Evaporative Cooling: A Postharvest Technology for Fruits and Vegetables Preservation

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ABSTRACT

The quality and storage life of fruits and vegetables may be seriously compromised within a few hours of harvest unless the crop has been cooled promptly to control deterioration. The major problem during storage is the change in the quality parameters of the produce especially the physical characteristics such as; the color, texture, and freshness in which the price sometimes depend on. In order to extend the shelf life, fruits and vegetables need to be properly stored. Proper storage means controlling both the temperature and relative humidity of the storage area. Although, refrigeration is very popular but it has been observed that several fruits and vegetables, for example banana, plantain, tomato etc. cannot be stored in the domestic refrigerator for a long period as they are susceptible to chilling injury. Apart from this, the epileptic power supply and low income of farmers in the rural communities' makes refrigeration expensive. 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 cooling structure depends on the humidity of the surrounding air. Therefore, this paper reviews the theory, advances, principles, methods of evaporative cooling, and also the optimum storage temperature, relative humidity and shelf life of fruits and vegetables. An Evaporative cooler reduces the storage temperature and also increases the relative humidity within the optimum level of the storage thereby keeping the fruits and vegetables fresh. It can be use for short term preservation after harvested. Thus, an evaporative cooling is a low cost technology for storage of fruits and vegetables. The Technology of evaporative cooling is cost effective and could be used to prolong the shelf-life of agricultural produce.

Keywords: *Evaporative cooling, storage life, deterioration, shelf life.*

I. Introduction

In Nigeria and other countries of the world vegetables and fruits are important food items that are widely consumed because they form an essential part of a balanced diet. Fruits and vegetables are important sources of minerals and vitamins especially vitamin A and C. They also provide carbohydrates and protein, which are needed for normal healthy growth (Abdul, 1989; Salunkhe and Kadam, 1995; Adetuyi et al 2008; Olusunde et al, 2009).

However, the quality and storage life of fruits and vegetables may be seriously compromised within a few hours of harvest unless the crop has been cooled promptly to control the deterioration. The major problem during storage is what happens to the quality parameters of these produce especially the physical characteristics such as; the color, texture, and freshness in which the price sometimes depends on (Jeffries & Jeger, 1990). In order to extend their shelf life, fruits need to be properly stored. Proper storage means controlling both the temperature and relative humidity of the storage area (Susan & Durward, 1995).

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 cooling structure is made of a porous material that is fed with water. Hot dry air is drawn over the material. The water evaporates into the air raising its humidity and at the same time reducing the temperature of the air (FAO, 1995).

Aeration, temperature and relative humidity management, microorganisms control, sanitation and preventing moisture loss greatly improves the storability of produce by maintaining a cool and uniform environment throughout the storage period (Suslov, 1997; Melnick, 1998; Wilson *et al*., 1995; Lutz & Hardenburg, 1968; Bjczvnski, 1997; Hardenurg, 1986; Geeson, 1983).

Low temperature prolongs storage life by reducing respiration rate as well as reducing growth of spoilage microorganisms (Rouraa *et al*, 2000; Watada *et al*., 1996). Temperature, relative humidity and atmospheric composition during prestorage, storage, and transit could control decay. For optimum decay control, two or more factors often are modified simultaneously and these are temperature and relative humidity. Proper management of temperature is so critical to post harvest disease control that all other treatments can be considered as supplements to refrigeration (Sommer, 1989). However, temperatures as low as possible are desirable because they significantly slow growth and thus reduce decay.

Respiration is one of the basic physiological factors, which speeds up ripening of fresh commodities and is directly related to maturation, handling, and ultimately to the shelf life (Ryall & Lipton, 1979; Ryall & Pentzer, 1982). Generally, the loss of freshness of perishable commodities depends on the rate of respiration. A common acid found in fruit includes citric, malic and ascorbic acid. During ripening, organic acids are among the major cellular constituents undergoing changes (Salunkhe *et al*., 1991). Studies have shown that there is a considerable decrease in organic acid during ripening of fruits. Modi & Reddy (1966), in Salunkhe *et al*. (1991), showed that concentrations of citric, malic and ascorbic acids declined 10, 40 and 2.5 fold, respectively.

An aspect to consider when handling fruits and vegetables is the temperature and relative humidity of the storage environment. For fresh harvested produce, any method of increasing the relative humidity of the storage environment (or decreasing the vapour pressure deficit (VPD) between the commodity and its environment) will slow the rate of water loss and other metabolic activities (Katsoulas et al., 2001). This will slow both the respiratory processes and activities of micro-organisms (pathogens) which are the most destructive activity during storage of fruits and vegetables (Barre et al, 1988).

Although, refrigeration is very popular but it has been observed that several fruits and vegetables, for example banana, plantain, tomato etc. cannot be stored in the domestic refrigerator for a long period as they are susceptible to chilling injury (Shewfelt, 1994; Olusunde et al. 2009). Apart from this, the epileptic power supply and low income of farmers in the rural communities' makes refrigeration expensive.

FAO (1983) advocated a low cost storage system based on the principle of evaporative cooling for storage of fruits and vegetables, which is simple, and relatively efficient. The basic principle relies on cooling by evaporation. However, sometimes when evaporative cooling system is used in preservation, it is used with shade on top (Kittas et al 2003). The objective of this study is review the theory, advances, principles, methods of evaporative cooling, and also the optimum storage temperature, relative humidity and self-life of fruits and vegetables.

II. Advances in Evaporative Cooling Technology

Different designs of evaporative coolers have been reported in literature for the preservation of fruits and vegetables (Redulla, 1984a; FAO 1986; Roy 1989; Thompson and Scheureman 1993; Acedo 1997, Noble 2008).

The design ranges from straw packing house to some sophisticated design. FAO (1986) reported that the packing houses of typical evaporative coolers are made from natural materials that can be moistened with water. Wetting the walls and roof first thing in the morning which is tedious creates conditions for evaporative cooling of the packing house. The major problem of these structures is the constructing material which deteriorates quickly and is susceptible to rodent attack.

Redulla (1984b) presented an evaporative cooler for preservation of fruit and vegetable which complements natural air with forced air to cool small lots of produce. The report also showed some other evaporative cooler which he called drip coolers and can be constructed from simple material such as burlap and bamboo. They operate solely through the process of evaporation without the use of fan. These coolers are cumbersome and have the same problem of the packing house.

Vakis, (1981) developed a cheap cool store in Kenya, with the help of local grass for storage of vegetables. He kept the roof and walls wet by dripping water from the top of the roof. Evaporative coolers, which rely on wind pressures to force air through wet pads, have also been designed and constructed, especially in some developing countries like India, China and Nigeria (FAO, 1986).

Construction of various evaporative systems was done by Rusten, (1985) using available materials as absorbent (pads). Materials used include canvas, jute curtains and hourdis clay blocks. Also a mechanical fan was introduced to some of the coolers constructed.

Rusten, (1985) did an extensive research in the construction of different evaporative cooling systems using locally available absorbent materials such as canvas, jute curtains, etc. Mechanical fans were used in some of the designs which drew air through a continuously wetted pad. The continuous wetting of the pad was achieved by placing elevated water basins on the fabric material, which absorbed the water gradually and eventually got saturated. He described the functionality of a hourdis clay block coolers which was constructed by two researchers.

Alebiowu, (1985) worked on the development of hexagonal wooden evaporative cooling systems and the system could be sub-divided into three parts head tank and pipe lines work ,the through and the frame work made of woods and its adjoints. The pipe line works at the top of the hexagonal frame supplied water constantly to wet the pad which is made of jute fibre. Wind pressure forced the air through the wetted jute pad. Limitation of this design is that the sufficiency of the evaporative cooler depends on wind velocity FAO/SIDA (1986). Roy and Khurdiya, (1986) constructed an evaporative cooled structure for storage of fruits and vegetables with a double wall made of baked bricks and the top of the storage space covered with *khaskhas*/gunny cloth in a bamboo framed structure.

Sanni, (1999) did a research on the development of evaporative cooling system on the storage of vegetable crops .The major development was implemented by adding a regulated fan speed, water flow rate and wetted-thickness .This was possible as a result of varying temperature and relative humidity within the facility.

Dzivama, (2000) researched on the performance evaluation of an active cooling system using the principles of evaporative cooling for the storage of fruits and vegetables. He developed mathematical models for the evaporative process at the pad-end and the storage chamber and a stem variety of sponge was considered to be the best pad material from the local materials tested as pad material.

Mordi and Olorunda, (2003) in their study on storage of tomatoes in Evaporative cooler environment reported a drop of 8.2°C from ambient condition of 33°C while the relative humidity increased by 36.6% over an ambient 60.4%. They further reported storage life of unpacked fresh tomatoes in evaporative cooler environment as 11 days from the 4 days. Storage life under ambient conditions while in combination with sealed but perforated polyethylene bags; it was 18 days and 13 days respectively.

Olosunde, (2006) also did a research on the performance evaluation of absorbent, materials in evaporative cooling system for the storage of fruits and vegetables. Three materials were selected to be used as pad materials: jute, Hessian and cotton waste. The design implemented a centrifugal fan, high density polystyrene plastic, Plywood used as covering for the walls and basement and the top and the main body frame was made of thick wood. The performance criteria included the cooling efficiency, amount of heat load removed and the quality assessments of stored products. The result showed that the jute material had the overall advantage over the other materials. The cooling efficiency could be increased if two sides were padded.

Sushmita et al., (2008) researched on Comparative Study on Storage of Fruits and Vegetables in Evaporative Cooling Chamber and in Ambient. An evaporative cool chamber was constructed with the help of baked bricks and riverbed sand. It was recorded that weight loss of fruits and vegetables kept inside the chamber was lower than those stored outside the chamber. The fruits and vegetables were fresh up to 3 to 5 days more inside the chamber than outside.

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. He prevented decay by washing the product first in the chlorinated water. Jain (2007) presented a two stage evaporative cooler for fruits and vegetable which incorporated a heat exchanger. This design is expensive but he could only achieve a storage life of 14 days for tomato. Anyanwu (2004) developed a porous wall (pot in pot) evaporative cooler for preservation of fruits and vegetables. He got a storage life of less than four days (93hours) on tomato. In this research work, an evaporative cooler with locally sourced materials for the construction was developed and evaluated. The evaporative cooler fabricated with mud (clay) directly excavated from the swamp is not electricity dependent will help farmers and marketers of fruits and vegetables to be able to store and preserve efficiently their products.

III. Factors Affecting the Shelf Life of Fruits and Vegetables

There are various factors that do affect the shelf life of fruits and vegetables which would lead to their spoilage. The various factors include:

i) Ambient Condition
ii) Temperature
iii) Relative Humidity
iv) Variety and stage of ripening

A. Ambient Condition

The environmental condition has a great influence on the shelf life of fruits and vegetables and the factors can be sub-divided into temperature and relative humidity.

B. Temperature

Temperature is defined as the degree of hotness or coldness of a material. Temperature has a great influence on the shelf life of agricultural products. FAO, (1998) found that all produce are subject to damage when exposed to extreme temperatures which will lead to increase in their level of respiration. Also, it was further disclosed that agricultural products vary in their temperature tolerance.

Gravani, (2008) observed that for every 18°F (-7.7°C) rise in temperature within the moderate temperature range (50°F-100°F)/(10°C-37.8°C) where most food is handled, the rate of chemical reactions is approximately doubled. As a result, excessive temperatures will increase the rate of natural food enzyme reactions and the reactions of other food constituents.

C. Relative Humidity

This is the measurement of the amount of water vapour in the air as a percentage of the maximum quantity that the air is capable of holding at a specific temperature. It has a great effect on the deterioration of fruits and vegetables because it has a direct relationship with the moisture content in the atmosphere which determines whether the shelf life will not be exceeded. The relative humidity of storage unit directly influences water loss in produce (Wilson et al., 1995).

D. Variety and Stage ripening

Post-harvest operation does not stop the fruits and vegetables from respiring which if not controlled will lead to the over-ripening of the fruits which will lead to early deterioration. Depending on the stage the fruits are harvested, which in practice varies from mature green to fully ripened, the commodities have different storage conditions (Olosunde, 2007).

Table 1 shows the storage temperature, relative humidity and shelf-life of some fruits and vegetables.

Table 1: Storage Temperature, Relative Humidity and Shelf Life of Fruits and Vegetables

COMMODITY	STORAGE TEMPERATURE (^{0}C)	RELATIVE HUMIDITY (%)	SHELF LIFE
Asparagus	0-2	95	2-3 weeks
Beans (green)	5-7	90-95	7-10 days
Carrot	0	90-95	2-5 months
Cauliflowers	0	90-95	2-4 weeks
Cucumbers	7-10	90-95	10-14 days
Cabbage	0	90-95	3-6 weeks
Pepper	7-10	90-95	2-3 weeks
Couregettes,	0-10	90	5-14 days
Eggplants, Brinjals	7-10	90	1 week
Melons	0-4.4	85-90	5-14days
Okra	7-10	90-95	7-10 days
Onion (dry)	0	65-70	1-8 months
Potatoes (white)	5-10	93	2-5 months
Potatoes (sweet)	12-16	85-90	4-6 months
Tomatoes (ripe)	7-10	85-90	4-7 days
Tomatoes (green)	12-20	85-90	1-3 weeks
Watermelons	4.4-10	90	2-3 weeks
Apples	1-4.4	85-90	3-8 months
Avocados	4.4-12.5	85-90	2-4 weeks
Mangoes	12	85-90	2-3 weeks
Pineapples	7-12.5	85-90	2-4 weeks
Pawpaw	7.0	85-90	1-3 weeks
Carnations	0-2	90-95	3-4 weeks

Source: FAO 1989

IV. Principles of Evaporative Cooling

A. Evaporative Cooling with Psychrometric Chart

According to Rusten, (1985) cooling through the evaporation of water is an ancient and effective way of cooling water. He further disclosed that this was the method being used by plants and animals to reduce body temperature. The conditions at which evaporative cooling would take place which are stated below:

(1) Temperatures are high
(2) Humidity is Low
(3) Water can be spared for its use
(4) Air movement is available (from wind to electric fan)

Also the change of liquid stage to vapour requires the addition of energy or heat. The energy that is added to water to change it to vapour comes from the environment, thus making the environment cooler.

Therefore, the use of the psychrometric chart is of great importance in order to discover whether evaporative cooling has taken place. Air conditions can be quickly characterized by using a special graph called a psychrometric chart. Properties on the chart include dry-bulb and wet-bulb temperatures, relative humidity, humidity ratio, specific volume, dew point temperature, and enthalpy Beiler, (2009).

When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect (Wikipedia.com).

Therefore for optimum cooling efficiency using the evaporative cooling technique temperature and the relative humidity measurement is needed to be taken and the psychrometric chart defines these variables at various stages.

B. Factors Affecting Rate of Evaporation

Evaporative cooling results in reduction of temperature and increase in relative humidity (Olosunde, 2006).It is necessary to understand the factors that can limit the efficiency of the system from producing the intended results. There are four major factors that affect the rate of evaporation which was analysed. According to Rusten, (1985). He later added that though they are discussed separately but it is important to keep in mind that they all interact with each other to influence the overall rate of evaporation, and therefore the rate of cooling. These factors discussed by (Rusten, 1985) include:

(1) Air Temperature:

Evaporation occurs when water is absorbs sufficient energy to change from liquid to gas. Air with a relatively high temperature will be able to stimulate the evaporative process and also be capable of holding a great quantity of water vapour. Therefore, areas with high temperatures will have a high rate of evaporation and more cooling will occur. With lower temperature, less water vapour can be held and less evaporation and cooling will take place.

(2) Air Movement

Air movement velocity either natural (wind) or artificial (fan) is an important factor that influences the rate of evaporation. As water evaporates from wet surface, it raises the humidity of the air that is closest to the water surface (moist area) .If the humid air remains in place, the rate of evaporation will start to slow down as the humidity rises. On the other hand if the humid air near the water surface is constantly being moved away and replaced with drier air, the rate of evaporation will either increase or remain constant.

(3) Surface Area

The area of the evaporating surface is another important factor that affects the rate of evaporation. The greater the surface area from which the water evaporates, the greater the rate of evaporation.

(4) Relative Humidity of the Air

This is the measurement of the amount of water vapour in the air as a percentage of the maximum quantity that the air is capable of holding at a specific temperature. When the relative humidity of the air is low, this means that only a portion of the total quantity of water which the air is capable of holding is being held. Under this condition, the air is capable of taking additional moisture, hence with all other conditions favourable, the rate of evaporation will be higher, and thus the efficiency of the evaporative cooling system is expected to be higher.

VI. Methods of Evaporative Cooling

Rusten, 1985 specified that there are two main methods of evaporative cooling namely:
(1) Direct evaporative cooling (2) Indirect evaporative cooling

(1) Direct Evaporative Cooling

This is a method by which air is passed through a media that is flooded with water .The latent heat associated with the vaporizing of the water cools and humidifies the air streams which now allows the moist and cool air to move to its intended direction. (Sellers, 2004) Sanjeev, (2008) disclosed that direct evaporative cooling has the following major limitations:

i) The increase in humidity of air may be undesirable.

ii) The lowest temperature obtainable is the wet-bulb temperature of the outside air,

iii) The high concentration and precipitation of salts in water deposit on the pads and the other parts, which causes blockage, and corrosion, and requires frequent cleaning, replacement, and servicing.

(2) Indirect Evaporative cooling:

A heat exchanger is combined with an evaporative cooler and the common approach used is the passes return/exhaust air through an evaporative cooling process and then to an air-to air heat exchanger which in turn cools the air, another approach is the use of a cooling tower to evaporatively cool a water circuit through a coil to a cool air stream (Sellers, 2004) and Sanjeev, (2008) also said indirect cooling differs from direct cooling in the sense that in indirect cooling the process air cools by the evaporation of water but there is no direct contact of water with process air. Instead a secondary airstream is used for evaporation of water. So the moisture content of process air remains the same

VII. Forms of Direct Evaporative Cooling

Dzivama, (2000) did a study on the forms of evaporative cooling process and discovered that there are two forms in which the evaporative cooling principle can be applied. The difference is based on the means of providing the air movement across/through the moist materials .These is the passive and non-passive forms. The passive form of evaporative cooling relies on the natural wind velocity, to provide the means of air movement across/through the moist surface to effect evaporation. This form can be constructed on the farm, for short term on farm storage while the non- passive form uses a fan to provide air movement.

A. Passive-direct evaporative cooling system

Construction and design varies but the general principles are the same. The main components include:

i) The cabinets where the produce is stored.

ii) The absorbent material used to expose the water to the moving air

iii) An overhead tank/through which the water seeps down on to and wet the absorbent material. The absorbent material covering the cabinet absorbs water from the tank on top of the cabinets, the entire cloth that was used as cabinet is soaked in water and the air moves past the wet cloth and evaporation occurs. As long as evaporation takes place, the contents of the cabinet will kept at a temperature lower than that of the environment and the temperature reduction obtained in this type of cooler ranged from 5°C to 10°C. Different researches have been done by researcher: Rusten, (1985), Susanta and Khurdiya, (1986), Olosunde, (2007), Sushmita et al.,(2008) have designed various forms of coolers.

B. Non- passive direct evaporative cooling system

This uses a small fan, a water pump which is powered by electricity. The products are kept in storage cabins inside the coolers, Absorbent material which receives the water and expose it to evaporation with the help of the fan which draws air through the pad and a overhead tank which is constantly supplying water to the absorbent material. Materials used as the absorbent materials are hessian materials, cotton waste and celdek and the body frame is made of wood. The pad and the fan are directly opposite to each other.

VIII. Recommended minimum temperature to increase storage time

There is no ideal storage temperature for all fruits and vegetables, because their response to reduced temperatures varies widely. The importance of factors such as mould growth and chilling injuries must be taken into account, as well as the required length of storage (Wills et al., 1989). Storage temperature for fruits and vegetables can range from -1 to 13°C, depending on their perishability. Extremely perishable fruits such as apricots, berries, cherries, figs, watermelons can be stored at -1 to 4°C for 1-5 weeks; less perishable fruits such as mandarin, nectarine, ripe or green pineapple can be stored at 5-9°C for 2-5 weeks; bananas at 10°C for 1-2 weeks and green bananas at 13°C for 1-2 weeks. Highly perishable vegetables can be stored up to 4 weeks such as asparagus, beans, broccoli, and Brussels sprouts at -1-4°C for 1-4 weeks; cauliflower at 5-9°C for 2-4 weeks. Green tomato is less perishable and can be stored at 10°C for 3-6 weeks and non-perishable vegetables such as carrots, onions, potatoes and parsnips can be stored at 5-9°C for 12-28 weeks. Similarly, sweet potatoes can be stored at 10°C for 16-24 weeks. The storage life of produce is highly variable and related to the respiration rate; there is an inverse relation between respiration rate and storage life in that produce with low respiration generally keeps longer. For example, the respiration rate of a very perishable fruit like ripe banana is 200 mL $CO2.kg^{-1}h^{-1}$ at 15°C, compared to a non-perishable fruit such as apple, which has a respiration rate of 25 mL $CO2.kg^{-1}$ h^{-1} at 15°C.

Exposure of fruits and vegetables to high temperatures during post-harvest reduces their storage or shelf life. This is because as living material, their metabolic rate is normally higher with higher temperatures. High temperature treatments are beneficial in curing root crops, drying bulb crops, and controlling diseases and pests in some fruits. Many fruits are exposed to high temperatures in combination with ethylene (or another suitable gas) to initiate or improve ripening or skin colour.

IX. CONCLUSION

When fruits and vegetables are exposed to high temperatures during post-harvest it reduces the storage or shelf life and as such, the shelf life of most fresh vegetables can be extended by prompt storage in an environment that maintains product quality. Although, refrigeration is very popular but it has been observed that several fruits and vegetables, for example banana, plantain, tomato etc. cannot be stored in the domestic refrigerator for a long period as they are susceptible to chilling injury. Apart from this, the epileptic power supply and low income of farmers in the rural communities' makes refrigeration expensive. Hence the need for an evaporative cooling structure for storage of fruits and vegetables.

REFERENCES

Abdul A.K (1989). Postharvest losses during processing and preservation of fruits and vegetables. A PhD thesis submitted to University of Punjab Pakistan Acad. Press, NY, pp. 125-156.

Acedo, A.L.(1997). Storage life of vegetables in simple evaporative coolers. *Tropical Science37:169-175.*

Adetuyi ,F.O. , T.A. Ayileye and I.B.O. Dada .(2008) Comparative Study of Quality Changes in Shea Butter Coated Pawpaw Carica papaya fruit during Storage *Pakistan Journal of Nutrition 7 (5): 658-662, 2008*

Ajibola, O.O. (1991). Storage Facilities and Requirements for Fruits and Vegetables. Paper presented at the Nigeria Society of Engineers Course on Designing , Construction and Maintenance of Food Storage System. Pp. 9-

Anyanwu E.E; (2004). Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables, *Energy Conversion and Management (45) 2187–2195*

ASHRAE (2003) Evaporative Cooling System. American Society of Heating and Refrigeration and Air Conditioning.www.ashare.com

Byczynski, L. (1997). Storage Crops Extend the Season. Growing for Market. p. 1, 4–5.

Carrasco, A.D. (1987) Evaluation of Direct Evaporative Roof-Spray Cooling System .Proceedings on Improving Building Systems in Hot and Humid Climates, Houston ,Texas US., September 15- 16 Pp.1-4

Dvizama, A. U. (2000). Performance Evaluation of an Active Cooling System for the Storage of Fruits and Vegetables. Ph.D. Thesis ,University of Ibadan , Ibadan.

FAO (1983). FAO production yearbook, vol. 34. FAO, Rome.

FAO 1989. Prevention of Post-harvest food losses of fruits, vegetables and root crops training manual. Training ;17(2). Rome, Italy.

FAO. (1986). Improvement of post-harvest fresh fruits and vegetables handling- a manual. Bangkok : FAO/SIDA . Rome. Harris, N.C. (1987). *Modern Air Conditioning Practice*, 3rd edition, McGraw-Hill Book Co., New York. FG/IITA/USAID/UNICEF/USDA Report, 2004

Geeson, J.D. (1983). Brassicas. In: C. Dennis (ed) Postharvest Pathology of Fruits and Vegetables,

Hardenburg, R (1986). The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks.

Ihekoronye, A.I. and P.O. Ngoddy (1985): Tropical Fruits and Vegetables. In*: Integrated Food Science and Technology for the Tropics*, Macmillan Publ. Ltd.; London and Basingstoke ; 293 – 311.

IITA, Nigeria Food Consumption and Nutrition Survey (2001-2003)

Jain .D (2007).Development and testing of two-stage evaporative cooler .*Building and Environment) 2549–2554*

Jeffries, P. and Jeger, M.J. (1990). The Biological Control of Postharvest Diseases of Fruit. Biocontrol

Kader, A.A. 1985. Biochemical and Physiological Basis for Effects of Controlled and Modified Atmospheres on Fruits and Vegetables. Food Technol. 40:99-104.

Katsoulas N; Baille A and Kittas C (2001);. Effect of misting on transpiration and Conductance of a greenhouse rose canopy. *Agricultural and Forest Meteorology,106,233–47*

Kittas C.; Bartzanas T. and Jaffrin. A (2003). Temperature Gradients in a Partially Shade Large Greenhouse equipped with Evaporative Cooling

Melnick, R. (1998). Safety Sets the Table. American Vegetable Grower. February. p. 9–11, 13, 15.

Moddy, V.V. and Reddy, V.V. (1966). Carotenogenesis in Ripening Mangoes. Indian Journal Exp. Biology. 5 (4):233-51
nc1055.htm

Ndukwu. M. C. Development of a Low Cost Mud Evaporative Cooler for Preservation of Fruits and Vegetables. Agricultural Engineering International: CIGR Journal. Manuscript No.1781. Vol. 13, No.1, (2011). Provisional PDF Version. 3rd edition. Series No. 8. News Info. 11:333-336.

Noble, N. (2008) www.practicalaction.org

Olosunde William Adebisi ; J.C. Igbeka and Taiwo Olufemi Olurin (2009). Performance Evaluation of absorbent materials in Evaporative Cooling System for the Storage of Fruits and Vegetables *International Journal of* Food Engineering Volume 5, Issue 3

Olosunde, W.A. (2006) .Performance Evaluation of Absorbent Materials in the Evaporative Cooling System for the Storage of Fruits and Vegetable M.Sc thesis, Department Of Agricultural Engineering, University of Ibadan, Ibadan.

Parsons, R.A. and Kasmire, R.F. (1974). Forced-air unit to rapidly cool small lots of packaged produce. University of California cooperative extension, OSA #272. Tubers. *Hortscience 12:294-298*

Redulla ,1984b. Keeping perishables without refrigeration: use of a drip cooler. *Appropriate Postharvest Technology* 1(2): 13-15)

Redulla . 1984a. Temperature and relative humidity in two types of evaporative coolers. *Postharvest Research Notes*, 1(1): 25-28.

Roura, , S.J., Davidovich, L.A. and Valle, C.E.(2000). Quality Loss in Minimally Processed Swiss Chard Related to Amount of Damage Areas. Lebensmittel Wissenschaft Technol. 33: 53- 59.

Roy S.K, (1989). A low cost cool chamber: an innovative technology for developing countries (Tropical fruits storage), Johnson GI,(Commonwealth Scientific and Industrial Research Organisation, St Lucia (Australia). Division of Horticulture),Editor. Postharvest handling of tropical fruits. Canberra, A.C.T., Australia: Australian Centre for International Agricultural Research 1994. p. 393–5.

Roy, S.K.and Khurdiya, D.S. (1986) cited in Dash S.K. paper, presented at training course on *'Zero Energy Cool Chamber'* held at I.A.R.I. New Delhi, 8-10 Nov., 2000.

Ryall, A.L. and Lipton, W.J. (1979). Handling, Transportation and Storage of Fruits and Vegetables. Volume 1. Vegetables and Melons. 2nd edition. AVI Westport, CT.

Ryall, A.L. and Pentzer, W.T. (1982). Handling, Transportation and Storage of Fruits and Vegetables Vol. 2. Fruits and Tree Nuts. 2nd ed. AVI Publishing. Westport. CT.

Salunkhe, D.K., and S.S. Kadam. 1995. Handbook of Fruit Science and Technology.New York: Dekker

Sanni, L.A (1999). Development of Evaporative Cooling Storage System for Vegetable Crops .M.Sc. project report, Department of Agricultural Engineering, Obafemi Awolowo

Sellers (2004). Evaporative Cooling: *Design Considerations HPAC Engineering* Service. p136.

Shewfelt, R. (1994). Quality characteristics of fruits and vegetables.

Sommer, N.F. (1989b). Suppressing Postharvest Disease with Handling Practices and Controlled Environments. In: J.H. LaRue and R.S. Johnson (ed) Peaches, Plums, and Nectarines Growing and Handling for Fresh Market. Univ. Calif., DANR Pub. No. 3331, pp. 179-190.

Susan D.S. and Durward S. (1995). G95-1264 Storing Fresh Fruits and Vegetables. Historical Materials from University of Nebraska-Lincoln Extension. Retrieved online from http://digitalc ommons.unl.edu/extensionhist/1042/

Thompson, J.F. and Scheuerman, R.W. 1993. Curing and storing California sweet potatoes. Merced County Cooperative Extension, Merced , California 95340

UNFAO regional office for Asia and the pacific. University, Ile-Ife, Nigeria Univ. of Calif., Agric. Exp. Station, Bull. No. 1914 (Pub. NE-87), pp. 67-72. USDA Handbook No. 66. United States Department of Agriculture, Agricultural Research

Vakis, N.J. (1981) Handling Fresh Tropical Produce for Export. *International Trade Forum* 17(1): 13-23

Watada, A.E., K.O, N.P. and Minott, D.A. (1996). Factors Affecting Quality of Fresh-Cut Horticultural Products. Postharvest Biology Technology. 9: 115-125

Wilson, L.G., . Boyette, M.D and Estes, E. A. (1995). Postharvest Handling and Cooling of Fresh Fruits, Vegetables and Flowers for Small Farms. Leaflets 800– 804. North Carolina Cooperative Extension Service. 17 p. Accessed on- line at: http://www.foodsafety.org/nc/