher saturation efficiency of the jute sack (Dzivama *et al*., 2006). The higher relative humidity is in line with the 82% to 100% result obtained by Babarinsa (2006).

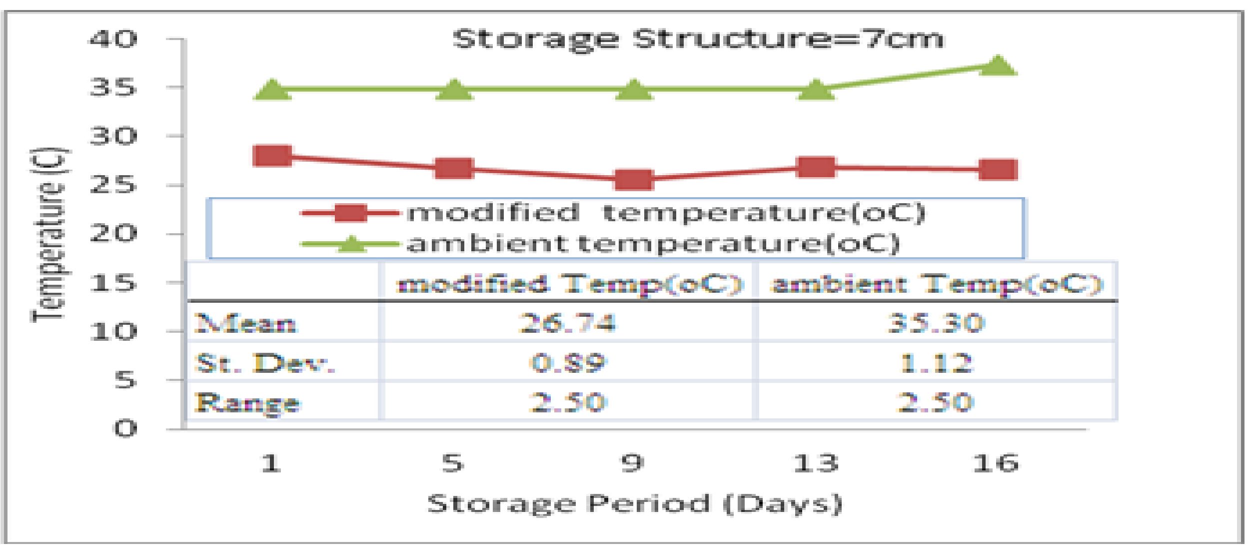
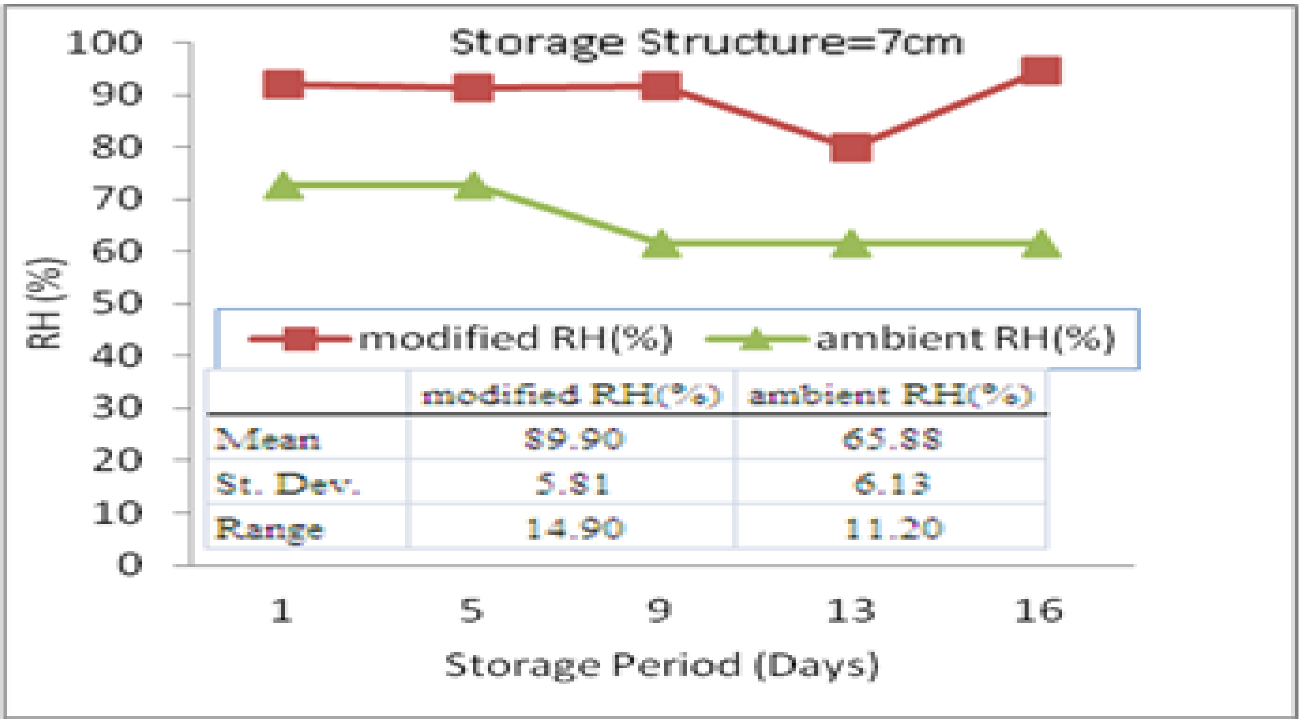


Figure 3: Variation in Temperature inside the Cooling Structures for Stored Tomatoes (Cylindrical Structure)



	modified RH(%)	ambient RH(%)
Mean	89.90	65.88
St. Dev.	5.81	6.13
Range	14.90	11.20

Figure 4: Variation in Relative Humidity inside the Cooling Structures for Stored Tomatoes (Square Structure)

4. Conclusion

This research focused on the development of wind operated passive evaporative cooling structures for the storage of fruits. The following conclusions were drawn from the research:

1. The average temperature recorded in the cooling chambers was lower than that of the ambient when used to store fresh tomatoes.
2. Also higher relative humidity was recorded in the structure compared with the ambient. The higher value of relative humidity recorded is an indication of the effectiveness of the evaporative cooling structures. This tends to lower the temperature in the cooling structures and thus extends the shelf life of the stored vegetables.
3. The use of square structures is also recommended if higher numbers of produce (vegetables) is to be stored since it has a higher storage capacity compared with the cylindrical structures.

References

Babarinsa, FA. 2006. Performance evaluation of an evaporative cooling structures for fruits and vegetables in the tropics. Agricultural Mechanization in Asia, Africa and Latin America (AMA), 37(4): 60-65.

Dzivama, AU., Igbeka, JC. And Audu, I. 2006. Performance efficiency of an active evaporative cooling system for the storage of fruits and vegetables in semi arid environment. Agricultural Mechanization in Asia, Africa and Latin America (AMA): 37 (4): 36-41.

FAO. 1994. Fats and oils in human nutrition; Report of a joint FAO/WHO expert Consultation. FAO Food and Nutrition Paper 57, FAO. Rome.

FAO. 1995. Small scale postharvest handling practices- A manual for horticultural crops, 3rd edition. Food and Agricultural Organization of the United Nations, Rome.

FAO. 2011. Global food losses and waste: Extent, Causes and Prevention. Food and Agricultural Organization of the United nations, Rome, pp. 37.

IEA. 2002. IEA renewable energy working party. Renewable Energy into the mainstream. pp. 9. Published by World energy Outlook. www.worldenergyoutlook.org/media/weowebsite/2008-*1994/weo2002*

Kader, AA. 1987. Postharvest biology and technology research on deciduous tree fruits. Recent trends and future outlook. In: Proceedings of the Summerland Research Station, Commemorative Symposium (April 27-28, 1987). Agriculture Canada, Summerland, B.C. Canada. pp. 96-105.

Manwell, JF., McGowan, JG. and Rogers, AL. 2012. Wind Energy Explained: Theory, Design and Application. Chichester, West Sussex, UK: John Wiley & Sons Ltd. pp. 92–96. ISBN 9780470015001.

Medugu, DW. and Malgwi, DI. 2005. A study of wind energy potentials: Remedy for fluctuations of electric power in Mubi, Adamawa State, Nigeria. Nigerian Journal of Physics, 17: 40-45.

NSPRI. 1990. Storing your Products Advisory Booklet, No 4. Nigeria Stored products and Research Institute, Ilorin, Nigeria.

Roy, SK. and Khurdiya, D. 1986. Studies on evaporative cooled zero energy input cool chambers for the storage of horticultural produce. India Food Packer, 40 (6): 26-31.

Stuart, T. 2009. Waste uncovering the global food scandal. Penguin Books: London, ISBN: 978-0-141-03634-2.

Susan, DS. and Durward S. 1995. G95-1264 Storing fresh fruits and vegetables. Historical materials from University of Nebraska, Lincoln Extension. Retrieved online from http://digitalcommons.unl.edu/extensionhist/1042/ retrieved on 1/1/1995.

Thompson, AK. 1998. Controlled atmosphere storage of fruits and vegetables. CAB International Publisher, London. pp. 11-12.

Tony, B. 2001. Wind Energy Handbook. John Wiley and Sons ISBN 04714 89972 pp. 65.