A SYSTEM FOR RURAL STORAGE OF FRESH TOMATO

BY

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DEPARTMENT OF AGRICULTURAL ENGINEERING
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1992

DECLARATION

I hereby declare that this thesis is written by me (NDIRIKA, VICTOR OBIORA IFEANYI) and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All the sources of information which are not my own originals were duely acknowledged by means of references.

DEDICATION

I dedicate this work to my beloved parents Mr. and Mrs. S.C. Ndirika with profound affection and gratitude for the good foundation they have laid on my academic life.

CERTIFICATION

This thesis entitled A SYSTEM FOR RURAL STORAGE OF FRESH TOMATO by the author NDIRIKA, VICTOR OBIORA IFEANYI meets the regulations governing the award of the degree of Master of Science(Agricultural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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NDIRIKA, V.I.O.

ABSTRACT

As a result of the need to minimize the huge losses of perishable agricultural crops produced in the rural communities and preserve their fresh qualities before getting to the consumer, at the farm and market levels, a storage system for fresh tomato was designed and constructed with the locally available raw materials.

The storage system works on the principles of evaporative cooling involving the process of heat transfer from the storage chamber to the wet Hessian sack which encloses the cooling medium.

A preliminary experiment was carried out during the harmattan period and a second experiment off-harmattan period. The result obtained during the off-harmattan period reveals that the equipment can store fresh tomatoes for 30 days at average temperature and relative humidity of 22.9°C and 98.2% respectively when the average ambient temperature and relative humidity respectively were 30.9°C 8nd 37.3%. Also, the result obtained during the harmattan period shows that the equipment could store fresh tomatoes for 23 days at average temperature and relative humidity of 17.1°C and 82.1% respectively when the average ambient temperature and relative humidity respectively were 25.15°C and 28.29%.

Compressive strength of the stored produce varies between (o.550 N/mm^2 - 0.122 N/mm^2) and (0.550 N/mm^2 - 0.081 N/mm^2) respectively with the storage equipment and the control system from the initial to the final day of storage during the harmattan period. And also varies

between (0.546 N/mm^2 - 0.112 N/mm^2) and (0.546.6 N/mm^2 - 0.073 N/mm^2) respectively with the storage equipment and the control system from the initial to the final day of storage during off-harmattan period.

The initial state of the tomato before testing was green and the state at the end of the test during the the harmattan and Off-harmattan period was deepred with rot appearance. The duration of test were 30 days and 23 days respectively for off-harmattan and harmattan period,

A factorial experiment was considered for estimating the effect of size, thickness of the Hessian sack and interraction of the variables under room condition. The result obtained during the experiments (off-harmattand and harmattan) reveals that the calculated effect of size of the storage system was statistically significant while the calculated effect of thickness of the Hessian sack and interraction between size and thickness of the Hessian sack was not significant at 0,05 confidence level.

Cooling efficiencies of over 93% and 98% respectively was achieved with the storage system during the harmattan and off-harmattan period while the humidification efficiencies attained was 93% and 95% respectivley during the harmattan and off-harmattan seasons.

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LIST OF SYMBOLS

b : Constant determined experimentally

c : Product specific heat

C_s : Concentration of saturated water vapour in air

C's: Concentration of saturated water vapour on the surface of material

DC : Concentration difference

d : Deviation

db : Dry bulb temparature, ^oC

Db : Bulk density, kg/m^3

F : Load on the tray, N

F^1 : Surface area of 1 kg of material, m^2

g : Acceleration dur to gravity, 9.81 m/s^2

G : Moisture removed in unit time

Gm : Loss of dry substance

Go : Amount of moisture removed during cooling

h : Capillary height, m

L : Length, m

m_c : Daily sugar loss as a weight percent of beet

m_s : Mass of sample, kg.

p : Pressure, N/m^2

P_g : Pressure of water in capillary, N/m^2

P_s : Pressure of saturated vapour over a tree water surface, N/m^2

q : Quantity of heat released in pile, J.

qo : Constant determined experimentally

r : Radius of capillary, m

t : Cooling period

V_s : Volume occupied by samples, m^3

W_b	:	Wet bulb temperature, ^oC
α	:	Heat coefficient, $KJM^{-2}h^{-1}C^{-1}$
β	:	Evaporation coefficient (Relative to free water surface)
γ	:	Moisture exchange coefficient of the material
ρ_g	:	Density of water in capillary, kg/m^3
ρ_w	:	Liquid density, kg/m^3
θ	:	Temperature, ^oC
$\Delta\theta$	:	Change in temperature, ^oC
$\theta_1;\theta_2$	:	Initial and Final temperature respectively, ^oC
θ_e	:	Equilibrium temperature, ^oC
θ_k	:	Medium temperature, ^oC
σ	:	Surface Tension, N/m
σ_c	:	Compressive resistance, N
ϕ	:	Relative vapour pressure, N/m^2
ϕ_r	:	Relative humidity, %
$\leq$	:	Summation

LIST OF ABBREVIATIONS

CA	:	Controlled atmosphere
CO_2	:	Carbon dioxide
ECS	:	Evaporator coolant system
MA	:	Modified atmoshere
MH	:	Maleic hydrozide
ns	:	Not significant
O_2	:	Oxygen
RH	:	Relative Humidity, %
SE	:	Standard Error

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CHAPTER ONE

1. INTRODUCTION

1.1 Statement of Problem

Fruits and vegetables are of great importance in human nutrition as they supply vitamins and minerals to the diet, provide variety to the food and make food appetising and more attractive by adding flavour. In their fresh form, fruits and vegetables are highly perishable after harvest, they tend to shrivel, wither or rot away at a very fast rate (Oyeniran, 1986), particularly under hot tropical conditions. The damages that occur in these crops are caused primarily by loss of moisture, change in composition and pathological attack or metabolism.

Factors contributing these causes include: Nature of crop; initial quality of crop, mechanical injury, temperature, humidity, handling given to the crop and storage atmosphere.

Vegetable production forms 25% of the major food crops grown in the tropics (Eric and Bani, 1988) and so is the means of livelihood for a considerable section of the population.

Inspite of their importance in the diet, per capita consumption of vegetables in the developing world is only 100g compared with 200g in the more advanced countries (Grubben, 1977). In the continual

fight against hunger and malnutrition, significant increases in food production have been achieved throu the use of improved seeds, fertilizers, improved production practices etc.

Post-harvest loss estimates for fruits and vegetables are difficult to substantiate except on limited, controlled experimental basis. Shulka and Royer (1984) reported that an assessment of the post-harvest losses of fruits and vegetables by the National Academy of Science, Washinton D.C. and the Food and Agriculture Organization of the United Nations shows that losses are as high as 50%.

In the recent past several methods have been introduced for the storage of raw and processed fruits and vegetables, these include: storage in ventilated shed, storage at low temperatures, evaporative coolant system, waxing and chemical treatment, delayed ripening of fruits etc.

Majority of the rural communities where fruits and the vegetables and produced have no electricity, this prevents the installation of domestic refrigerators in the rural areas.

Tomato being one of the fruit often in great demand consumed wholly by every households are used as ingredient in soup preparation and condiments in other food items. Unfortunately, this important commodity is highly perishable in its fresh form and short-seasoned due to its storage difficulties, especially at the rural level. However, due to its unique importance, a form of storage becomes imperative.

To this end, it is therefore necessary to develop a simple, cheap and efficient technique for the storage of fresh tomatoes affordable by the rural communities.

1.2 Objectives of the Study

The objectives of the study include:

(i) To design and construct a simple, cheap and efficient storage system for fresh tomatoes.

(ii) To test and evaluate the performance of the storage equipment.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Classification of the major Fruits and Vegetables

Terra (1966) had defined vegetables and fruits as "those fresh and juicy parts of plants, which are eaten as supplementary food, as a side dish or simply by themselves." Fruits may be dry or fleshy, irrespective of whether they are simple, aggregate and multiple or composite. On account of the agreeable sweet-acid, or aromatic flavour of their freshy pulp or seeds and kernel, fruits are usually prepared, preserved and eaten in their raw stage. On the other hand, vegetables are mostly prepared and eaten in the fresh, raw state, or cooked when they are tender and immature.

It should, however, be pointed out that there is no general agreement as to what is meant by vegetables. Terra (1966) has distinguished several types, including bulbs, young flower-heads etc. The wild (uncultivated) vegetables, however, come under the category of leaf vegetables and they are usually harvested immature, mostly cooked, or rarely eaten raw.

2.2 Problems of Fruits and Vegetables Storage and Preservation

In Nigeria, the rural farmers constitute about 80% of the entire population and they are responsible for about 90% of the country's agricultural

output (Omoregie, 1989). The rural areas lack electricity and thus the rural farmers face serious problems of storage and preservation during harvesting periods, particularly, at seasons of increased yields.

Preservation and storage of fruits and vegetables are important due to:

(i) The need to keep excesses not presently required.

(ii) The need to guard against scarcity during unfavourable harvests and off season periods.

(iii) The fact that proper storage results in reduced losses of fruits and vegetables and high profit level for producers.

(iv) The fact that proper storage helps to stabilize prices as a result of availability of fruits and vegetables in their fresh form throughout the year.

(v) The necessity for short term storage in case of long distance between centre of production and markets for disposing of farm products in their fresh form.

From the foregoing, the importance of proper storage and preservation of fruits and vegetables cannot be over-emphasized.

2.2.1 Wastages of Fruits and Vegetables

Huge losses can result from poor storage of fruits and vegetables. The level of losses depend on the storage structure, method of storage, the product being stored, the state of the product under storage and the storage environment. Fruits and vegetables production process cannot be said to be complete without adequate storage.

Agricultural produce is subject to attack by a wide range of pests and diseases in storage. Losses due to poor storage have been classified by Taylor (1977) into:

(i) weight loss

(ii) quality loss

(iii) food loss

(iv) monetary loss

(v) seed loss and loss of goodwill.

Losses for vegetables, fruits and animal products are much higher than the figures for grains because they are highly perishable products. About 35% of these products; especially in the rural areas, are lost in storage (Omoregie, 1989).

Quality of products is also lost under poor storage. Fruits and vegetables products become unfit for consumption resulting in enormous financial losses. Losses of fruits and vegetables will continue to widen the food supply demand deficit if not arrested.

2.2.2 Factors affecting Fruits and Vegetables in Storage

Some of the factors identified as causes for losses of fruits and vegetables in storage are:

(i) Chemical and physical changes resulting from high microbial growth, insect activities which are highly favoured by the environmental conditions of temperature, relative humidity and moisture. Rodents also posee serious problem in storage.

(ii) Mishandling while in transit. If proper care is not taken while moving produce from farm sites to stores or between one town and another, physical injury to the products will predispose them to

fungi and bacterial attack. This hastens the rottening process of fruits and vegetables particurly.

(iii) Use of poor storage containers and stores. Because there is no special storage facilities for easily perishable products like fruits and vegetables, local farmers depend on the traditional method of preservation in baskets. This method results in high loss of fruits and vegetables.

(iv) Poor state at maturity and physical condition at harvesting. Harvesting is mostly done at an advanced stage of ripening, even after some damages had been done to the fruits and vegetables.

(v) Inappropriate storage moisture content; and

(vi) Poor farming practice, for example, fertilizer application in Nigeria, is not based on soil test values (Omoregie, 1989). It has been shown by Kpeglo et. al. (1980) that high nitrogen application reduces storage life.

(vii) Physiological activity in harvested fruits and vegetables may lead to a deterioration in quality due to high metabolic activity taking place in harvested products as a result of respiration which involves the break lown of organic substances with a consequent progressive depletion of the accumulated reserves of dry matter.

2.2.3 Minimizing Losses of Fruits and Vegetables

Since most of the rural producers are poor and illiterate, sophiscated methods like cold storage cannot be meaningfully utilised. Hence methods which can be easily adopted by these rural producers are being advocated. Emphasis is on preventing factors which can lead to serious loss and encouraging easily adoptable technology.

Ways of minimizing losses of fruits and vegetables as summarised by Omoregie (1989) are:

(i) Harvesting at mature green stage, for highly perishables like tomeato, pepper, banana etc.

(ii) Proper storage practices.

(iii) Good sanitary conditions of the storage environment e.g. cleaning etc.

(iv) Development by breeders of varieties which have relative low moisture content, mechanical and textural properties.

(v) Processing of farm products into forms that can keep for long and proper package thereafter.

2.3 Preservation of Fruits and Vegetables

All methods used for preserving fruits and vegetables are based upon the general principles of providing an environment which is unfavourable to the growth of spoilage organisms.

Aremu (1975) discussed the basic methods of preserving fruits and vegetables. The methods outlined are as follows:

2.3.1 Blanching

In the case of vegetables, blanching is carried out to remove some air from the tissues and make them more compact and also to enhance their colour. The enzymes which would otherwise cause deterioration in palatability, colour and ascorbic acid content are also inactivated when vegetable is blanced. For blanching, vegetables are plunged into boiling water and then cooled. Blanching times vary for different vegetables as shown in Table 2.1.

Table 2.1: Blanching times for Vegetables

Vegetable	Time (Minute)
Green beans	3
Spinach	1
Cabbage	1
Sliced carrot	3
Corn-on the cob	10
Okro	1

2.3.1.1 Water Blanching

Water blanching results in leaching of soluble constituents which contribute to flavour, and of water - soluble vitamins, notably ascorbic acid. Most water - blanchers consist of a horizontal cylindrical tank holding the hot liquor through which the material is passed by the movement of a metal scroll, either open and moving at a very clearance from the inner surface of the tank or enclosed in a perforated drum. The liquor is heated by direct steam

injection normally between 87.78 and 98. 89°C. Blanching times of between 1½ and 5 minutes are normally used, the precise time depends on the material and on the purpose of the blanch.

2.3.1.2 Steam Blanching

In steam blanching the material is passed through a steam chamber, either on a moving belt or by means of a turning screw conveyor which fits closely the inner contours of the base of the chamber. Blanching times vary with the material over a range similar to that used in water blanching.

Various other methods of blanching have been used experimentally, or to a limited extent in commercial operation. These include in-can blanching prior to canning, hydraulic hot-water blanching in steam-heated pipes, and blanching of dielectric heating or by infra-red irradiation. None of these methods has proved sufficiently advantageous for general use to supplant the established conventional methods of blanching in hot water or steam.

2.3.2 Drying

Drying is one of the oldest methods of preserving fruits and vegetables. Practically, the fruit and vegetable is dried in the sun or by air-current and artificial heat. The aim is to reduce moisture content of the food to a safe level such that will inhibit the growth of micro-organisms. Besides, removing the moisture contents, drying also checks undesirable chemical changes that take place

naturally in fruits and vegetables. Many fruits and vegetables are sundried in various parts of the world. This is possible because of the climatic condition of the areas. In places where there is abundant heat for most part of the year, such as in the tropics, more vegetables and fuits can be dried successfully.

In sundrying any food utensils employed must be thoroughly clean. To keep away contaminating insects and flies, the fruits and vegetables sundried must be covered. Trays and mats used for drying are placed on a raised platform out of reach of animals. Fruits and vegetables that have been dried are kept in air-tight containers to avoid insects and rodents. A scientific method of drying is freeze-drying. It involves removal of water from frozen fruits and vegetables by sublimation. Being fairly expensive it is not very common. Commercial firms in develped countries find it viable with high value products because it saves transportation and storage costs, since the weight of the original product is greatly reduced. Once freeze-dried, such fruits and vegetables do not require refrigeration.

2.3.3 Freezing

Freezing is a method of preserving fruits and vegetables which can be practiced when cold storage facilities exist. Low temperatures inhibit microbial growth. Freezing may preserve fruits and vegetables almost indefinitely if the quality of the fruits and vegetables are good and temperature conditions are favourable. However, when vegetables are frozen without blanching, marked off-flavours develop rapidly, while chlorophyll and carotene may also be lost during storage. Vegetables to be frozen need not otherwise be cooked. After blanching the vegetables must be cooled immediately by immersion in cold water before they are frozen.

Apart from the use of suitable methods, success in freezing fruits and vegetables depends largely on the selection of types and varieties. Correct maturity of fruits and vegetables is also very important. Most vegetables need to be harvested when they are young and tender. Inevitably, fruits must be at the optimal stage of ripeness for best flavour, colour and texture.

2.3.4 Bottling and Canning

Fruits are usually preserved in syrup. Firm fruit is first soaked in water before being cooked in the syrup until tender. During cooking, the fruit cells

take up syrup. Good products should be bright and sparkling. Rapid boiling tends to preserve colour better than slow cooking. The amount of sugar required in the syrup is usually equal in proportion to the fruit. Both vegetables and fruits are preserved by heating in air-tight containers. The time and temperature required vary with the type of fruits, vegetables and micro-organisms that occur in it. Acid fruits are successfully canned at atmospheric temperatures. In the case of non-acid vegetables, higher temperatures are necessary, and therefore, pressure cooking must be applied.

2.3.5 Techniques for Storage and Preservation of Fruits and Vegetables

Ngoddy (1975) tabulated the general techniques for the storage and preservation of fruits and vegetables as shown in Table 2.2.

Table 2.2: General Techniques for the Storage and Preservation of Fruits and Vegetables.

Controlled Environment	Heat Treatment	Dehydration and Related Methods	Other Methods
1. Controlled atmosphere storage	1. Blanching	1. Sundrying	1. Sugar preservation
2. Reduced temperature - chilling - freezing - Cryogenic techniques	2. Pasteurization	2. Dehydration by various methods including new advanced techniques, such as freeze drying.	2. Salt preservation
3. Packaging	3. Bottling and glass packaging 4. Canning		3. Chemical preservation 4. Fermentation 5. Irradiation

2.4 Research Development on Fruits and Vegetables Storage

Fruits and vegetables are very highly perishable crops in their raw state. Once harvested, they tend to shrivel, wither or rot away at a very fast rate (Oyeniran, 1986). However, based on the different test reports, research papers and available technical litera-

tures, it was revealed that some work has been done on the storage of fruits and vegetables. The storage techniques that have been found helpful for fruits and vegetables storage are enumerated below.

2.4.1 Improved Packaging and Storage in Ventilated Shed

Rough handling and packaging during storage and transportation have been identified as major causes of spoilage and losses in fruits and vegetables in Nigeria.

Onwuzulu (1984) investigated the packaging of fruits in slated wooden boxes, specially designed plastic crates, and perforated cartons for storage and transportation and used Dufaylite paper cells in some of the containers. In his trials with transportation of oranges from Ibadan to Kano, those packed in slatted boxes and perforated cartons with dufaylite cells had losses below 1%. Those without dufaylite cells had 3 - 5%, while the control transported naked, had 20 - 25% losses when assessed at destination. However, storage of oranges in these structures in a cool shed preserved them for 3 - 4 weeks, with less than 10% spoilage in Southern Nigeria, while storing them in unprotected heaps caused 40 - 50% spoilage within 2 weeks.

2.4.2 Storage at Low Temperature

Several studies have been done on the storage of fruits and vegetables at low temperatures in different compartments of several models of conventional refrigerators (Sowumi et. al. 1984; Onyekwelu and Aror 1984; Onyekwelu and Fajemisin, 1984). These studies also involved the use of various packaging and wrapping materials. The general result indicates that fruits and vegetables store much longer at these low temperatures than ambient. For fruits generally, temperatures of 5 - 12^{o}C were found suitable. Storing fruits naked encouraged drying up and storing in sealed polythene encouraged accumulation of carbon dioxide (Co_2) and mould development, while storing in perforated polythene was good. Wrapping in tin foil paper gave the best result. With leafy vegetables, wrapping in sealed polythene at 3 - 8^{o}C was found effective especially when prewashed with milton solution to arrest biodeterioration.

Though, these studies gave encouragine results, much emphasis was not placed on the studies in this work due to the following reasons:

(i) The use of refrigerators for fruits and vegetable storage is well known.

(ii) The erratic nature of electric power in Nigeria discourages dependence on low temperature storage. Spoilage is usually faster and more severe in cold stored crops when power fails.

However, for those who can afford it on a large commercial scale, low temperature storage of fruits and vegetables could be a profitable business venture.

2.4.3 Evaporator Coolant System (E.C.S.)

As a possible alternative to the conventional refrigerator, the ECS was developed to reduce the temperature in the storage chamber.

Babarinsa et. al. (1984), Sowunmi et. al. (1984), Adu et. al. (1984) constructed and tested two models. The first model is a rectangular double-walled structure made of burnt bricks on a solid foundation and carries a heat insulating roof. The space between the double wall which is the cooling medium, is filled with riverbed sand that is constantly kept wet with water. The inner chamber which forms the storage chamber is divided into shelves or compartments for fruits and vegetable placement. The second model of ECS which is the portable model, consists of two burnt clay pots, one placed inside the other and the space in between is filled with river bed sand that is constantly kept wet. The smaller pot is coated externally with cement to prevent inside seepage of water. The process of cooling is based on the transfer of heat from the storage chamber to the wet river bed sand which forms the cooling

medium, from where the heat is also conducted across the outer wall by the evaporation of water from the outermost surface of the structure.

A temperature drop of 8 - 12°c below ambient has been achieved in ECS chambers especially in Kano. Storage trials were conducted with mangoes, pineapples, tomatoes and leafy vegetables. The system was found to extend the shelflife of the fruits and vegetables tested in them.

2.4.4 Waxing and Chemical Treatment of Fruits

Oyeniran (1986) reported that the effects of fungicidal wax on stored oranges has been investigated. He stated that valencia oranges, harvested at their optimum maturity, were bulk-dipped in benamyl, waxed and packed into slatted wooden boxes and perforated paper cartons. Storage was on shelves in a store at mean ambient temperature and relative humidity of 29.1°c and 71% respectively. Results showed that oranges stored well for 8 weeks and wax emulsions decreased weight loss by more than 5%. The perforated cartons preserved the oranges better.

Many researchers have attempted to use waxing to generate modified atmosphere conditions inside the fruit, in order to extend the shelflife, but with very limited success (Janbay, 1988). Nevertheless, research in this field is still active, and new coating materials are frequently being introduced.

Couey (1982) reported that application of ethylene to avocado induces ripening of the fruit, and makes the fruit less sensitive to chilling injury and more tolerant to longer periods of storage at $2^{o}c$.

2.4.5 Delayed Ripening of Fruits

Oyeniran (1986) stated that a method of delaying the ripening of mature fruits had been developed and this is achieved by using a vermiculite preparation of potassium permanganate in proportion of 4:1. The vermiculite carrier mixture is allowed to set and form a cube which is placed in perforated polythene with green mature fruits. The vermiculite cubes absorb ethylene produced by the green fruits and so delays ripening thereby extending the shelflife of plantains and bananas tested, by about 4 weeks.

Fruits thus treated can be transported over a fairly long distance for sale without recording the usual deterioration of ripening and mould infection. Such treated fruits can also be kept in storage until needed for the market when it would be brought out for ripening.

Ndubizu (1975) carried out studies on the delayed ripening in harvested Nigerian green plantains and reported that mature Nigerian green plantains (Bini Variety) dipped in fungicide suspension of Thiabendazole or Diathane M45 were stored in polythylene bags

containing potential anti-ripening chemicals. Storage was at room temperature (26 - 27°c). Fruits stored in bags containing purafil or potassium per manganate, kept green and hard for over 3 weeks. Fungicide treated fruits stored in potassium iodate, potassium dichlorate or calcium hypochlorite, ripened after 2 weeks. Storage in iodate, dichromate or hypochlorite was not significantly better than storage in polythylene bags alone.

2.4.6 Irradiation

Irradiation has been tried as a means of extending the post harvest life of fruits.

Maxie et.al. (1971) concluded that it was unfeasible to irradiate fruits and vegetables. However, it may still be possible to use irradiation to treat fruits to disinfest it of insects (Burditt, 1982; Sommer, 1984).

2.4.7 Storage of Fresh leafy vegetables

Onyekwelu and Aror (1984) investigated and reported that when the leaves of fresh leafy vegetables were sprinkled with water and covered with polythene sheet, the vegetables kept fresh for 6 - 7 days. The fresh leafy vegetables were harvested in cool weather. The roots, were washed off with clean water, and cut off. The vegetables were bunched together and stem tied. The bunched stem was dipped into a suitable

container of water.

Mejule (1984) investigated and reported that vegetables remained fresh for 6 days when a moist piece of hessian sack was placed at the bottom of a clay pot of suitable size.

2.4.8 Storage of Processed Fruits and Vegetables

Fruits are consumed mostly for their juices. Only a few of them get their fleshy parts eaten. Therefore, the storage of fresh fruits is mainly for the preservation of the juice. Technology exists for the industrial processing by extraction and canning of fruit juices to retain more or less the fresh state. The canned fruit products can be stored in ambient conditions on the shelf for several months. Examples of these are citrus, mangoes, and pineapples.

Other fruits and vegetables which are consumed wholly such as peppers, onions, tomatoes etc. are used as ingredients in other food items. They are sparingly eaten raw but they may also be processed in purees and pastes as canned products. These products also store well in ambient conditions for several months (Oyeniran, 1986).

Leafy vegetables in Nigeria are hardly eaten raw but cooked. Onyekwelu and Aror (1984), Sowunmi et.al. (1986) conducted several studies and have successfully dried many varieties of leafy vegetables

at regulated temperatures between 32 - 38°c to retain their greenness. Such dried vegetables packed in polythene bags have been stored ordinarily for periods ranging from 6 - 12 months without spoilage. Reconstituting these into soup compared favourably with the fresh vegetables. Similarly, blanched leafy vegetables packed in polythene bags have been stored at freezing temperatures for 6 - 12 months with no adverse effects on their soup qualities.

2.5 Storage of Tomato

Storage condition of green and ripe tomatoes vary widely. Ripe tomatoes can only be stored for a short period at temperatures not below 5°c (Narkviroj and Ranganna, 1976). Partially ripe tomatoes may be stored for 7 - 10 days at 5 - 10°c (Anon, 1960). If the temperature falls below 5°c, rapid decay may occur after removal from the cold room. The most satisfactory results have been obtained with fruit picked soon after the beginning of ripening and held at 21°c. The temperature of ripe fruit could be dropped for a period of time without deterioration provided it is consumed on the day of removal from cold storage (Truscott and Warner, 1966). Green tomatoes are even more susceptible to cold temperature, and the minimum temperature should not be less than 12 - 15°c (Narkviroj and Ranganna, 1976). At lower temperature, the ripening

process may be interrupted altogether, and after storage for over a week, they may not ripen properly after removal from storage. The concentration of malic acid in the pericarp declined during chilling, but citric acid accumulated. Citric acid was considerably higher after ripening of fruit chilled for 21 days than in non-chilled fruit. Sucrose and fructose levels declined during storage while the concentration of glucose remained fairly constant. Both glucose and fructose levels were lower in fruit ripened after 14 and 21 days of low temperature storage than in non-chilled fruit (Buescher, 1975). The green tomatoes can be stored for 3 - 5 weeks at 12 - 15°c. Ripening of green tomatoes may be accelerated by storing at 18 - 24°c which is the optimum temperature range for the formation of lycopene, the pigment responsible for the red colour of tomato (Sayre et.al.,1953).

The fruit ripen even faster, if stored at temperature higher than 25°c, but are apt to decay too quickly on removal from storage. Above 30°c, the formation of lycopene is inhibited, the fruit being yellow to orange in colour. Relative humidity of the air should be 80 - 85 percent for good storage (Narkviroj and Ranganna, 1976).

The storage life of tomatoes can be extended when stored at pressure from 125 - 260mm Hg (Wu et.al.,

1972). Pairat and Ranganna (1976) stated that the loss of chlorophyll from the fruit is delayed by storage at sub-atmospheric pressure; the lower the pressure the greater the delay. Lower pressure hinders the synthesis of lycopene and B-carotene; the lower the pressure the longer the inhibition. In tomato, the ripening process is accompanied by decrease in chlorophyll and starch, and an increase in lycopene, B-carotene, sugar and flavour. Therefore, the inhibition of these changes under the sub-atmospheric pressure can be attributed to the inhibition of ripening processes of the fruit. Low oxygen atmospheres inhibited ripening, and thus increased the storage life at 12.78°c (55°F) of tomato fruit (Narkviroj and Ranganna, 1976).

The maximum life of tomato fruit at 1 percent oxygen (O_2) and 99 percent nitrogen (N_2) storage was 87 days (Salunkhe and Wu, 1972). Low oxygen atmospheres inhibited degradation of chlorophyll and starch, and synthesis of lycopene, beta-carotene, and soluble sugars (Narkviroj and Ranganna, 1976).

Storage of tomato in water resulted in cracked fruit, the cracking being more severe in round shaped than the pear shaped varieties. However, cracking was controlled to a large extent by reducing the temperature of water. Microbial fermentation was

controlled for 4 hours by a prior dip in chlorinated water, which also prevented the growth of mould (O'Brien et. al., 1963).

Treatment of tomatoes with wax emulsion containing maleic hydrazide (MH 40) has been found to extend the storage life of green or partially ripe tomatoes by 50 percent as compared to untreated when stored at room temperature (25 - 28°C) (Srivastava, 1962). Further, ripening is uniform and the red colour developed is more deeper and richer.

Herregods (1969) discussed the different symptoms of breakdown during the storage of tomatoes and factors affecting the storage of tomatoes. He attributed the symptoms of breakdown as: (i) too low or too rapid colouring (ii) softening of the fruits (iii) moulds breakdown. Even at low temperature (2 to 8°C) Herregods (1969) found an increase of red pigments with pink and red tomatoes. With green tomatoes at 2 to 8°C the increase of red pigments is very low.

Hall (1961, 1963) found a decrease of total carotenoids at 5°C; (Apeland 1960) also found a decrease of red pigments at 2 and 8°C with pink-red, not with green tomatoes.

Softening of the fruit increases more at high temperatures about 15°C and low temperatures 2°C than at medium temperatures of 8 to 12°C (Herregods, 1969).

At high temperatures of 15°C the attacks of mould are higher than at lower temperatures. However, after a storage period at low temperatures of about 2°C during 8 - 10 days, tomatoes become very susceptible to moulds invasion after storage.

However, Herregods (1969) recommended a storage temperature of 15°C with pink-green, 10°C with pink and 8°C with red ones as optimal storage temperature for tomatoes. With this, a storage period of 2 to 3 weeks is possible. Truscott and Bruchacher (1967) found that the most successful procedures for storage of tomatoes was to hold tomatoes 10 days at 10°C following by a ripening period at 21.1°C (2 to 6 days) and a storage period at 10°C (8 to 10 days).

Herregods (1969) recommended that to inhibit rots a low relative humidity (R.H.) of 70 - 75% is effective.

Lockhart and Eaves (1967) found that rots were controlled at 69 - 70% R.H., but at 86 - 92% R.H. considerable fungal rotting was evident after 20 days.

2.6 Factors influencing the Design and Development of post-Harvest Handling Systems for Fruits and Vegetables

To design and develop an efficient post harvest handling and storage system,, a sound knowledge of fruit response to mechanical stress, temperature, humidity, atmospheric composition and other factors is needed. The situation of the consumer should also be understood. Increased investment in improved post harvest systems is only justified if the consumer can pay for the increased cost. The success of new technology depends on how well it can be integrated into the existing system, as well as the effectiveness of the technology itself (Liu, 1987).

2.6.1 Response to various Temperatures, Humidities, and Atmosphere

Refrigeration is one of the most effective ways of extending the post harvest life of fruits. When economic conditions permit, refrigeration is often recommended for shipping and storage of fruit. However, many fruits of tropical and subtropical origin, and some fruits of temperate origin are sensitive to chilling injury (Bramlage, 1982; Couey, 1982; Hardenburg, et.al., 1986).

In addition, all fruit is sensitive to freezing injury. Therefore, the response of each

fruit to different degrees of low temperatures need to be studied thoroughly. Tolerance to high temperatures also needs to be studied. Many tropical and subtropical fruits develophigh temperature injury before being shipped to market. The high temperatures fruit may encounter may be in the field, if the fruit lacks proper protection from the sun, or in packages or stacks with poor ventilation.

Relative humidity also has a great effect on the post harvest life and quality of fruits (Grierson and Wardowski, 1978). Some fruits require high relative humidity (90 - 95%), while others may require slightly lower humidity (Hardenburg et.al., 1986). Those fruits which cannot tolerate high humidity or occasional water condensation on the skin are not kept in polymetric film bags.

Many other fruits beside apples and pears have a positive response to controlled atmosphere (CA) and modified atmosphere (MA) storage (Kader, 1985). Some fruits respond favourably to CA or MA even at relative high temperatures. Banana is one example of such a fruit (Liu, 1970; Liu et.al., 1972). Each fruit has its beneficial range of O_2 and Co_2 combinations, and its injurious levels may change with temperature, duration of exposure and the physiological age of the fruit. This kind of information is

useful in developing handling methods, particularly if CA or MA storage or packaging is to be considered. The information will also be useful for identifying disorders caused by low O_2 or high Co_2, or a combination of the two, if the fruit is accidentally exposed to such conditions. In addition to O_2 and Co_2 concentrations, ethylene accumulation in the storage atmosphere can have a significant effect on the post harvest life of fruit (Reid, 1985). The sensitivity of fruit to ethylene depends on the species and varieties concerned, and the physiological age of the fruit, as well as on the temperature and the O_2 and Co_2 concentrations.

Many fruits, such as avocado, banana, mango and papaya, are often harvested at the "mature green" or partially ripe stage and ripened after harvest. The ripening treatment, such as ethylene application, and the ripening environment they receive, including temperature, humidity, and O_2 and Co_2 concentrations affect the quality of the fruit after it ripens. The currently recommended best ripening temperatures for various fruits differ slightly according to the species, but are mostly within the range 16^{o} - 27^{o}c (Hardenburg et.al., 1986). However, there is some evidence that the best ripening temperature of any one kind of fruit may vary according to the growing

conditions, and therefore, reassessment of the temperature may be necessary for different production areas.

Many published research papers give only the best temperature, humidity, or controlled atmosphere for each fruit. This information is often not sufficient for practical application. Too often, the best conditions are difficult to obtain or economically unfeasible. There are occasions when the second best or third best condion is most practical. Therefore, researchers should be encouraged to collect and report data covering a wide range of conditions, and include harmful as well as beneficial ones.

2.6.2 Resistance to Mechanical Stress

Mechanical damage, such as bruises, cuts, breaks, deformation, and invisible wounds which lead to fungal attack and physiological disorders, is a major cause of post-harvest losses of fruit. Damage may occur during harvesting, handling, transportation or marketing (Liu, 1987). Iit is easy to blame workers for not being careful enough, or sinply to tell them there is need to be more careful in harvesting and handling fruit. Some small fruits such as straw berries and raspberries should be handled more gently. Other fruits which have relatively tough rinds are more resistant to mechanical stress. Provision of information by researchers on

what level of compression; abrasion and impact forces a fruit can withstand and on which practices are likely to cause damage and which are not, are likely to guide the Engineers and designers to design suitable handling machinery and containers.

2.7 Biological Heat Generation Equations in Fruits and Vegetables during Storage

Gyorgy and Elsevier (1986) gave the biological heat generation equation in fruits and vegetables as:

$$q = q_o e^{b\theta} \qquad \text{2.1}$$

where,

θ = Temperature, ^oC

q_o and b are constants determined experimentally. Values of q_o and b are contained in Table 2.3.

Gyorgy and Elsevier (1986) also gave the loss of dry matter as a function of the quantity of heat released as:

$$Gm = 2.66 \times 10^{-4} q_o e^{b\theta} \qquad \text{2.2}$$

where,

Gm = loss of dry matter, $KJKg^{-1}h^{-1}$

q_o and b are constants determined experimentally.

Table 2.3: Values of q_o and b for some important fruits and vegetables.

Product	q_o		b($^oC^{-1}$)
	KJ $Kg^{-1}h^{-1}$	KCal $Kg^{-1}h^{-1}$	
Green peas	0.4	0.097	0.085
Straw berries	0.16	0.038	0.094
Peaches	0.083	0.020	0.114
Cucumbers	0.071	0.017	0.119
Carrots	0.048	0.0116	0.132
Apples	0.043	0.0104	0.093
Potatoes	0.036	0.0086	0.062
Onions	0.039	0.0094	0.067
Sugar beet	0.026	0.0062	0.084

The time (period) required to release a quantity of heat in bulk materials as given by Gyorgy and Elsevier (1986) is:

$$t = \left(\frac{c}{q_o\, b}\right)\left(\frac{1}{e^{b\theta_1}} - \frac{1}{e^{b\theta_2}}\right) \quad \text{2.3}$$

where,

t = cooling period, min
e = product specific heat, $KJKg^{-1}h^{-1}$
θ_1 = Initial temperature, ^oC
θ_2 = Final temperature, ^oC
b = constant

This equation is based on the assumption that the total quantity of heat released is spent in increasing

the temperature of the material since the heat conduction coefficient of bulk material is low, and so significant heat-conduction into the environment can be neglected.

The quantity of heat released in piles during cooling may be calculated approximately according to the equation (Gyorgy and Elsevier, 1986).

$$q = \left(\frac{c}{\alpha F'}\right) q_o \left[4\Delta\theta/(\Delta\theta+1)+\left(\frac{1}{b}\right)\left(2-\frac{1}{\Delta\theta}\right)\right]\left(e^{b\theta_1}-e^{b\theta_2}\right) \text{----2.4.}$$

where,

q = Quantity of heat released in piles, KJ

F^1 = Surface area of 1kg of material, m^2

$\Delta\theta$ = Change in temperature (^oc)

α = Heat coefficient ($KJM^{-2}h^{-1}c^{-1}$)

C = Product specific heat, $KJKg^{-1}h^{-1}$

θ_1 = Initial temperature, ^oC

θ_2 = Final temperature, ^oC

q_o & b = Constants

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Also, in storing sugar beet, a close correlation exists between q_o and the daily sugar loss (Gyorgy and Elsevier, 1986).

$$q_o = 1.65\,Mc \text{ ------ 2.5}$$

where, Mc = daily sugar loss as a weight-percentage of beet.

q_o = constant.

2.8 Moisture Exchange Equations of Fruits and Vegetables with the Air

For high quality storage of fruits and vegetables there are two basic requirements: uniform maintenance of the optimal temperature, and preservation of moisture content. The moisture content of fruits and vegetables is generally 80 - 85% (Gyorgy and Elsevier, 1986). However, with the loss of only a few percent of the moisture content, the turgor pressure decreases, the product begins to wither and its resistance to damage and shelflife decreases. At the same time condensation on the surface of the product must be avoided since it also decreases the preservability.

The natural removal of water during the storage of agricultural products is a result of relative slow diffusion processes, in which diffusion due to concentration differences plays the main role, while the thermal diffusion and other phenomena are generally negligible. The exchange of moisture between fruits or vegetables and the air may be described well by Dulton's law, which states that the moisture removed in unit time may be expressed as:(Gyorgy and Elsevier, 1986).

$$G = \beta \gamma F (C^{1}s - C_s \phi) \text{ - - - - } 2.6$$

where,

C^1_s = Concentration of saturated water vapour on the surface of the material, Kgm^{-3}.

C_s = The concentration of saturated water vapour in air, Kgm^{-3}.

ϕ_r = Relative air humidity, %.

γ = Moisture exchange coefficient of the material.

β = Evaporation coefficient (relative to the free water surface).

The coefficient, γ expresses the proportion of the product's surface area which may be taken into account as a free water surface in terms of moisture exchange and it is established experimentally.

Green peas has high value of γ which indicates a very intense moisture exchange. It can dissipate water very rapidly. In contrast, onions have low γ value and dissipate water very slowly, and may thus be kept for a long time, even under ambient conditions, without moisture loss. The moisture content of products grown on irrigated fields is generally higher, but they also discharge water more easily and so their value are higher. These products require more careful storage and are less preservable.

Table 2.4 lists γ Values for some fruit and vegetable products (Gyorgy and Elsevier, 1986).

Table 2.4: γ Values for some fruits and vegetable products.

Product	γ
Apples (Summer)	0.025 - 0.030
Apples (Winter)	0.011 - 0.014
Pears	0.015 - 0.020
Cherries, sour Cherries	0.15 - 0.18
Potatoes	0.009 - 0.012
Carrots	0.35 - 0.40
Red beet	0.2 - 0.3
Sugar beet	0.25 - 0.30
Sugar beet (Irrigated)	0.35 - 0.45
Onions	0.002 - 0.003
Cabbages	0.37 - 0.45
Green peas in shell	0.7 - 0.8

The heat introduced into a product during aeration in changing the enthalpy of material and in evaporation can be expressed as (Gyorgy and Elsevier, 1986):

$$Q = \alpha F \Delta\theta + \beta\gamma F \Delta C r \quad ---- \quad 2.7$$

where,

r = heat of evaporation

α = Heat coefficient, $KJm^{-2}h^{-1}C^{0-1}$

$\Delta\theta$ = Change in temperature, ^{o}C

γ = Moisture exchange coefficient of the material

β = Evaporation coefficient

ΔC = Concentration difference

The ratio of the quality of heat introduced and the amount of moisture removed is a quantity which can be used to characterize a conditioning process; its value is expressed as:

$$\frac{Q}{G} = \left(\frac{\alpha}{\beta}\right)\left(\frac{L}{\gamma}\right)\left(\frac{\Delta\theta}{\Delta C}\right) + r = \frac{\Delta i}{\Delta x} \qquad 2.8$$

The ratio α/β in equation 2.8 may be determined, by means of the analogy of heat and mass transfer by the relationship.

The ratio of Nusselt numbers, $\frac{Nu}{Nu^{1}} = 1$, From which $\alpha/\beta = \lambda/D$ and its value for the temperature range 0 - $20^{o}C$ is 1.21 - 1.25 $KJM^{-3}\ h^{-1}$ (0.29 - 0.30 K Cal $M^{-3}h^{-1}$). The ratio $\frac{\Delta\theta}{\Delta C}$ affects the moisture exchange significantly. The concentration difference, ΔC is a function of temperature and of relative humidity. The saturated concentration may be calculated in the interval -2 to +4 ^{o}C to good approximation using the equation (Gyorgy and Elsevier, 1986):

$$C_s = (4.9 + 0.35\ \theta) \times 10^{-3} \qquad 2.9$$

The ratio can be determined graphically.

The amount of moisture removed during cooling may be calculated on the basis of equation 2.8 with appropriate substitution of the quantity of heat, Q (Gyorgy and Elsevier, 1986):

$$G_o = [c(\theta_1 - \theta_2) + q] / [(\alpha \Delta\theta / \beta\gamma\Delta c) + r] \ (Kg\,Kg^{-1}) \quad \text{--- 2.10}$$

where,

θ_1 and θ_2 are respectively the initial and final temperatures of the material, and q is the quantity of heat released in the material according to equation 2.4. By the end of the cooling process the equilibrium temperature, θe of the material and the temperature θk of the medium may develop differently in relation to each other. For lower relative humidities, $\theta k > \theta e$, as the intense evaporation implies additional heat removal. At a certain relative humidity, $\theta k = \theta e$, while in the case of $\emptyset = 1.0$, generally $\theta k < \theta e$. The main test during the storage is the preservation of moisture in the material, so the first case is unfavourable and is to be avoided. The conditioning parameters are usually determined for the second case ($\theta_k = \theta e$), since the moisture loss is then minimal.

In the latter case, physiological heat is removed by cooling via evaporation, . (Gyorgy and

Elsevier, 1986): i.e.

$$G = q_o \, e^{bQ} / r \ (Kg\ kg^{-1}\ h^{-1}) \ - - - \ 2.11$$

The relative humidity ϕ corresponding to the condition $\Theta_k = \Theta e$ may be determined on the basis of the heat balance,

$$1 - \phi = q_o \, e^{be} / 2069 \propto F^1 \gamma \, Cs \ - - - \ -2.12$$

If all the heat released is removed by evaporative cooling, the temperature of the air passing through the pile will not change.

However, the air takes up moisture, and so it may occur that air of already high relative humidity will become saturated with moisture and condensation will appear in the upper layers. Therefore it is advisable to select parameters ensuring that the relative humidity of the cooling air remains nearly constant during its passage. This requires that the ratio of the sensible and latent heats has a preset value, such that the cooling air will be heated by a few degrees centigrade during its passage, and so its relative humidity will not be increased by any moisture taken up.

Related investigations have shown that the optimum value of the ratio Q/G determined by means of equation 2.8 is 6278KJkg^{-1} (1500KCal kg^{-1}) at around 0^{o}c, from which the optimum ratio of the sensible and

latent heats during the cooling process may be determined. The ratio of the sensible heat (Q^1) to the total quantity of heat may be written as -

$$\frac{Q^1}{Q} = (Q - G_r)/Q = 1 - (r/Q/G) = 1 - \frac{(600/1500)}{} = \underline{0.6}$$

This means that 60% of the total quantity of heat is sensible heat and 40% latent heat in the optimal case. On the basis of this result, equation 12 was modified, since 40% of the total physiological heat q is removed by evaporation (Gyorgy and Elsevier, 1986).

NOW,

$$1 - \phi = 0.4\ q_o\ e^{b\theta/2069 \alpha F^1 \gamma Cs} \text{--- } 2.13.$$

The equilibrium temperature of a material at the end of cooling may be calculated from the heat balance, (Gyorgy and Elsevier, 1986).

$$\theta_e = q_o\ e^{b\theta/\alpha F^1} + \theta_k - 9.97\ (1-204Cs\phi))/(1+0.7122\ r) \text{--- } 2.14.$$

The total loss of a stored product is the sum of the dry-substance loss due to oxidation, and the removal of moisture. Table 2.4 lists the Critical relative humidity values for some characteristic products as given by Gyorgy and Elsevier, (1986).

Table 2.5: Critical Relative humidity values for some characteristic products.

Product	θ_k(oC)	dc (m)	$KJm^{-2}h^{-1}C^{o-1}$	γ	ϕ(%) Eqn. 12	ϕ(%) Eqn. 13
Carrot	2	0.035	19.88	0.35	99.5	99.8
Potatoes	2	0.045	17.58	0.012	86.4	94.5
Cabbages	2	0.18	9.63	0.37	96.9	98.7
Apples	2	0.06	15.36	0.014	79.2	91.6
Onion	2	0.05	16.74	0.003	38.0	75.0

2.9 Physics of Water Storage

2.9.1 Molecular and Capillary adsorption

Gyorgy and Elsevier (1986) reported that water is stored by biological materials in two ways: by molecular and by capillary adsorption. There is an essential difference between the two state modes. Starting from completely dry material, water is bound first by molecular adsorption, and then by capillary adsorption only after a certain moisture content has been attained. The two processes are explained below.

2.9.1.1. Molecular adsorption

During molecular adsorption, molecules of water are adsorbed very close to the cell walls (at a distance of order of magnitude 10^{-7}cm, comparable to the diameter of the water molecule), and adhere by attractive forces to the surface molecules.

The attractive force acting on the first layer of water molecules is the greatest, and the force decreases gradually for subsequent layers. The field of molecular forces holds the water molecules under a pressure which is proportional to the attractive force, whereby the density of the water increases and pressure (compression) develops in the system. Thus the volume of the product increases (i.e. the product swells) on adsorption of water, but by an amount somewhat less than the volume of this water owing to the pressure caused by the attractive forces. Molecular adsorption is accompanied by heat generation, whose value is 840 - 1680 KJ kg^{-1} water (200 - 400 kcal kg^{-1}) (Gyorgy and Elsevier, 1986).

2.9.1.2 Capillary adsorption

During capillary adsorption, water is retained by means of surface tension forces in the capillary sized cavities found in cellular systems. The surface tension of water is 76×10^{-3} N/m at °C, and decreases linearly with temperature according to the relationship (Gyorgy and Elsevier, 1986).

$$\sigma = 75(1-0.0020\ \theta) \text{ - - - } 2.15$$

Where, θ = Temperature (°C), σ = Surface tension.
The molecular pressure about a liquid surface is a function of the curvature. The surface of wetting liquids found in capillaries is concave, and for small capi-

llaries the radius of half-spherical surface is identical to that of the capillary. In this case the capillary pressure is negative, and its value is (Gyorgy and Elsevier, 1986)

$$P = 2\sigma/r \quad ----- \quad 2.16$$

where, r is the radius of capillary

Liquid rises in a capillary tube, owing to wetting and to capillary pressure, to a certain height h, whose value is (Gyorgy and Elsevier, 1986).

$$h = 2\sigma/r\, g\rho_w \quad --- \quad 2.17$$

where,

ρ_w = density of the liquid.

g = acceleration due to gravity.

r = radius of capillary

From this relationship, it follows that the capillary rise is inversly proportional to the capillary radius. The smaller the radius, the higher the capillary rise.

A consequence of capillary pressure is that the saturated vapour pressure over a concave surface is lower than over a plane surface. The relative vapour pressure may be calculated from Thompson's formular (Thompson, 1967).

$$\phi = Pg/Ps = \exp - (2\sigma\rho_g/\rho_s\rho_w r) \quad --- \quad 2.18$$

where, ϕ = Relative Vapour Pressure

Pg and ρ_g are the pressure and density of the water vapour in the capillary respectively.

Ps = The pressure of saturated vapour over a free water surface.

This relationship may be applied to capillaries whose radius is in the interval $0.5 \times 10^{-7} - 10^{-5}$cm. The variation of Ø as a function of capillary radius at 20°c is shown in Table 2.6 as given by Gyorgy and Elsevier, 1986).

Table 2.6: Variation of Ø as a function of capillary radius at 20°c.

Ø	r(x10^{-7}cm)	Ø	r(x10^{-7}cm)	Ø	r(x10^{-7}cm)
0.05	0.36	0.45	1.56	0.90	21.9
0.10	0.46	0.50	1.80	0.95	26.3
0.15	0.57	0.55	2.11	0.96	35.3
0.20	0.67	0.60	2.5	0.97	53.3
0.25	0.78	0.65	3.01	0.98	106.6
0.30	0.89	0.70	3.73	0.99	1077.6
0.35	1.17	0.75	6.51	0.999	10770.0
0.40	1.34	0.85	10.23	1.0	∞

If the radius of the capillary exceeds 10^{-5}cm, then the saturated vapour pressure over the meniscus agrees practically with the vapour pressure over a free water surface.

A cavity in a body may be termed capillary until the surface of the liquid found in it is determined mainly by surface tension and the effect of the

weight force is negligible. This unit is at a radius of about 10^{-3} cm. On removal of moisture; energy must be impacted to a system. In the case of free water this energy is the latent heat of evaporation. Its value is 2385 KJ Kg^{-1}.

2.10 Principles of Evaporative cooling and Humidification

2.10.1 Principles of Evaporative cooling

In the broadest sense, the evaporative cooling appies to all equipment that exchanges sensible heat for latent heat. Coding apparatus, air washers and packaged evaporative coolers utilize the principle. The evaporative air coolers fall into two general categories: (1) apparatus for air cooling and (2) apparatus for heat rejection. Evaporative air cooling applies the well-known process of evaporating water into an air stream. The following themodynamic changes can take place between air and water:

1. Water is constantly recirculated so that it soon reaches an equilibrium with the thermodynamic wet bulb temperature of the air becoming the same. The constant temperature water lowers the dry-bulb temperature of the entering air so that it approaches the water temperature. This is an adiabatic heat transfer process in which the wet-bulb temperature of the air remains constant, but the dry bulb temperature drops as the humidity rises.

2. If the air is heated, the warm water entering the apparatus will be cooled as the wet-bulb temperature of the air is increased. In such a heating process, the final water temperature approaches the final wet-bulb temperature of the air.

3. If the air is cooled, the cold water entering the apparatus will be warmed as the wet-bulb temperature of the air is lowered. In such a cooling process, The final water temperature of the air will always be higher than the final water temperature evaporative air cooling equipment may be placed in two general classes, direct and indirect. The direct class uses primary wet surfaces which evaporate water directly into the air supplied to the space being cooled. This may be done with a series of sprays as in air washer or by use of an extended wetted-surface material as in packaged air coolers. The indirect class coolers uses the evaporative principle to cool air or water in a device such as a cooling tower. The resultant cool air or water is then used by means of a secondary heat exchanger to cool the air in the occupied space. More complex arrangements of this principles have been used. By applying recirculating, regenerating principles, temperatures below the initial wet-bulb may be produced.

2.10.2 Principles of Humidification

Air may be humidified by passing it through a water spray or over saturated pads thus adding moisture to the air by an adiabatic process. The cooled air is then heated to the desired temperature.

There is a difference between domestic humidification and industrial humidification, even though the same equipment and the same method of calculating can be used. In residential humidification, also called comfort humidification, a humidity range from 20 to 60 percent is permissible since the human body is comfortable within that range (ASHRAE, 1963). In process humidification, the humidity control must be much closer and in many cases the relative humidity maintained must be higher. In comfort humidification, the determining factor then becomes the design of the building. In process humidification, the humidity must be maintained irregardless of the ability of the building to withstand the effect of high humidity. The relative humidity to be maintained would vary with the product being produced and may vary with a specific product, depending on the process being done at the time.

Types of Residential humidifiers include: pan-type, Externally heated pans, pans with wicking-type ploutes, Evaporative pads, sprays and Atomizing type. Industrial humidifiers are available in many types; including: centrifugal atomizer, steam coils, evaporative pad-type (evaporative coolers) and air washers (both spray and cell-type).

The humidifier capacity required will be determined by the following factors: (1) The volume being humidified (2) The air change rate (3) The design conditions and (4) other sources of humidity.

The amount of humidity required can be calculated with the following formula (ASHRAE, 1963)

$$H = VR\ (W_i - W_o) \qquad \text{2.19}$$

where

H = Kg_s of moisture per second required to maintain indoor design conditions.

V = Volume to humidified, m^3

R = Number of changes of air per second

w_i = Kg_s of moisture per Kg of dry air at desired indoor conditions (from psychrometric chart).

w_o = Kg_s of moisture per Kg of dry air at desired outdoor conditions (from psychrometric chart).

The extent to which the leaving air temperature approaches the thermodynamic wet-bulb temperature of the or the extent to which complete saturation is approached with air washed is expressed by a ration known as humidifying effectiveness or saturating effectiveness, and is defined as (ASHRAE, 1963).

$$e_h = \frac{t_1 - t_2}{t_1 - t'} \times 100 \qquad \text{2.20}$$

where

e_h = humidifying or saturating effectiveness, %

t_1 = dry-bulb temperature of the entering air, ^oC

t_2 = dry-bulb temperature of the leaving air, ^oC

t^1 = thermodynamic wet-bulb temperature of the entering air, ^oC.

2.11 Cooling And Humidification Efficiencies of Evaporative cooling system

The cooling and humidification efficiencies of evaporative cooler respectively, can be compared to the refrizeration system efficiency with the use of psychometric chart at constant enthalpy and the following equations

$$\eta_c = \frac{T_1 - T_2}{T_1 - T_s} \times 100 \qquad \text{2.21}$$

$$\eta_H = \frac{w_2 - w_1}{w_s - w_1} \times 100 \qquad \text{2.22}$$

where

η_c = cooling efficiency, %

η_H = humidification, %

T_1 = dry-bulb temperature of the entering air (ambient), ^oC

T_2 = dry-bulb temperature of the leaving air (storage temperature), ^oC

T_s = thermodynamic temperature of the air at saturation, ^oC (determined from psychometric chart)

w_1 = moisture content of the entering air, Kg/Kg dry air.

w_2 = moisture content of the leaving air, Kg/Kg dry air.

w_s = moisture content of the air at saturation, Kg/Kg dry air.

The process is represented in figure 2.1.

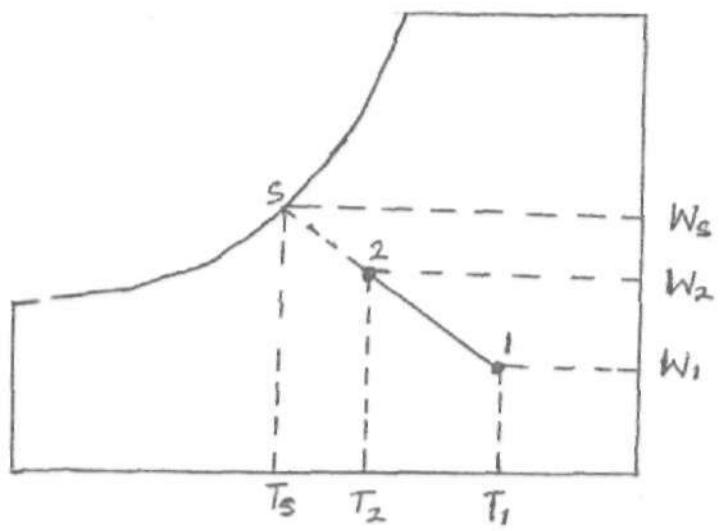


Fig. 2.1: Cooling process diagram

CHAPTER THREE

3. DESIGN METHODOLOGY

3.1 Design Considerations

Before the design of the storage equipment, it is necessary to consider certain design parameters based on the physical Engineering properties of the crop (Tomato) and its response to mechanical stress, temperature, humidity and atmospheric composition. Therefore, the following factors were considered in the design of the storage equipment:

3.1.1 Bulk density

The bulk density of Tomatoes was determined experimentally by weight volume method under natural filling conditions, in order to estimate the Theoretical capacity of the storage equipment and the tray dimensions.

25.75kg of green tomatoes occupied a volume of $7.62 \times 10^{-3} m^3$ of a standard container.

Therefore the bulk density can be calculated from the relation

$$Db = \frac{Ms}{Vs} \qquad 3.1$$

where,

Db = Bulk density (Kg/m^3)

Ms = Mass of samples (tomatoes) (kg)

Vs = Volume occupied by the samples (m^3)

$\therefore$ Db = $\frac{25.75kg}{7.62 \times 10^{-3}m^3}$ = 3379.26 kg/m^3.

3.1.2 Equipment capacity

Volume of each Tray = $7.2 \times 10^{-3}m^3$

Therefore, the capacity of each tray can be estimated from equation 3.1

$\therefore$ Capacity (Kg) = Db x Vs

= $3379.26kg/m^3 \times 7.2 \times 10^{-3}m^3$

= 24.33kg

3.1.3 Mechanical stress

In order to avoid mechanical damage such as bruises, cuts, deformation and invisible injury arising from Tomato to Tomato contact area which might lead to fungal attack and physiological disorder during the fruit storage, the tomato trays were designed to contain only single layer of tomatoes and the material of construction of the trays are free rough edges.

3.1.4 Temperature response

Many fruits of tropical and subtropical origin and some fruits of temperate origin are sensitive to chilling injury (Bramlage, 1982; Couey, 1982; Hardenburg et.al., 1986). For this reason, the storage equipment was designed to work by the

principles of evaporative cooling which provides no freezing temperature that would result in chilling injury of the crop during storage.

3.1.5 Relative humidity

Understanding the requirement and tolerance of each crop to humidity is important. Many fruits require higher relative humidity 90 - 95% (Liu, 1987) while others may require slightly lower humidity (Hardenbury et.al., 1986). This storage equipment is constructed with Hessian sack which can absorb and retain water when wetted. This arrangement would result in high relative humidity of the air in the storage chamber from which evaporation takes place relative to the ambient air, which would be more conducive for tomato storage.

3.1.6 Volume of water required

The volume of water required to wet the Hessian sack was considered in order to estimate the sizes of the water troughs. However, a water volume of $1.12 \times 10^{-2} m^3$ and $3.025 \times 10^{-2} m^3$ was assumed for the Top and Bottom water troughs respectively.

3.1.7 Water Delivery and Distribution

To ensure easy delivery and distribution of water through the Hessian sack, two water troughs were designed and positioned on the top and bottom of the storage equipment.

3.1.8 Structural size of the storage equipment

It was envisaged that the structural size of the storage equipment might affect the shelflife of the stored tomatoes, as a result of this two different sizes of the storage equipment were considered.

3.1.9 Type and Layer of Cover material

In order to ensure effective cooling of the stored product, a Hessian sack was considered as a suitable material for the design due to its ability to absorb and retain water for a long duration. It was anticipated that the number of layers of the Hessian sack might affect the shelflife of the stored products, therefore two of the storage equipment were constructed with single and double layers of the Hessian sack.

3.1.10 Tray Dimensions

Assuming the tray has a square cross-section of length (L) and width (L) and a depth of 45mm, the dimension of the tray can be computed from the relation;

$$V = L \times b \times h \qquad 3.2.$$

where,

V = Volume occupied by the samples (tomatoes)

L = Length of tray

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l = Width of tray

v = $7.2 \times 10^{-3} M^3$ (estimated above)

∴ From equation 3.2

$$L^2 = V/h$$

$$\therefore L = \sqrt{v/h} = \frac{7.2 \times 10^{-3} M^3}{0.045m} = 0.16m^2$$

$$= 0.4m = 400mm.$$

∴ The required dimension of the tray =

400mm x 400mm x 45mm

3.1.11 Water Trough Dimensions

3.1.11.1 Top Water Trough Dimensions

A volume of $1.12 \times 10^{-2} m^3$ was assumed for the top water trough.

Assuming the water trough have a square cross-section of length (L) and width (L) and a depth of 70mm. The dimensions of the water trough can be computed using equation 3.2.

Length of the water trough = 400mm

Width of the water trough = 400mm

Therefore the estimated dimension of the top water trough = 400mm x 400mm x 70mm.

3.1.11.2 Bottom Water Trough Dimensions

A volume of $3.025 \times 10^{-2} M^3$ was assumed for the bottom water trough. The water trough is assumed

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to have a square cross-sectional area of length (L) and width (L) and a depth of 100mm.

Applying equation 3.2, the length of the bottom water trough = 550mm. The width = 550mm. Therefore, the estimated dimensions of the bottom water trough = 550mm x 550mm x 100mm.

3.1.12 The capillary pressure and height

3.1.12.1 Capillary Pressure

The capillary pressure of the storage equipment can be estimated using equation 3.3. as given by (Gyorgy and Elsevier, 1986).

$$P = 2\sigma/r \quad \text{——————} \quad 3.3.$$

where,

P = Capillary pressure

σ = Surface tension of water

r = radius of capillary.

The surface tension of water can be estimated using 3.4.

$$\sigma = 75(1 - 0.0020\theta) \quad \text{——————} \quad 3.4.$$

where,

σ = Surface tension (10^{-3} N/m)

θ = Temperature (^{o}C)

Assuming a room temperature of 20^{o}c

$\therefore$ $\sigma = 75(1 - 0.0020 \times 20) = 72$dyne/cm

$= 72 \times 10^{-3}$N/m.

Assuming the radius of capillary for the Hessian sack = 1.37×10^{-5}m.

The capillary pressure, P can now be estimated as

$$P = \frac{2 \times 72 \times 10^{-3} N/M}{1.37 \times 10^{-5} m} = \underline{10.51 KN/M^2}$$

The calculated capillary pressure is sufficient, since it exceeds the minimum capillary pressure (144N) as recommended by (Gyorgy and Elsevier, 1986).

3.1.12.2 Capillary Height

The capillary height (h) of the storage equipment can be estimated from equation 3.5 as stated by (Gyorgy and Elsevier, 1986)

$$h = 2\sigma / rg \rho_w \quad \text{_____} \quad 3.5.$$

where,

ρ_w = Density of liquid (water); $10^3 kg/m^3$

g = acceleration due to gravity; $9.81 m/s^2$

σ = surface tension of water ($72 \times 10^{-3} N/M$)

r = radius of capillary ($1.37 \times 10^{-5} m$).

$$\therefore h = \frac{2 \times 72 \times 10^{-3}}{1.37 \times 10^{-5} \times 9.81 \times 10^{3}} = 1.07m$$

Hence the estimated height of the storage equipment = 1.07m = 1070mm. The calculated height is adequate since it is calculated based on the required capillary pressure.

3.1.13 Overall dimension

The overall dimensions of the storage equipment is 450mm x 450mm x 1070mm (large storage equipment) and 450mm x 450mm x 535mm (small storage equipment).

3.1.14 Pressure on the floor of the Tray

Weight of tomatoes in each tray = 24.33 kg

Cross-sectional area of each tray = 400mmx400mm =

$= 0.16m^2$

Pressure on the floor of each tray can be estimated from equation 3.6.

$$P = F/A \qquad \text{3.6.}$$

where,

P = Pressure (N/M^2)

F = Load on the tray (N)

A = Cross-sectional area of each tray (m^2)

$$\therefore P = \frac{24.33 \times 9.81}{0.16} = 1491.73N/m^2 = \underline{\underline{1.49KN/m^2}}$$

Since the calculated pressure is less than the allowable stress for mild steel, mild steel cross netting wire is selected for the floor of the trays.

CHAPTER FOUR

4. CONSTRUCTION AND ASSEMBLY

4.1 The Storage Equipment

The storage equipment has four basic features which includes:

(1) The storage chamber

(2) Hessian sack

(3) Water trough

(4) Frame

The storage chamber consists of four trays where the Tomatoes are to be stored. The trays are constructed with wooden and cross netting wire materials. The storage chamber is covered by a hinged door to ease opening and closing .

The whole structure of the storage equipment is covered with water absorbing material (Hessian sack) which forms the cooling medium.

Two water troughs filled with water are positioned each at the top and bottom of the storage structure, in order to provide water for the continous wetting of the Hessian sack by gravity and capillary action. The water troughs are constructed with steel material and coated with oil paint to prevent rusting.

The whole structure sits inside the Bottom water trough to facilitate water movement through the Hessian sack.

4.1.1 Working Principles

The storage equipment works on the principles of evaporative cooling. The process of cooling is based on the transfer of heat from the storage chamber to the wet Hessian sack which encloses the cooling medium, from where the heat is also conducted across the outer by evaporation of water, aided by airflow.

The Hessian sack is wetted by water from the top and bottom water troughs through gravity and capillary action respectively.

Apart from the cooling, the evaporative action results in high relative humidity of the air in the storage chamber, making the atmosphere in the storage chamber more conducive for storage of tomatoes.

The detailed assembly drawings and sectional drawings are shown in Figures 4.1, 4.4; 4.2 and 4.3 respectively.

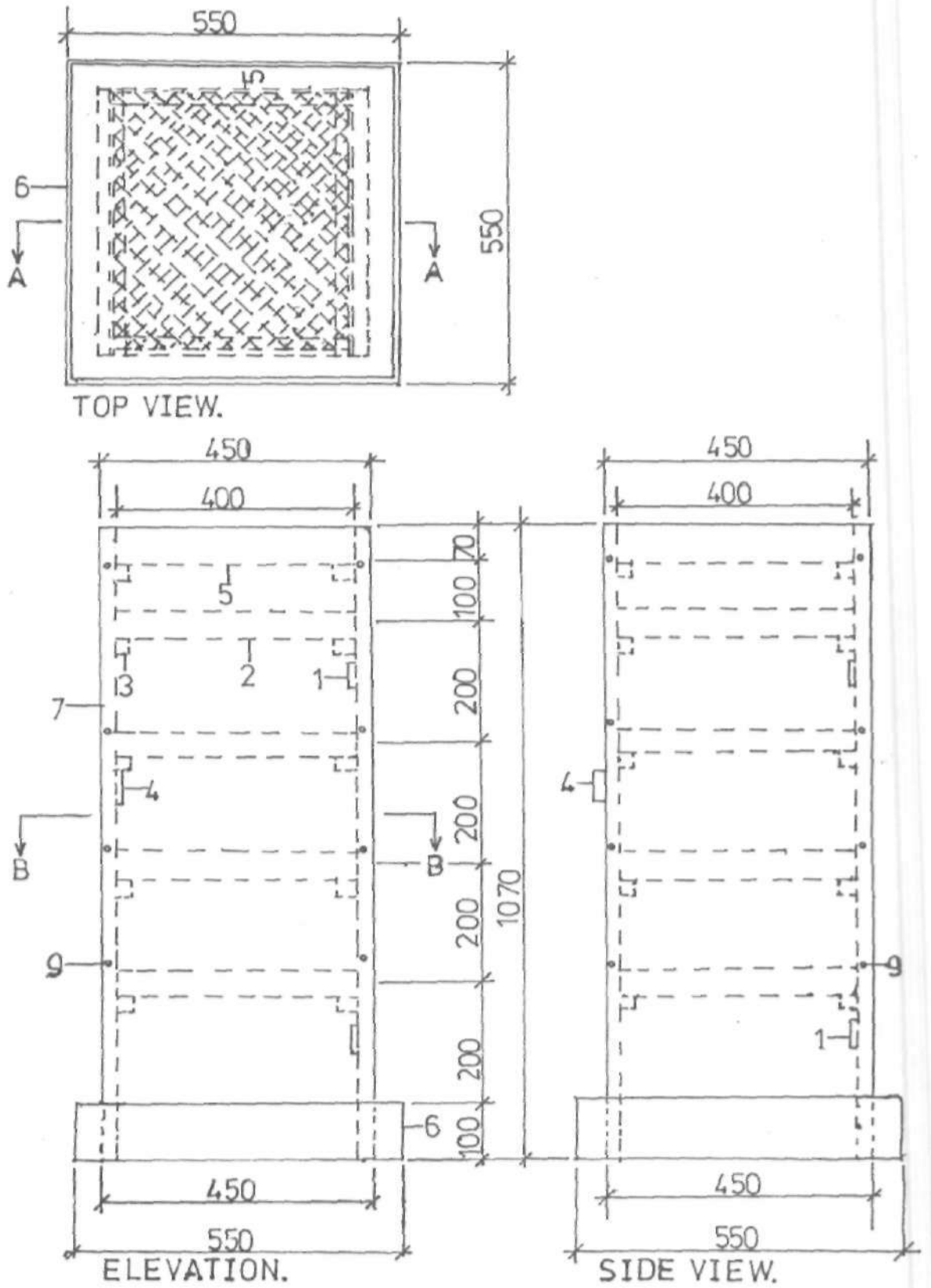


FIG.4.1: ASSEMBLY DRAWING(LARGE STORAGE EQUIPMENT.

Figure 4.1: Key for Assembly Drawing (Large storage equipment)

Number of part	Name of parts
1	Hinge
2.	Tray
3.	Wooden Support
4	Door Handle
5	Top water trough
6	Bottom water trough
7	Wooden Frame
9	Pin

Scale 1:10/Dimensions in mm.

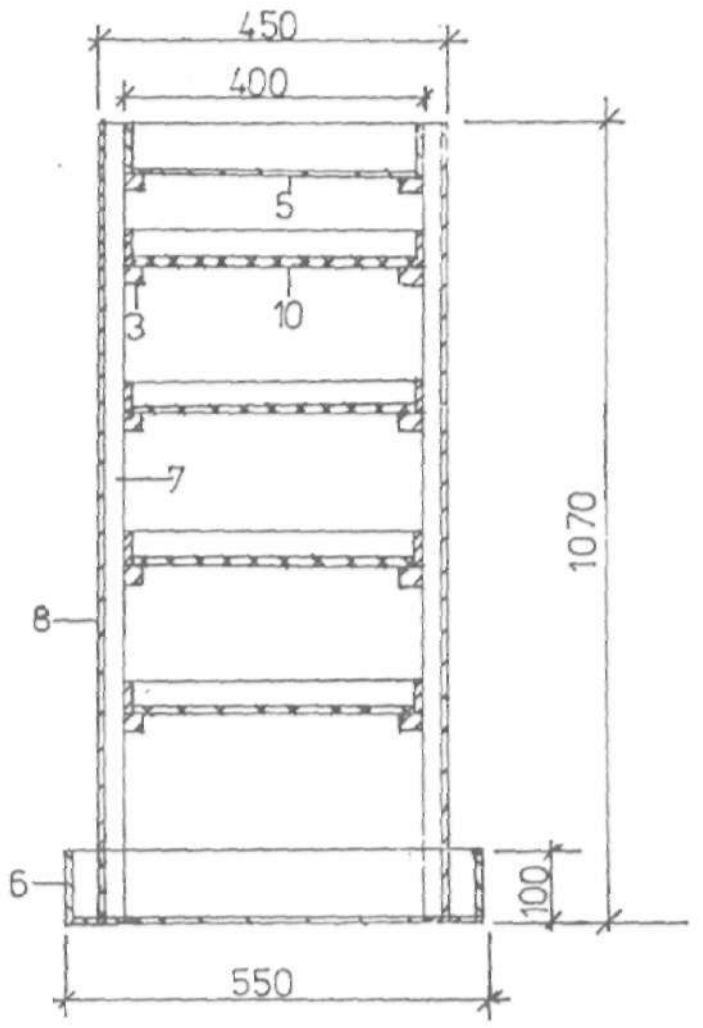


FIG.4.2: SECTION A-A

Figure 4.2: Section A - A

Number of part	Name of parts
3	Wooden Support
5	Top water trough
6	Bottom water trough
7	Wooden Frame
8	Hessian sack
10	Wire netting (Tray)

Scale 1:10/Dimensions in mm.

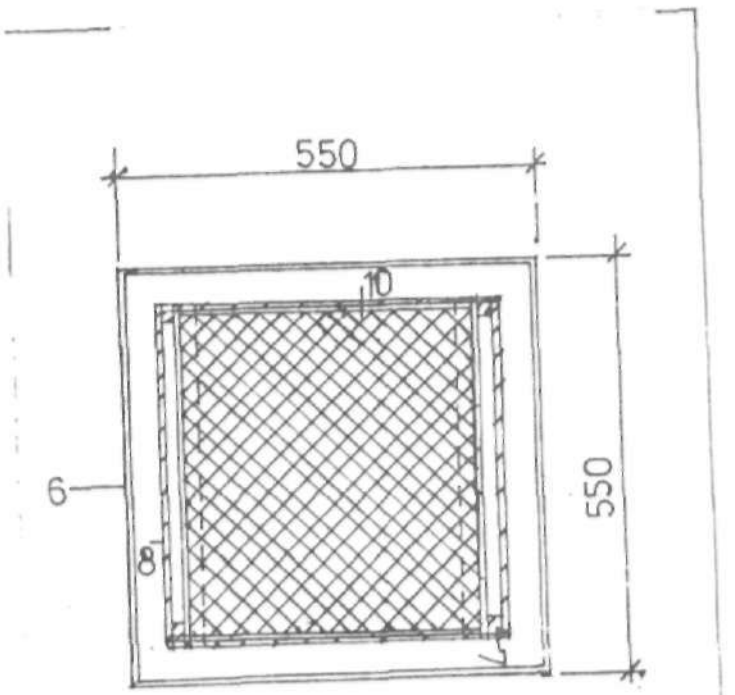


FIG.4.3: SECTION B-B.

Figure 4.3: Section B - B.

Number of part	Name of parts
6	Bottom water trough
7	Wooden Frame
8	Hessian sack
10	Wire netting (Tray)

Scale 1:10/Dimensions in mm.

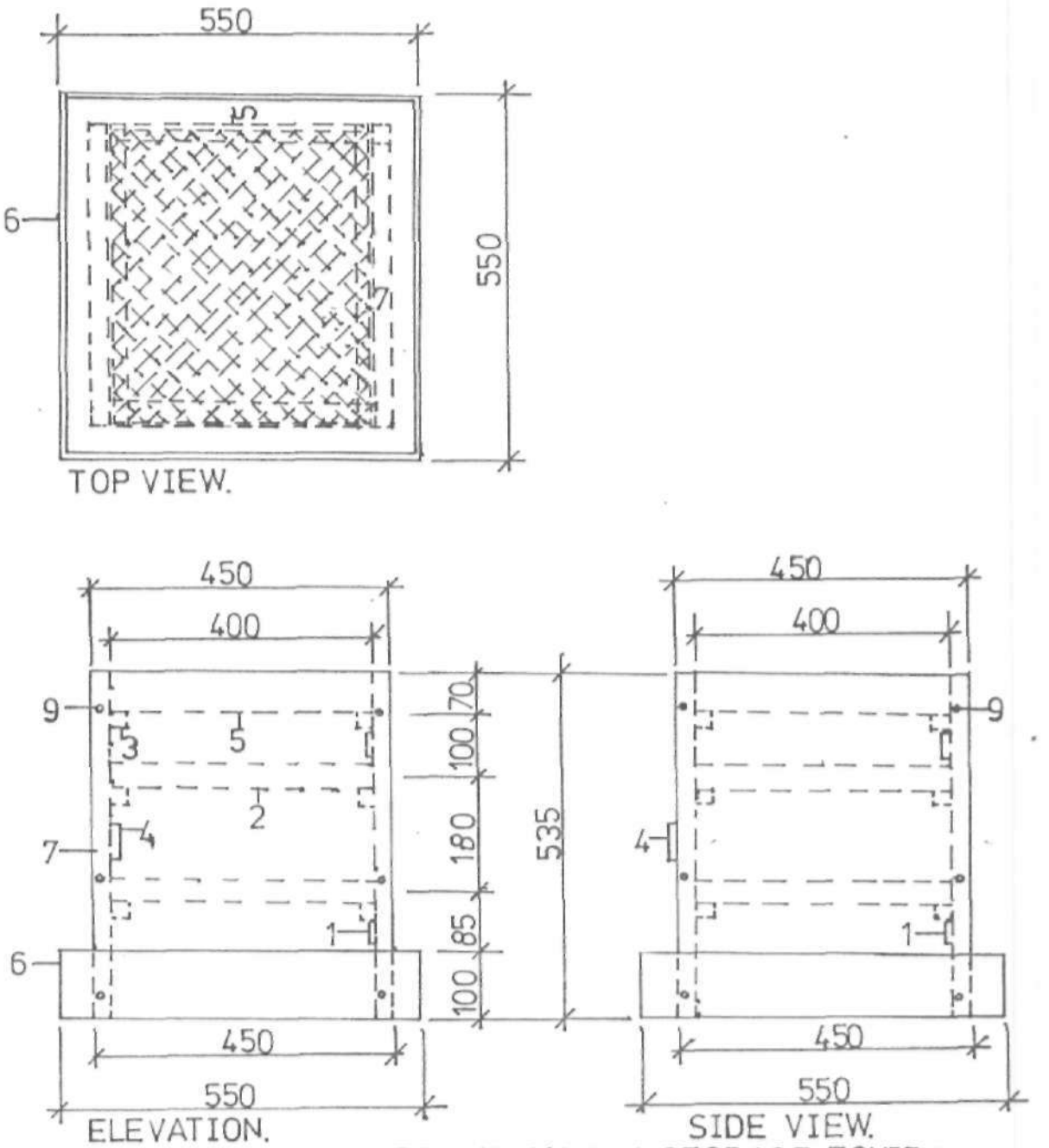


FIG. 4.4: ASSEMBLY DRAWING(SMALL STORAGE EQUIPMENT.

Figure 4.4: Assembly Drawing (Small Storage Equipment)

Number of part	Name of part
1	Hinge
2	Tray
3	Wooden Support
4	Door Handle
5	Top water trough
6	Bottom water trough
7	Wooden Frame
9	Pin

Scale 1:10/Dimensions in mm.

CHAPTER FIVE

5. EXPERIMENTAL PROCEDURE

5.1 Preliminary Experiment

A preliminary experiment was carried out during the Harmattan period, from 8 - 30th January, 1992. The experiment is aimed at investigating the effect of two variables; the size of the storage equipment and the number of layers of the Hessian sack on the shelflife of fresh tomato. The responses measured are: Temperature/ Relative humidity, of storage chamber, compressive resistance colour changes and the duration of storage.

However, to determine the number of equipment required to be constructed for investigating the two variables, there is the need to choose an appropriate experimental design.

For the purpose of this investigation, a factorial experiment was considered fit for estimating the main effects and interractions of the variables. The number of equipment to be constructed was determined using the 2^n series of the Factorial experiment as given by (Federer, 1963). Where, n is the number of variables. Thus, the number of equipment required for this experiment is $2^2 = 4$. The combination of the variables are shown in Table 5.1.

However, due to the replication of the experiment, the total number of equipment constructed was 8. Four large size types were constructed, two of which are covered with double layers of the Hessian sack while the rest two are covered with single layer. Plate 5.1 shows the large size types of the storage equipment. The overall dimension for the large types is 450mm x 450mm x 1070mm. The detailed assembly drawings for the large types is shown in Figure 4.1 while the two sectional drawings (A - A) and (B - B) are shown in Figures 4.2 and 4.3 respectively.

Also, four of the small size types were constructed, two of which are covered with double layer of Hessian sack while the rest are covered with single layer of the Hessian sack. Plate 5.2 shows the small size types of the storage equipment. The overall dimension of the small types is 450mm x 450mm x 535mm. Detailed assembly drawings for the small types are shown in Figure 4.4.

Some of the test samples of tomatoes were kept inside an open basket to serve as control as shown in Plate 5.3. The control is kept at different location from the storage equipments. The daily temperatures and relative humidities of the room where the control was kept were recorded three times (morning, afternoon and evening) and some samples of tomatoes were also taken from the control at 2 days in-

tervals and tested for the compressive resistance.

The water troughs for each of the storage equipment are refilled daily, immediately after measurements had been taken for the day. The tests were continued from the green stage to the ripening stage and finally to the stage of deterioration of the test samples.

Colour changes of the stored tomatoes were observed daily during the experiment. The colour changes were quantified and recorded based on the area of coverage of colour on the tomato samples. The initial colour condition which is green is quantified as zero (o). Yellow green colour is quantified as 1, 2, 3. This values represents the tomatoes that are less than 50%, approximately equal to 50 - 70% and more than 70% yellow green colour respectively. The light red colour is grouped as 4, 5, 6. The values represents the tomatoes that are less than 50%, approximately equal to 50 - 70% and more than 70% light red colour respectively. Also, the values 7, 8, 9 represents the tomatoes that are less than 50%, approximately equal to 50 - 70% and more than 70% deep red colour respectively. While 10 represents the rot appearance, that is the final expected condition before spoilage.

Four of the storage equipment with variable combinations as shown in Table 5.1 were grouped as A; while the rest four (replicates) were grouped as B.

Table 5.1: Combination of the variables.

Number	Size	Layer of the Hessian sack
1	-	-
2	+	-
3	-	+
4	+	+

- - : Implies small size of the storage equipment with single layer of the Hessian sack.

+ - : Implies large size of the storage equipment with single layer of the Hessian sack.

- + : Implies small size of the storage equipment with double layer of the Hessian sack.

+ + : Implies large size of the storage equipment with double layer of the Hessian sack.

Groups A and B were kept within the same room but at different positions. The testing was carried out under room condition. Dry and wet bulb Thermometers are positioned inside the storage chamber of each of the storage equipment in groups, A and B. for temperature and relative humidity measurements.

Matured samples of tomatoes to be stored were harvested green on the day storage begins from an irrigation plot in Shika, Zaria. The green samples were sorted and distributed into each of the storage equipment in groups A and B. But before the introduction of the tomatoes to the storage chambers, the initial temperature and the relative humidities of the chambers were recorded.

Thereafter, the physical condition of the samples were determined by measuring the compressive resistance of the test samples of tomatoes using the Hounsfield Tensometer. The temperatures and relative humidities of the storage chambers were recorded three times (morning, afternoon and evening) daily, while samples were taken at 2 days intervals and tested for compressive resistance.

5.1.1 Temperature and Relative Humidity Measurement

The dry bulb thermometer was used to record the ambient temperatures. With the measured values of wet and dry bulb thermometers the ambient relative humidity was read directly from the psychrometric chart.

5.1.2 Weight measurement

The Mettler balance of 0.01g accuracy was employed to obtain the weight of samples of tomatoes.

5.1.3 Strength measurement

Plate 5.4 shows the Hounsfield Tensometer measuring equipment of scale range 0 ~ 2.5KN used for measuring the compressive resistance of some samples of tomatoes.

The equipment consists of four basic operating components which include: The chuck, scale, operating screw and

the quick return wheel.

A sample of tomato was positioned upright (the Head facing upward) and held between the compression chuck by turning the operating screw lever clockwise until there is a slight contact between the tomato and the compression chuck to hold it in position. The mercury level is then adjusted to zero (0) on the scale. As the compression continues by the continuous turning of the operating screw which compresses the tomato between the chuck, the mercury level rises and drops as soon as the tomato breaks. The breaking load in (KN) is then recorded from the scale. The quick return wheel is rotated anticlockwise to disengage the compressed tomato from the compression chuck. Another fresh sample is then replaced and the process is repeated.

The range of compressive chucks and scales are changeable depending on the type of material under test.

The only variety of tomato considered for the experiment was Roma VF variety, which is the most common and available variety.



Plate 5.1: Large Storage Equipment.



Plate 5.2: Small Storage Equipment



Plate 5.3: Control system

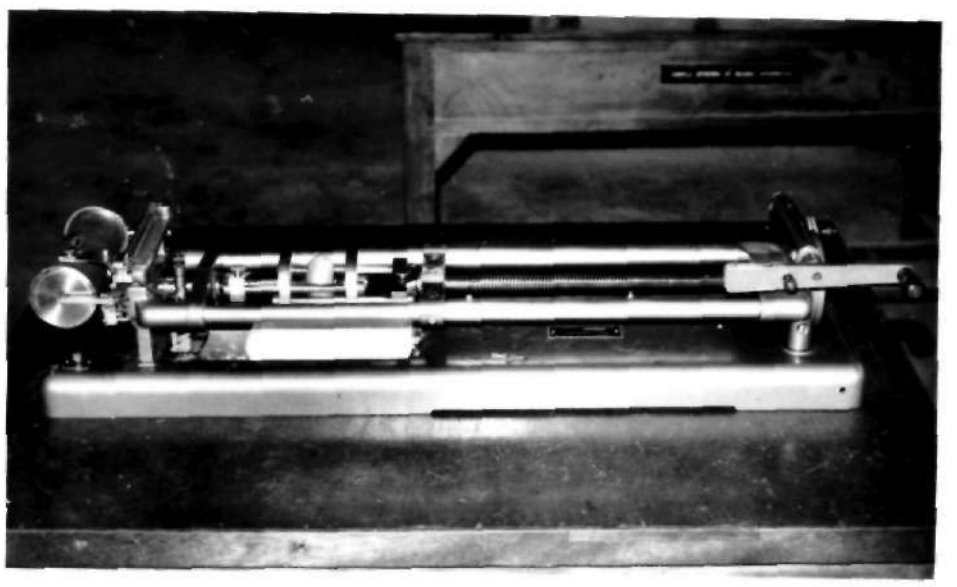


Plate 5.4: Hounsfield Tensometer

5.2 Second Experiment

A second experiment was carried out with the primary aim of evaluating the performance of the storage systems during off-harmattan period, and to correct any abnormality that may have occured during the preliminary experiment.

The second experiment was carried out from the 18th March - 16th April, 1992. The same experimental procedures and measurements, as in the preliminary experiment was followed during the second experiment. However, in this situation, the initial Hessian sack (cover material) used for the preliminary experiment was removed and replaced with another type which can improve capillary activity. The cover material used is softer and more dense than the initial type used during the preliminary experiment which is silky and less dense.

CHAPTER SIX

6. RESULTS AND DISCUSSION

6.1 Preliminary Experiment

6.1.1 The storage structure

The variation of temperature and relative humidity with period of storage for the control system and the four storage equipment during the harmattan period is shown in Figure 6.1. The result reveals that the temperature of the storage chambers changes with changes in temperature and relative humidity of the control environment. The average temperature and relative humidity of the control environment between the first and the 23rd days are 25.15°c and 28.29% respectively while the average temperature and relative humidity of the four storage equipment, a, b, c and d for the same period are 17.15°c and 90.07%; 18.23°c and 70.23%; 15.67°c and 91.89%; 17.45°c and 76.2% respectively. This shows that the temperature of the control environment is considerably higher than the average temperatures of the four storage equipment and the relative humidity of the control environment is lower than the average relative humidity of the four storage equipment. This also reveals that equipment a and c which are the two smaller equipment maintained higher relative humidities when compared with equipment b and d which are the larger equipment. On close examination, it was observed that the Hessian sack used for the two smaller equipment got saturated with water faster than those of the larger ones which

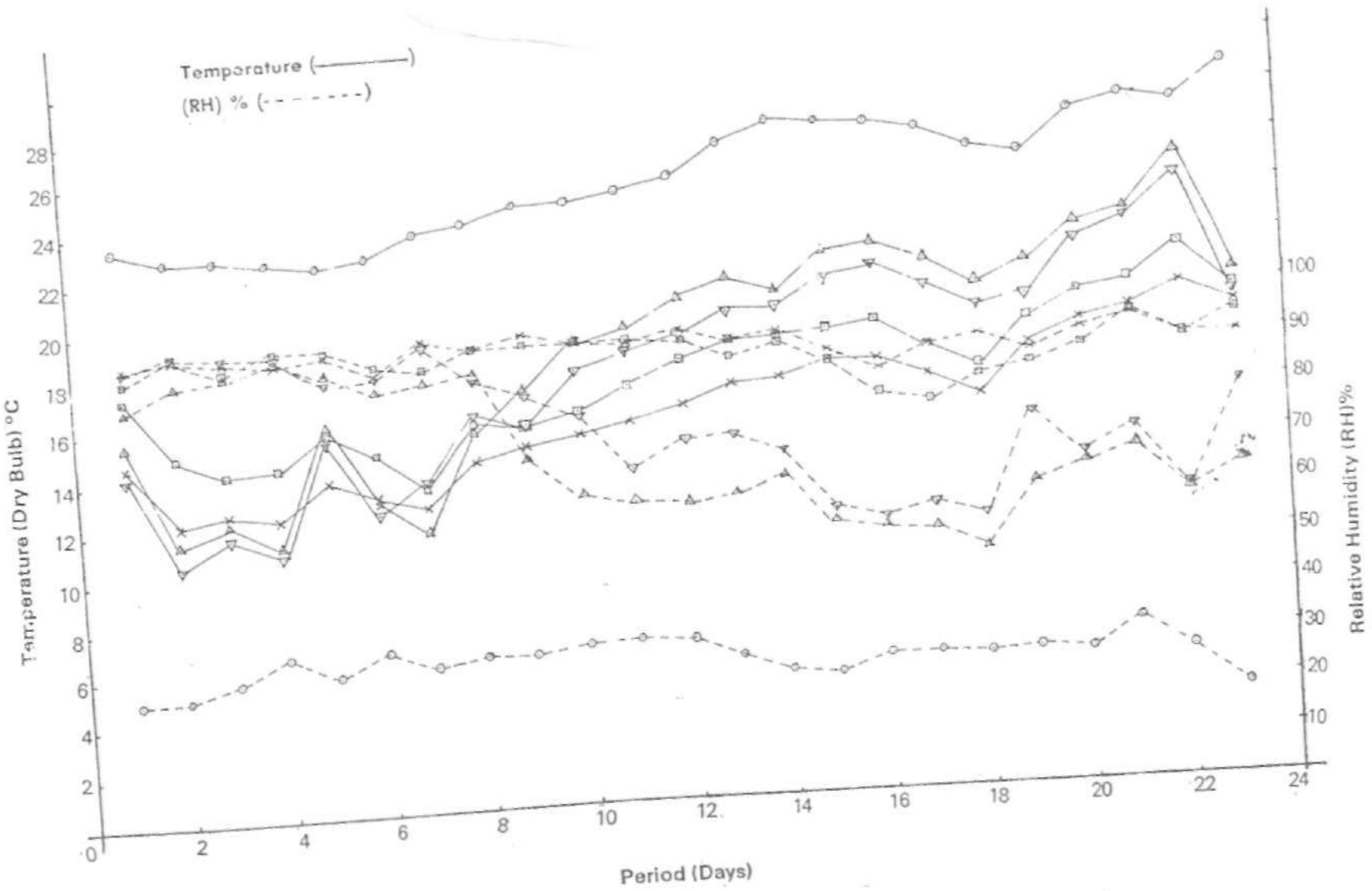


FIG 6.1: Variation of Temperature, Relative Humidity Responses with days for the four storage equipment .

Legend for Figure 6.1

Control

a(- -) = small size storage equipment with single layer of Hessian sack.

b(+ -) = Large size storage equipment with single layer of Hessian sack.

c(- +) = Small size storage equipment with double layer of Hessian sack.

d(+ +) = Large size storage equipment with double layer of Hessian sack.

Temperature = (———)

Relative Humidity (RH) % = (-----)

Scale: 1:1 (ox - axis)

1:2 (oy - axis) - Temperature

1:10(oy - axis) - (RH)%

Tomato Variety - Roma VF

Storage dates = January 8 to January 30, 1992

Place of storage = Agric. Engineering Laboratory, IAR/ABU., Zaria.

Result = Average daily temperatures and relative humidities (morning, afternoon and evening) for each of the storage equipment, the control and the replicated equipment.

make the smaller storage equipment to remain wet for longer duration. This could be due to the short distance covered by water movement through the Hessian sack as compared with the larger types. This could also be a reason for the higher relative humidity achieved by the smaller storage equipment.

During the experiment it was observed that the absorption of water through the Hessian sack of the storage equipment, b and d stopped at the fifth, eight and twenty second days as shown by the corresponding points in Figure 6.1. This is because the type of Hessian sack used for the two equipment are silky in texture, less dense and not favouring capillary activity in the cover material (Hessian sack), this must have been the reasons for the sudden rise in the storage temperatures of the two large storage equipment at the fifth, eight and the twenty second days and their corresponding fall in the relative humidity.

6.1.2 Characteristics of stored product

Figure 6.2 shows the variation of average compressive strength of the stored produce with period of storage for both the control and the four storage equipment during the harmattan period. The result reveals that the strength (compressive stress) of tomatoes decreases with the storage period. On the day of harvest, the average compressive strength of the tomato samples in both the control and the storage systems is 0.550N/mm^2 and the values decreased over time to 0.081N/mm^2; 0.153N/mm^2, 0.122N/mm^2, 0.143N/mm^2, 0.132N/mm^2 respectively by the twenty second day of storage. It was also observed that the tomato samples in the control system experienced rapid decrease in strength than the

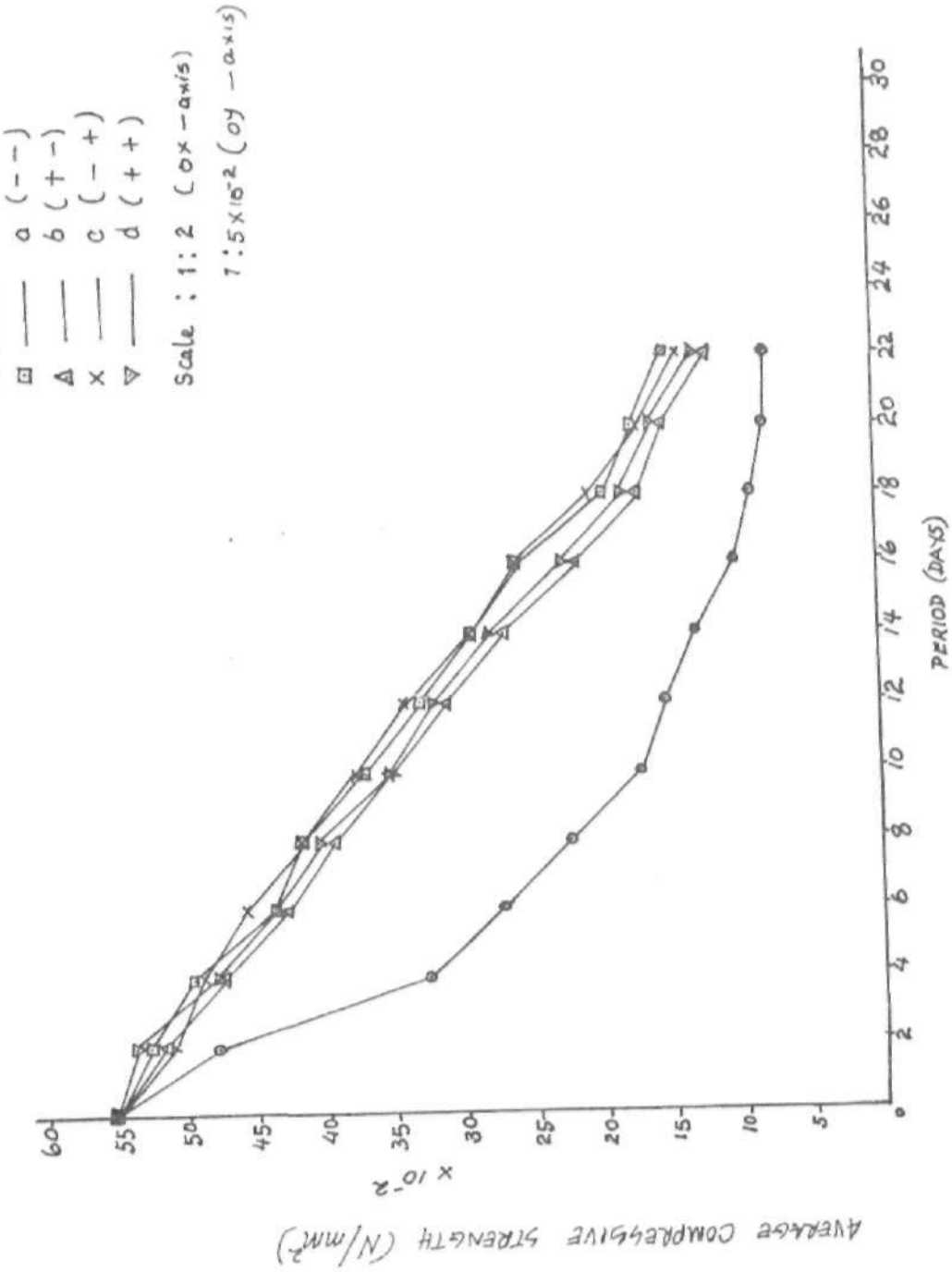


Fig. 6.2 : Variation of Average compresive strength with days for the control and the four storage equipment (Harmattan Period)

Legend for Figure 6.2

Control

a(--) = Small size storage equipment with single layer of Hessian sack.

b(+-) = Large size storage equipment with single layer of Hessian sack.

c(-+) = Small size storage equipment with double layer of Hessian sack.

d(++) = Large size storage equipment with double layer of Hessian sack.

Scale: 1:2 (ox-axis)

1:$5x10^{-2}$ (oy-axis)

Tomato variety = Roma VF

Storage dates = January 8 to January 30, 1992.

Place of storage = Agric. Engineering Laboratory, IAR/ABU., Zaria.

Result = Average compressive strength of samples of tomatoes from each storage equipment and the control at two days intervals and the replicated equipment.

samples kept in the storage equipment. This may be attributed to the higher temperatures and low relative humidities of the control environment, which is in line with the result of an eminent tomato researcher (Herregods, 1969) who found that softening of fruit increases more at high temperatures over 15°c.

Figure 6.3 shows the variation of colour with days after harvest for tomato samples in both the control and the storage systems. From the figure, it was evident that the storage equipment delayed the ripening from Green to Yellow green of the tomatoes for 8 days as against 4 days in the case of the control samples.

The result also shows that the rate of ripening is faster within the control than within the storage equipment, this may be due to increased temperature of the control environment. Rot was also observed on the samples after three weeks (23rd day) of storage with the large storage equipment as against 16 days for the control.

During the experiment it was observed that there was no rot appearance of tomato samples in the two smaller equipment uptil the end of the experiment. Rot appearance was only observed in the two large storage equipment. This implies that the smaller storage systems were more effective. The colour coding is shown in table 6.1. When the result of figure 6.3 was compared with the average compressive strength as shown in figure 6.2, it was observed that the average compressive strength of tomato at different colour changes for the control samples are:

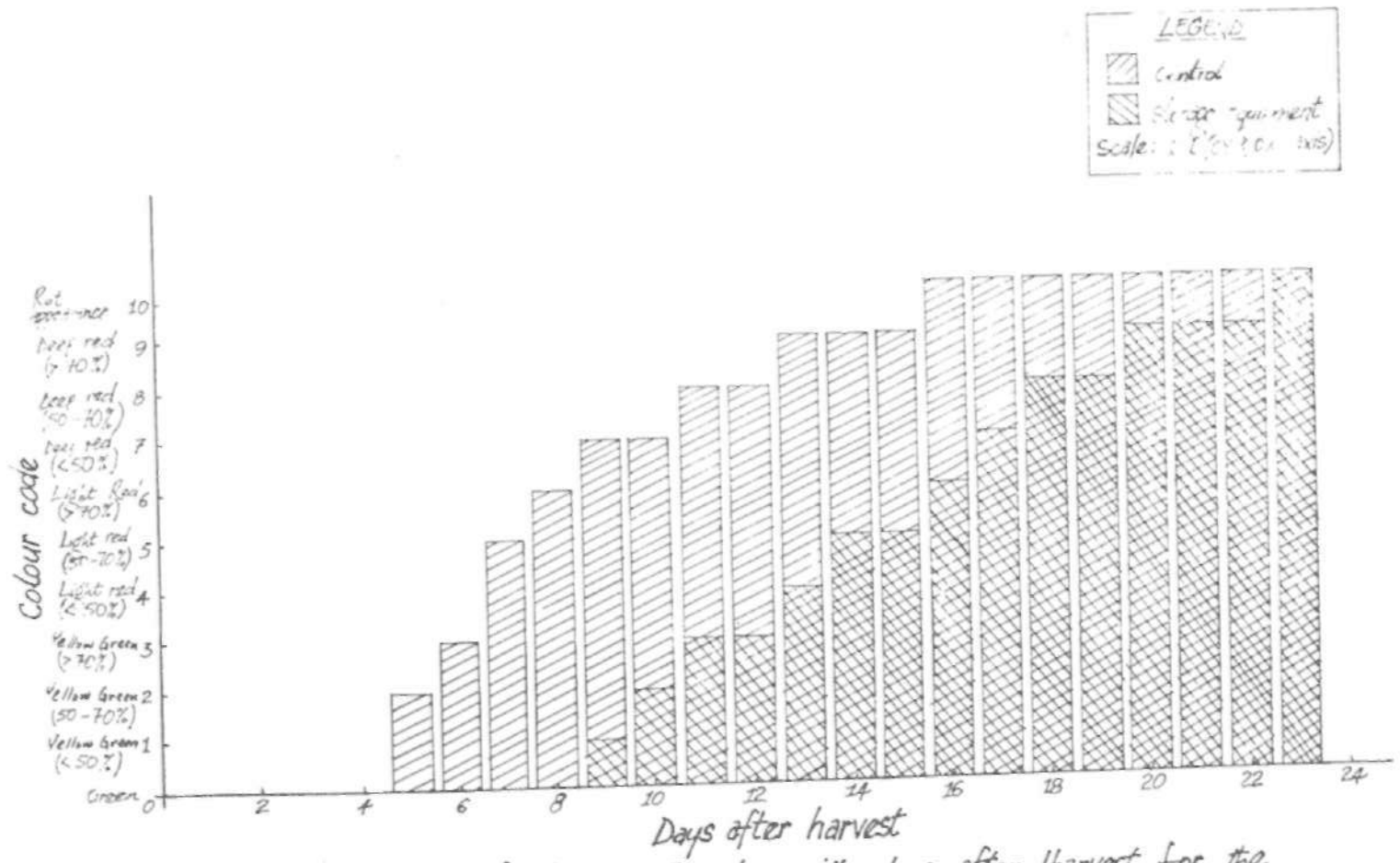


FIG.6.3 : Variation of colour for Tomato with days after Harvest for the Control Samples and the Storage Equipment.

Table 6.1: Colour Coding

Colour	% Area of coverage	Code
Green	100	0
Yellow Green	< 50	1
" "	50 - 70	2
" "	> 70	3
Light Red	< 50	4
" "	50 - 70	5
" "	> 70	6
Deep Red	< 50	7
" "	50 - 70	8
" "	> 70	9
Rot appearance		10

Green colour (1 - 4 days) - Between 0.550N/mm^2 - 0.326N/mm^2

Yellow green (5 - 6 days) - " 0.326N/mm^2 - 0.275N/mm^2

Light red (7 - 8 days) - " 0.275N/mm^2 - 0.224N/mm^2

Deep red (9 - 15 days) - " 0.224N/mm^2 - 0.132N/mm^2

Rot appearance (16 - 23 days) - " 0.102N/mm^2 - 0.082N/mm^2

While the average compressive strength of tomato at different colour changes for all the storage equipment are:

Green colour (1 - 8 days) - Between 0.550N/mm^2 - 0.428N/mm^2

Yellow green (9 - 12 days),- " 0.418N/mm^2 - 0.351N/mm^2

Light red (13 - 15 days) - " 0.341N/mm^2 - 0.270N/mm^2

Deep red (16 - 22 days) - " 0.295N/mm^2 - 0.163N/mm^2

Rot appearance (23rd day) - - 0.122N/mm^2

This result shows that the storage equipment mountain tomatoes tissue strength for a longer duration than with the control system. This could be as a result of the high relative humidity of the storage media which makes the tomatoes in the storage equipment more turgid as against the samples in the control system at the same stage of ripening.

6.1.3 Effect of variables

The detailed tabulation of data for this experiment is contained in appendix A.

The average weekly data was used to evaluate the effects of size and thickness of Hessian sack. The calculated effects and standard errors are shown in Table 6.2.

Table 6.2: Calculated Effects and Standard Errors for the Preliminary Experiment.+

Effect	Estimate + Standard Error		
	1st Week	2nd Week	3rd Week
Size(S)	-2.5± 1.53 n.s.	-10.42± 3.83*	-12.19± 4.49*
Thickness of Hessian sack (T)	2.5± 1.53 n.s.	2.92± 3.83n.s.	2.82± 4.49n.s.
Interraction (SXT)	2.5± 1.53 n.s.	0.42± 3.83n.s.	2.19± 4.49n.s.

+ mean value of weekly data; * significant; n.s - Not significant.

The results showed that the effect of size was statistically not significant at the first week but significant during the second and third week, at 0.05 confidence level. This could be the reason for the good performance of the two storage equipment (a and c). Also, when the calculated effects of thickness of Hessian sack were compared, it was observed that thickness of Hessian sack has no significant effect on the storage condition at the first, second and third weeks. Also, interraction between size and thickness of the Hessian sack in this experiment was not significant. The detailed calculation of the effects of the variables is contained in appendix C.

Black deposits of dirt was observed at the top and bottom tips of the cover material (Hessian sack) after a week of storage this was prevented by cleaning the cover material and changing the water at the top and bottom water

troughs after 1 - 2 weeks. This is necessary in order to allow free movement of water through the Hessian sack. It was also observed that the downward movement of water through the Hessian sack was faster than the upward movement. This may be because the downward movement is aided more by gravity.

6.2 Second Experiment

6.2.1 The storage structure

The variation of temperature and relative humidity with period of storage for the control system and the four storage equipment during the off-harmattan period is shown in Figure 6.4. The result reveals that the temperature of the storage chambers changes with changes in temperature and relative humidity of the control environment. The average temperature and relative humidity of the control environment between the first and the 30th days are 30.9°c and 37.3% respectively while the average temperature and relative humidity of the four storage equipment a, b, c and d for the same period are 22.2°c and 98.4%; 23.1°c and 97.4%; 23.7°c and 98.6%; 22.5°c and 98.3% respectively. The relative humidity obtained for this experiment agrees with the 98% relative humidity recommended (Adegboyega, 1990) for storage of some vegetable produce. This experimental result shows that the average temperature of the control environment is considerably higher than the average temperatures of the four storage equipment and the average relative humidity of the control environment is lower than the average relative humidity of the four storage equipment. This also reveals that equipment a and c

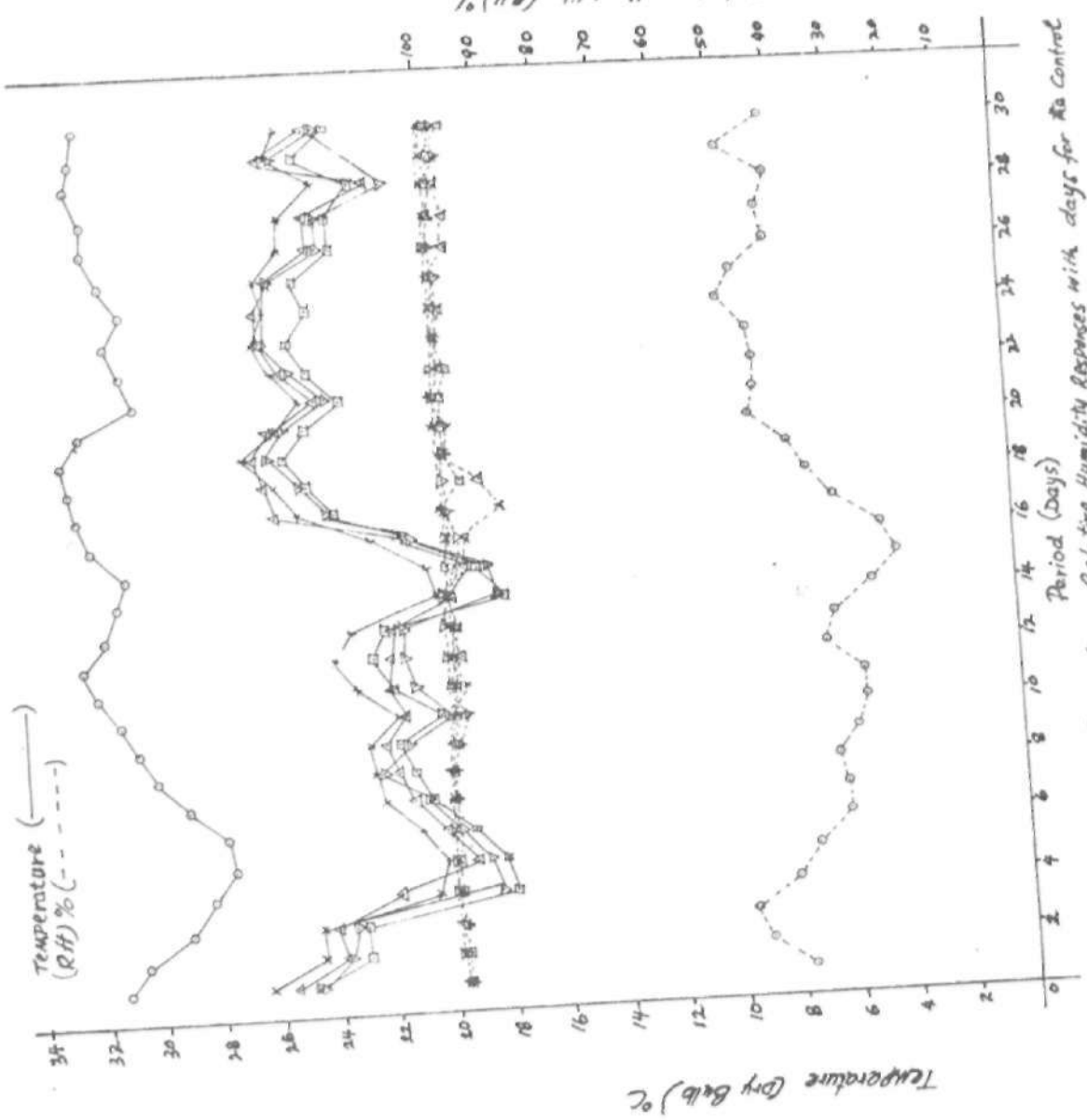


FIG. 6.4 : Variation of Temperature, Relative Humidity Responses with days for the Control and the four Storage equipment.

Legend for figure 6.4

Control

a(--) = Small size storage equipment with single layer of Hessian sack.

b(+-) = Large size storage equipment with single layer of Hessian sack.

c(-+) = Small size storage equipment with double layer of the Hessian sack.

d(++) = Large size storage equipment with double layer of Hessian sack.

Temperature = (_____)

Relative Humidity (RH)% = (-----)

Scale: 1:2 (ox-axis)

1:2 (oy-axis) - Temperature

1:10 (oy-axis) - (RH)%

Tomato Variety - Roma VF

Storage dates - 18th March to 16th April, 1992

Place of storage - Agric. Engineering Laboratory, IAR/ABU., Zaria.

Result = Average daily temperature and relative humidities (morning, afternoon and evening) for each of the storage equipment, the control and the replicated equipment.

which are the two smaller equipment maintained slightly higher relative humidities when compared with equipment b and d which are the larger storage equipment. On close examination, it was observed that with the same Hessian sack, the two smaller storage equipment get saturated with water faster than those of the larger ones. This could be due to the short distance covered by water movement through the Hessian sack as compared with the larger types. This could also be a reason for the slightly higher relative humidity achieved by the smaller storage equipment. Figure 6.4 also shows that the relative humidity of the four storage equipment was nearly constant and close to each other. But during the experiment, it was observed that the middle portion of the wet Hessian sack for the large storage equipment (d) with double layer of the Hessian sack dried up on the 17th day of storage. This must have been the reason for the fall in relative humidity and the corresponding rise in the storage temperature of that storage equipment as shown by the corresponding points in figure 6.4.

6.2.2 Characteristics of stored product

Figure 6.5 shows the variation of average compressive resistance of the stored produce with period of storage for both the control and the four storage equipment during the off-harmattan period. The result reveals that the strength (compressive strength) of tomatoes decreases with the storage period. On the day of harvest, the average compressive resistance of the tomato samples in both the control and the storage systems is 0.546N/mm^2 and the values decreased over time to 0.073N/mm^2; 0.143N/mm^2, 0.132N/mm^2,

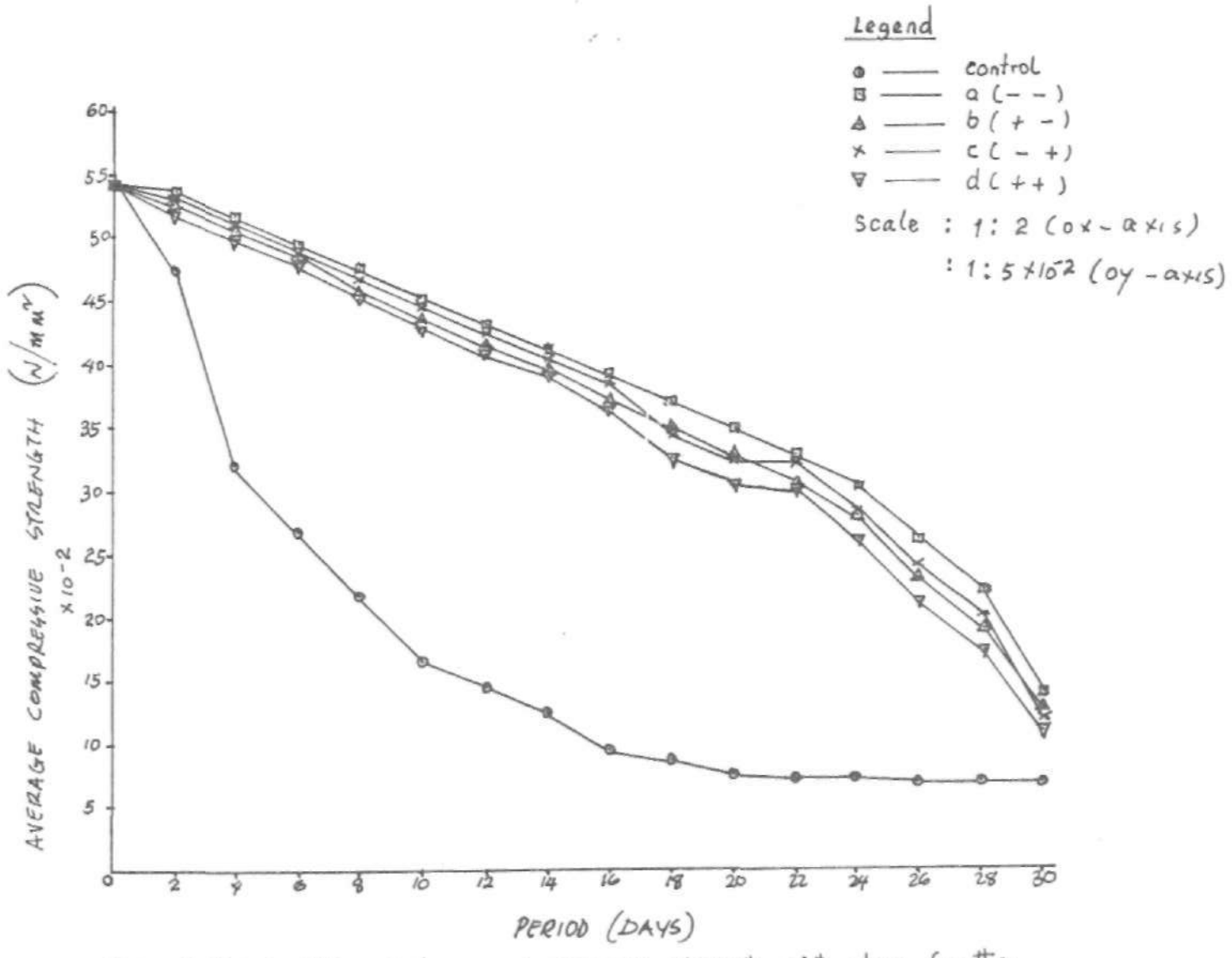


FIG. 6.5 : Variation of Average compressive strength with days for the control and the four storage equipment (Off - Harmattan Period)

Legend for figure 6.5

Control

a(--) = Small size storage equipment with single layer of Hessian sack.

b(+-) = Large size storage equipment with single layer of Hessian sack.

c(-+) = Small size storage equipment with double layer of Hessian sack.

d(++) = Large size storage equipment with double layer of Hessian sack.

Scale: 1:2 (ox-axis)

1:$5x10^{-2}$ (oy-axis)

Tomato variety = Roma VF

Storage Dates = 18th March to 16th April, 1992.

Place of storage = Agric. Engineering Laboratory, IAR/ABU., Zaria.

Result = Average compressive strength of samples of tomatoes from each storage equipment and the control at two days intervals and the replicated equipment.

$0.122N/mm^2$, $0.112N/mm^2$ respectively by the 30th day of storage. It was also observed that the tomato samples in the control system experienced rapid decrease in strength than the samples kept in the storage equipment. This may be attributed to the higher temperatures and low relative humidities of the control environment which is in agreement with the result of an eminent tomato researcher (Herregods, 1969) who found that softening of fruit increases more at high temperatures over $15^{o}c$ or it may be due to the change of protopectin to soluble pectin as stated by (Aboaba, 1987).

Figure 6.6 shows the variation of colour with days after harvest for tomato samples in both the control and the storage systems. From the figure, it was evident that the storage equipment delayed the ripening from Green to yellow green of the tomatoes for 7 days as against 3 days in the case of the control samples. The result also shows that the rate of ripening is faster within the control than within the storage equipment, this may be due to increased temperature of the control environment. This also agrees with the result obtained by (Sayre et.al., 1953) which indicated that ripening of green tomatoes may be accelerated by storing at $18 - 24^{o}c$ which is the optimum temperature range for the formation of Lycopene, the pigment responsible for red colour of tomato. Rot was also observed on the samples after 1 month (30th day) of storage with the storage equipment as against 15 days for the control. The colour coding is shown in table 6.1.

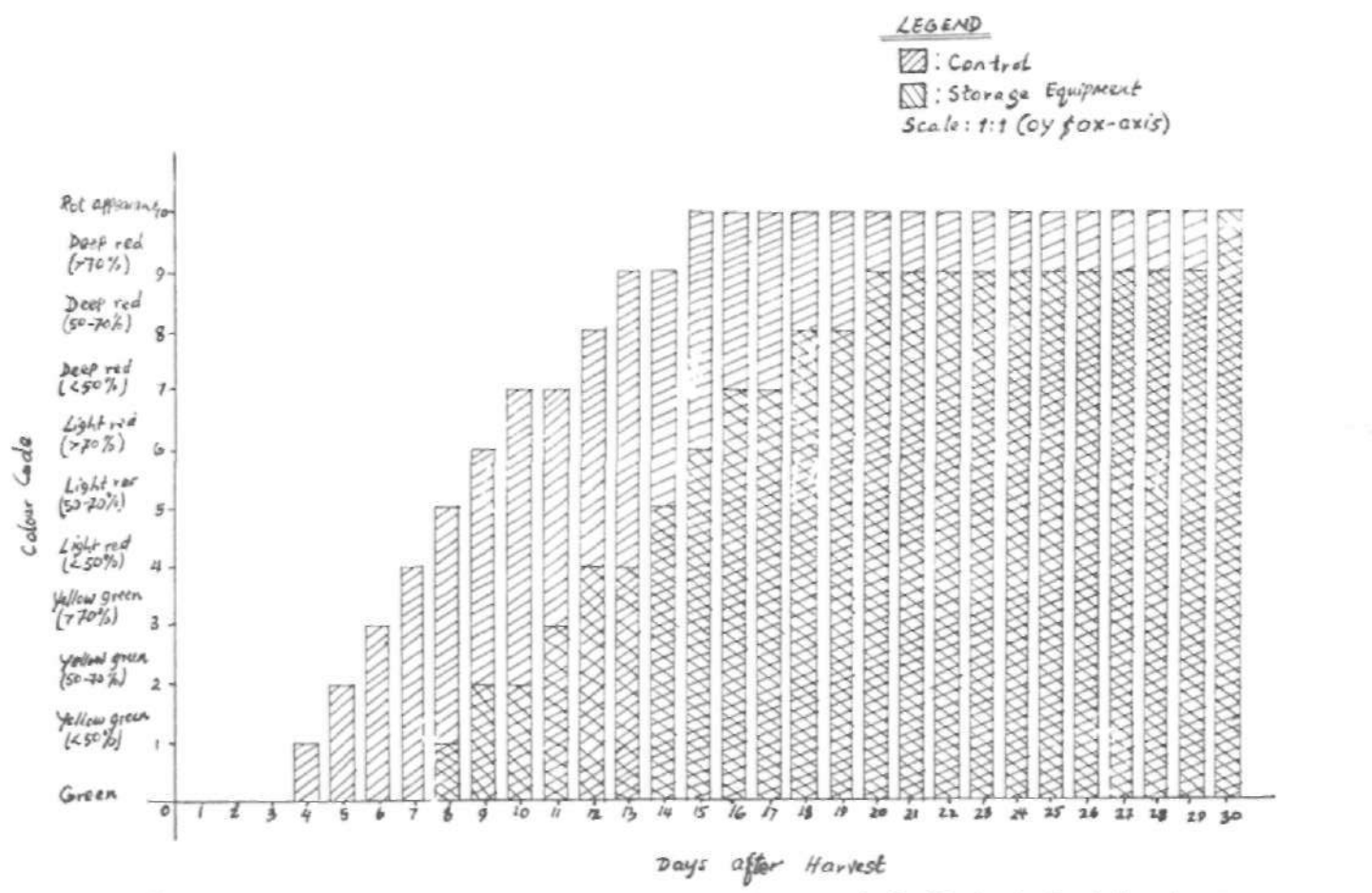


FIG. 6-6: Variation of colour for Tomato with days after Harvest for the Control and the Storage equipment.

Table 6.1: Colour coding.

Colour	% Area of Coverage	Code
Green	100	0
Yellow Green	< 50	1
" "	50 - 70	2
" "	> 70	3
Light Red	< 50	4
" "	50 - 70	5
" "	> 70	6
Deep Red	< 50	7
" "	50 - 70	8
" "	> 70	9
Rot appearance		10

When the result of figure 6.6 was compared with the average compressive strength as shown in figure 6.5, it was observed that the average compressive strength of tomato at different colour changes for the control samples are:

Green colour (1 - 3 days) - Between 0.546N/mm^2 - 0.473N/mm^2
Yellow green (4 - 6 days) - " 0.320N/mm^2 - 0.269N/mm^2
Light red (7 - 9 days) - " 0.269N/mm^2 - 0.218N/mm^2
Deep red (10 - 13 days) - " 0.167N/mm^2 - 0.147N/mm^2
Rot appearance(15 - 30 days) - " 0.126N/mm^2 - 0.073N/mm^2

While the average compressive strength of tomato at different colour changes for all the storage equipment are:

Green colour (1 - 7 days) - Between 0.546N/mm^2 - 0.479N/mm^2
Yellow green (8 - 11 days) - " 0.475N/mm^2 - 0.428N/mm^2
Light red (12 - 15 days) - " 0.432N/mm^2 - 0.391N/mm^2
Deep red (16 - 29 days) - " 0.391N/mm^2 - 0.173N/mm^2
Rot appearance(30th day) - " 0.112N/mm^2

This result shows that the storage equipment maintain tomatoes tissue strength for a longer duration than with the control system. This could be as a result of the high relative humidity of the storage media which make the tomatoes in the storage equipment more turgid as against the samples in the control system at the same stage of ripening.

6.2.3 Effect of variables

The detailed tabulation of data for this experiment is contained in appendix B.

The average weekly data was used to evaluate the effects of size and thickness of Hessian sack. The calculated effects and standard errors are shown in Table 6.3.

Table 6.3: Calculated Effects and Standard Errors for the Second Experiment.[+]

Effect	Estimate ± Standard Error			
	1st week	2nd week	3rd week	4th week
Size (S)	-3.75±1.55*	-8.35±3.1*	-9.5±4.2*	-11.8±5.12*
Thick-ness of Hessian sack (T)	-2.25±1.55 n.s.	-2.65±3.1 n.s.	-7±4.2n.s.	-8.4±5.12 n.s.
Interr-action (SxT)	0±1.55n.s.	-0.35±3.1	0±4.2n.s.	0±5.12n.s.

[+]mean value of weekly data; *significant; n.s - Not significant.

The results showed that the effect of size was satistically significant at 0.05 confidence level for the first, second, third and the fourth weeks. This could be the reason for the good performance of the two storage equipment (a and c). Also, when the calculated effects of thickness of Hessian sack were compared, it was observed that thickness of Hessian sack has no significant effect on the storage condition at the first, second, third and fourth weeks. Also, interraction between size and thickness of the Hessian sack in this experiment was not significant. The detailed calculation of the effects of variables is contained in appendix C.

Black deposits of dirt was observed at the top and bottom tips of the cover material (Hessian sack) after a week of storage, this was prevented by cleaning the cover material and changing the water at the top and bottom water troughs after 1 - 2 week(s). This is necessary in order to allow free movement of water through the Hessian sack. It was observed that the downward movement of water through the Hessian sack was faster than the upward movement. This may be because the downward movement is aided more by gravity.

On close examination, it was observed that even though the wooden frame does not exhibit any structural changes, black deposit which was suspected to be mould infection covered the wooden frame (Afara variety) used in constructing the storage equipment. This may be due to high moisture content developed by the wooden frame as a result of the persistent water contact during capillary activity. It may also be attributed to the high relative humidity within the storage chamber of the storage equipment. This phenomenon can be prevented by the use of a seasoned wooden frame, coated with emulsion paint that makes the structure water repellant.

6.3 Comparison of Results

The results of the two experiments reveal that a higher average temperature and relative humidity of the control environment and the storage equipment were observed during the second experiment than at the preliminary experiment. The higher temperature obtained during the second experiment could be the reason for the rapid deterioration in strength (Compressive strength) and ripening of the tomato samples in the control and storage systems experienced

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during the second experiment. It was also observed from figure 6.4 that the relative humidity of the storage equipment was nearly constant and equal during the second experiment than during the preliminary experiment. This could be due to the use of a better quality Hessian sack which is softer, more dense and favourable to capillary activity. This may also be a reason for the good performance of the storage equipment during the second experiment than at the preliminary experiment.

Tomato was preserved for over 1 month with the storage equipment during the second experiment as against (23 days) duration, obtained during the preliminary experiment.

An average temperature drop of 8.7°c, 7.8°c, 7.2°c, and 8.4°c below ambient was obtained with the four storage equipment a, b, c and d respectively during the second experiment and an average temperature drop below ambient of 8°c, 6.9°c, 9.5°c and 7.7°c was achieved with the four storage equipment a, b, c and d respectively during the preliminary experiment. The higher drop in temperature below ambient experienced within the four storage equipment during the second experiment may also be a reason for the prolonged storage life of the storage equipment.

During the second experiment, it was observed that the effect of size of the storage equipment is significant throughout the 4 weeks as against the result obtained during the preliminary experiment where the effect of size was not significant at the first week and significant for the second and third weeks at 0.05 confidence level. This may be due

to the failure of capillary activity caused by the Hessian material used for the preliminary experiment.

The cooling and humidification efficiencies respectively for the four storage equipment during the harmattan and off-harmattan period were calculated using equations 2.21 and 2.22 and the psychometric chart. The results are presented in table 6.4. The detailed values of the state points are presented in Appendix E.

Table 6.4: Cooling and Humidification efficiencies for the four storage equipment during the harmattan and off-harmattan period.

	Cooling efficiency,%		Humidification efficiency,%	
System design matrix	Harmattan period	Off-harttan period	Harmattan period	Off-harttan period
- -	93.57	97.75	91.38	95
+ -	69.2	96.30	70.83	93.3
- +	92.68	98.63	93.48	94.12
+ +	75.12	97.67	71.74	93.10

The table shows that the smaller storage equipment achieved the highest percentage cooling and humidification efficiencies during the two seasons of storage and the highest cooling and humidification efficiencies were achieved during the off-harmattan season. This indicates that the smaller storage equipment are more effective when compared with the larger ones.

Table 6.5 shows the analyses of variance for the experiment. As the calculated F-values for both block (season) and treatment (four storage equipment) is less than the table F-values (34.12) and (29.46) respectively at 0.01 level at 3 error degree of freedom. Therefore the difference between the means for the season and the four storage equipment on the compressive strength of the stored tomatoes are statistically insignificant.

Table 6.5: Summary of Analyses of variance (ANOVA) on the effect of season and the four different storage equipment on the compressive strength of the stored tomato.

Source of Variation	Degree of Freedom	Sum of Squares	Mean sum	Calculated F-values (compressive strength)
Block (season	1	153.12	153.12	30.20 n.s
Treatment (four ... storage equipment)	3	22.68	7.56	1.49 n.s
Residue	3	15.2	5.07	
Total	7			

n.s - Not significant at 0.01 level.

The average compressive stength used for the analyses of variance for the two seasons (harmattan and off-harmattan) is presented in table 6.6.

Table 6.6: Average compressive strength for harmattan and off-harmattan seasons

Variable combination	σ_c^*(N)	
	Harmattan	Off-harmattan
- -	246.25	256.75
+ -	241.25	253.0
- +	246.25	254.5
+ +	246.25	250.75

* Mean value of compressive strength for the first week.

Summary of the average data for the four storage equipment during harmattan and off-harmattan period are presented in tables 6.7 and 6.8 respectively.

Table 6.7: Summary of the average data for the four storage equipment during harmattan period.+

System design matrix	Date	Time	Storage Temp.°C Db	Wb	(RH)%	σ_c(N)
- -	8-14th	8am-4pm	14.87	14.25	92.56	246.25
+ -	Jan.	8am-4pm	12.88	11.98	88.70	241.25
- +	(week 1)	8am-4pm	12.97	12.42	93.29	246.25
+ +		8am-4pm	12.58	11.96	92.43	246.25
- -	15-21st	8am-4pm	16.87	16.12	92.15	183.33
+ -	Jan.	8am-4pm	18.71	15.21	67.22	172.5
- +	(week 2)	8am-4pm	15.45	14.86	93.43	185.83
+ +		8am-4pm	17.79	15.27	75.90	175.83
- -	22-28th	8am-4pm	18.75	17.26	85.21	114.38
+ -	Jun.	8am-4pm	21.71	16.65	57.52	100
- +	(week 3)	8am-4pm	17.52	16.49	89.66	115
+ +		8am-4pm	20.76	16.37	62.33	105

Table 6.8: Summary of the average data for the four storage equipment during off-harmattan period +

System design matrix	Date	Time	Storage Temp. °C Db	Wb	(RH)%	σ_c(N)
- -	18-24th	8am-4pm	20.9	20.8	98.8	256.75
+ -	March	8am-4pm	22.2	22	98.7	253
- +	(week 1)	8am-4pm	22.8	22.6	98.7	254.5
+ +		8am-4pm	21.3	21.1	98.6	250.75
- -	25-31st	8am-4pm	20.9	20.7	98.4	222.3
+ -	March	8am-4pm	21.4	21.1	98.1	214.3
- +	(week 2)	8am-4pm	22.3	22.2	98.3	220
+ +		8am-4pm	20.7	20.5	98.3	211.3
- -	1-7th	8am-4pm	22.9	22.6	97.9	187
+ -	April	8am-4pm	23.9	23.4	95.2	177.5
- +	(week 3)	8am-4pm	24.2	24	98.4	180
+ +		8am-4pm	23.1	22.8	97.6	170.5
- -	8-14th	8am-4pm	23.8	23.6	98.5	124.4
+ -	April	8am-4pm	24.6	24.2	97.4	112.6
- +	(week 4)	8am-4pm	25.2	25.1	98.8	116
+ +		8am-4pm	24.3	24.1	98.6	104.2

+ : Each column is the mean of 7 days data

σ_c(N) : Compressive resistance

(RH) % : Relative humidity

Db : Dry bulb temperature

W_b : Wet bulb temperature

6.4. Cost Analysis

The detailed breakdown of the cost of materials and labour for each sstorage equipment are contained in appendix D. The total estimated cost of production of each of thr four storage equipment a, b, c and d are ₦515.25, ₦688.00, ₦521.25 and ₦700.00 respectively.

7. CONCLUSION AND RECOMMENDATION

7.1 *Conclusion*

A system for rural storage of fresh tomato, which works on the evaporative cooling principles has been evolved.

From the results obtained during the experiments performed with the storage equipment, it was quite evident that:

1. A temperature drop of $8^{o}c$ below ambient can be achieved within the storage equipment during the harmattan and off-harmattan period.
2. A higher compressive strength for tomato samples can be achieved with the storage equipment than with the control system. The variation of compressive strength between ($0.550N/mm^2$ - $0.222N/mm^2$) and ($0.550N/mm^2$ - $0.082N/mm^2$) is possible with the storage equipment and the control system respectively during the harmattan period. Also, the variation of compressive strength between ($0.546N/mm^2$ - $0.112N/mm^2$) and ($0.546N/mm^2$ - $0.073N/mm^2$) is possible with the storage equipment and the control system respectively during off-harmattan period.
3. A storage period of over 1 month can be achieved at an average storage temperature and relative humidity of $22.9^{o}c$ and 98.2% respectively when the ambient temperature and relative humidity respectively were $30.9^{o}c$ and 37.3% during the off-harmattan period. Also, the equipment can attain an average storage temperature and relative humidity of $17.1^{o}c$ and

82.1% respectively if the ambient temperature and relative humidity are 25.15^{o}C and 28.29% respectively. Under this condition, fresh tomato produce can be preserved in the equipment for well over 3 weeks.

4. A system that is relatively cheap and falls within the farmers purchasing capability and constructed mainly of locally available materials is possible.

5. The large storage equipment can store about 97.32kg of fresh tomatoes at a batch at 24.33kg per tray.

6. Cooling efficiencies of over 93% and 98% respectived can be achieved with the storage system during the harmattan and off-harmattan seasons. Also, 93% and 95% humidification efficiencies respectively can be attained during the harmattan and off-harmattan period.

7.2 Recommendations

In order to effectively utilize the results obtained from the experiment for the benefit of the rural communities at farm and market levels, the following recommendations are imperative for future work.

1. To protect the stored produce from mould infections, application of fungitoxic agents is recommended. Little quantity of mild agents like sulphur and some of its compounds can be applied into the storage chamber.

2. To prevent persistent water contact which might reduce the structural strength of the wooden frame during capillary activity, a seasoned wooden frame, preferably Afara variety, coated with emulsion paint that makes the structure water repellant is recommended.
3. Where there is a prevalence of roddent and insect, the storage structure should be constructed and screened with mosquito net before fixing the cover material (Hessian sack).
4. For the purpose of commercial production of the storage equipment, is recommended while the height and width are maintained the length can be increased to accommodate large quantities of the stored produce, to allow quick saturation of the Hessian sack with water during capillary activity.
5. Similar experiment should also be carried out to ascertain characteristics of other fruits and vegetables stored in the equipment.
6. Further studies should be carried out, outside room condition to establish the effect of wind on the storage equipment.

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APPENDICES

APPENDIX A

Average daily and weekly experimental data for both control and the storage systems, during the Harmattan period.

APPENDIX A

Table A.1: Average daily data for the control system during Harmattan period.+

System Design	Date	Time	Ambient Temp. °c Db.	Wb.	(RH)%	σ_c (N)*	Colour change of tomato	Colour Code
Control system	8/1/92	8am-4pm	23.40	13.33	24.73	270	Green (100%)	0
	9/1/92	"	22.80	13.03	25.33		"	0
	10/1/92	"	22.80	13.53	28.20	235	"	0
	11/1/92	"	22.50	13.83	32.50		"	0
	12/1/92	"	22.30	13.33	29.07	160	Yellow green (50-70%)	2
	13/1/92	"	22.50	13.83	32.50		Yellow green (>70%)	3
	14/1/92	"	23.40	14.03	29.53	135	Light red (50-70%)	5
	15/1/92	"	23.70	14.43	30.87		Light red (>70%)	6
	16/1/92	"	24.33	14.90	30.50	110	Deep red (<50%)	7
	17/1/92	"	24.30	15	31.73		"	7
	18/1/92	"	24.63	15.40	32.30	85	Deep red (50-70%)	8
	19/1/92	"	25.07	15.60	31.67		"	8
	20/1/92	"	26.30	15.63	28.20	75	Deep red (>70%)	9
	21/1/92	"	27.20	15.90	25.10		"	9
	22/1/92	"	27.07	15.63	24.13	65	"	9

Table A.1 (contd.) APPENDIX A (contd.)

System Design	Date	Time	Ambient Temp. °c Db	Ambient Temp. °c Wb.	(RH)%	$\bar{f}_c$ (N)*	Colour change of tomato	Colour Code
Control system	23/1/92	8am-4pm	27	16.30	27.87		Rot appearance	10
	24/1/92	"	26.73	16.10	27.70	50	"	10
	25/1/92	"	25.83	15.40	27.07		"	10
	26/1/92	"	25.57	15.40	27.80	45	"	10
	27/1/92	"	27.17	16.27	27.10		"	10
	28/1/92	"	27.70	17.57	32.50	40	"	10
	29/1/92	"	27.40	16.30	26.33		"	10
	30/1/92	"	28.80	15.67	18.03	40	"	10

+ Each value of 3 readings in the morning, afternoon and evening, that is between 8am - 4pm daily.

*Mean of compressive resistance for three samples of tomato at 2 days interval.

Table A.2: Average daily data for the four storage equipment during Harmattan period.+

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	$\overline{V_c}$(N)**	Colour change of tomato	Colour Code
- -	8/1/92	8am - 4pm	17.33	16.45	90.42	270	Green (100%)	0
+ -	"	"	15.49	14.02	84.53	270	"	"
- +	"	"	14.59	14.05	93.16	270	"	"
+ +	"	"	14.05	13.50	92.79	270	"	"
- -	9/1/92	8am - 4pm	14.89	14.50	95.04		Green (100%)	0
+ -	"	"	11.52	10.65	89.22		"	"
- +	"	"	12.22	11.77	94.77		"	"
+ +	"	"	10.52	10.17	95.53		"	"
- -	10/1/92	8am - 4pm	14.12	13.35	91.20	257.5	Green (100%)	0
+ -	"	"	12.14	11.35	90.64	252.5	"	"
- +	"	"	12.55	11.99	73	250	"	"
+ +	"	"	11.52	11.02	94	262.5	"	"
- -	11/1/92	8am - 4pm	14.24	13.89	95.40		Green (100%)	0
+ -	"	"	11.07	10.55	93.14		"	"
- +	"	"	12.30	11.72	92.80		"	"
+ +	"	"	10.72	10.27	93.64		"	"
- -	12/1/92	8am - 4pm	15.60	15.10	94.39	242.5	Green (100%)	0
+ -	"	"	15.88	14.95	89.95	232.5	"	"
- +	"	"	13.64	13.12	93.84	240	"	"
+ +	"	"	15.25	14.30	88.12	232.5	"	"

Table A.2(contd.)

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	σ_c(N)**	Colour change of tomato	Colour Code
- -	13/1/92	8am-4pm	14.65	13.89	91.40		Green (100%)	0
+ -	"	"	12.60	11.57	85.99		"	"
- +	"	"	12.89	12.0	89.65		"	"
+ +	"	"	12.64	11.62	88.94		"	"
- -	14/1/92	8am-4pm	13.23	12.55	90.05	215	Green (100%)	0
+ -	"	"	11.47	10.77	87.42	210	"	"
- +	"	"	12.57	12.27	95.83	225	"	"
+ +	"	"	13.33	12.83	94	215	"	"
- -	15/1/92	8am-4pm	15.60	15.0	93.59		Green (100%)	0
+ -	"	"	15.35	14.34	88.70		"	"
- +	"	"	14.14	13.65	93.58		"	"
+ +	"	"	15.90	14.65	86.92		"	"
- -	16/1/92	8am-4pm	15.47	14.87	93.40	205	Yellow green (< 50%)	1
+ -	"	"	16.92	14.17	70.83	192.5	"	"
- +	"	"	14.63	14.24	95.17	205	"	"
+ +	"	"	15.47	13.83	83.08	197.5	"	"
- -	17/1/92	8am-4pm	15.83	15.33	93		Yellow green (50-70%)	2
+ -	"	"	18.67	14.72	63.24		"	"
- +	"	"	14.89	14.29	93.40		"	"
+ +	"	"	17.49	15.34	78.53		"	"

Table A.2(contd.)

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	18/1/92	8am-4pm	16.79	16.14	93.19	182.5	Yellow green (>70%)	3
+ -	"	"	19.07	14.75	61.37	172.5	"	"
- +	"	"	15.29	14.55	91.95	185	"	"
+ +	"	"	18.07	14.75	67.60	172.5	"	"
- -	19/1/92	8am-4pm	17.67	16.92	92.17		Yellow green (>70%)	3
+ -	"	"	20.22	15.74	60.35		"	"
- +	"	"	15.83	15.29	94.08		"	"
+ +	"	"	18.54	15.58	72.37		"	"
- -	20/1/92	8am-4pm	18.34	16.99	88.67	162.5	Light red (<50%)	4
+ -	"	"	20.84	16.44	61.63	152.5	"	"
- +	"	"	16.59	15.83	92.22	167.5	"	"
+ +	"	"	19.45	16.47	72.94	157.5	"	"
- -	21/1/92	8am-4pm	18.42	17.5	91		Light red (50-70%)	5
+ -	"	"	20.34	16.33	64.34		"	"
- +	"	"	16.79	16.15	93.62		"	"
+ +	"	"	19.58	16.25	69.84		"	"
- -	22/1/92	8am-4pm	18.67	17.5	87.42	145	Light red (50-70%)	5
+ -	"	"	21.78	16.4	55.04	132.5	"	"
- +	"	"	17.44	16.32	89.09	145	"	"
+ +	"	"	20.65	15.84	57.25	137.5	"	"

Table A.2(contd.)

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	23/1/92	8am-4pm	18.92	16.77	80.20		Deep red (>70%)	6
+ -	"	"	22.04	16.35	53.72		"	"
- +	"	"	17.37	15.85	84.90		"	"
+ +	"	"	21.14	15.74	54.72		"	"
- -	24/1/92	8am-4pm	17.97	15.7	78.14	127.5	Deep red (<50%)	7
+ -	"	"	21.22	15.7	52.49	107.5	"	"
- +	"	"	16.75	15.75	89.49	127.5	"	"
+ +	"	"	20.22	15.92	57.72	112.5	"	"
- -	25/1/92	8am-4pm	16.95	15.25	83.04		Deep red (50-70%)	8
+ -	"	"	20.33	14.3	48.07		"	"
- +	"	"	15.74	14.92	91.08		"	"
+ +	"	"	19.27	14.15	54.22		"	"
- -	26/1/92	8am-4pm	18.75	17.24	85.42	97.5	Deep red (50-70%)	8
+ -	"	"	21.17	16.67	61.17	85	"	"
- +	"	"	17.67	16.47	87.92	102.5	"	"
+ +	"	"	19.64	16.89	74.62	90	"	"
- -	27/1/92	8am-4pm	19.75	18.62	87.92		Deep red (>70%)	9
+ -	"	"	22.53	18.19	64.30		"	"
- +	"	"	18.60	17.7	91.35		"	"
+ +	"	"	21.82	17.75	66.20		"	"

Table A.2(contd.)

System* Design Matrix	Date	Time	Storage Temp.oc Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	28/1/92	8am-4pm	20.25	19.75	94.34	87.5	Deep red (70%)	9
+ -	"	"	22.92	18.95	67.82	75	"	"
- +	"	"	19.05	18.42	93.80	85	"	"
+ +	"	"	22.55	18.27	71.58	80	"	"
- -	29/1/92	8am-4pm	21.44	20.05	89.05		Deep red (70%)	9
+ -	"	"	25.2	19.72	58.14		"	"
- +	"	"	19.95	18.84	89.70		"	"
+ +	"	"	24.19	18.94	58.49		"	"
- -	30/1/92	8am-4pm	19.65	18.9	93.50	75	Deep red (70%)	9
+ -	"	"	20.4	16.22	63.20	60	Rot app-earance (100%)	10
- +	"	"	19	17.87	89.07	70	Deep red (70%)	9
+ +	"	"	19.4	17.2	79.44	65	Rot app-earance (100%)	10

* - System Design Matrix for four storage equipment.

(--) - Small size storage equipment with single layer of Hessian sack.

(+-) - Large size storage equipment with single layer of Hessian sack.

(-+) - Small size storage equipment with double layer of Hessian sack.

(++) - Large size storage equipment with double layer of Hessian sack.

** Mean of compressive resistance for three samples of tomato at 2 days interval.

\+ Each value is the mean of 3 readings at the morning, afternoon and evening, that is between 8am - 4pm daily.

Table A.3: Average weekly data for the four storage equipment during Harmattan period.+

System Design Matrix	Date	Time	Storage Temp. °c Db	Wb	(RH)%	σ_c (N)
- -	8 - 14th January	8am - 4 pm.	14.87	14.25	92.56	246.25
+ -	(Week 1)	"	12.88	11.98	88.70	241.25
- +	"	"	12.97	12.42	93.29	246.25
+ +	"	"	12.58	11.96	92.43	246.25
- -	15-21st January	8am-4pm	16.87	16.12	92.15	183.33
+ -	(Week 2)	"	18.77	15.21	67.22	172.5
- +	"	"	15.45	14.86	93.43	185.83
+ +	"	"	17.79	15.27	75.90	175.83
- -	22-28th January	8am-4pm	18.75	17.26	85.21	114.38
+ -	(Week 3)	"	21.71	16.65	57.52	100
- +	"	"	17.52	16.49	89.66	115
+ +	"	"	20.76	16.37	62.33	105

+Each column is the mean of 7 days data.

σ_c.(N) is the compressive resistance.

(RH)% is the relative humidity

Db is the Dry bulb temperature

Wb is the wet bulb temperature

Table A.4: Strength measurement data for the control samples (Harmattan period)

System design	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
Control system	8/1/92	9 a.m.	270	0.550
	10/1/92	"	235	0.479
	12/1/92	"	160	0.326
	14/1/92	"	135	0.275
	16/1/92	"	110	0.224
	18/1/92	"	85	0.173
	20/1/92	"	75	0.153
	22/1/92	"	65	0.132
	24/1/92	"	50	0.102
	26/1/92	"	45	0.092
	28/1/92	"	40	0.081
	30/1/92	"	40	0.081

* Mean of compressive strength (N/mm^2) for three samples of tomato at 2 days interval.

Table A.5: Strength measurement data for samples in the four storage equipment (Harmattan period)

System Design Matrix	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
--	8/1/92	9 a.m.	270	0.550
+-	"		270	0.550
-+	"		270	0.550
++	"		270	0.550
--	10/1/92	"	257.5	0.525
+-	"		252.5	0.514
-+	"		250	0.509
++	"		262.5	0.535
--	12/1/92	"	242.5	0.494
+-	"		232.5	0.474
-+	"		240	0.489
++	"		232.5	0.474
--	14/1/92	"	215	0.438
+-	"		210	0.428
-+	"		225	0.458
++	"		215	0.438
--	16/1/92	"	205	0.418
+-	"		192.5	0.392
-+	"		205	0.418
++	"		197.5	0.402
--	18/1/92	"	182.5	0.372
+-	"		172.5	0.351
-+	"		185	0.377
++	"		172.5	0.351

Table A.5 (contd.)

System Design Matrix	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
--	20/1/92	9 a.m.	162.5	0.331
+-	"		152.5	0.311
-+	"		167.5	0.341
++	"		157.5	0.321
--	22/1/92	"	145	0.295
+-	"		132.5	0.270
-+	"		145	0.295
++	"		137.5	0.280
--	24/1/92	"	127.5	0.260
+-	"		107.5	0.219
-+	"		127.5	0.260
++	"		112.5	0.229
--	26/1/92	"	97.5	0.199
+-	"		85	0.173
-+	"		102.5	0.209
++	"		90	0.183
--	28/1/92	"	87.5	0.178
+-	"		75	0.153
-+	"		85	0.173
++	"		80	0.163
--	30/1/92	"	75	0.153
+-	"		60	0.122
-+	"		70	0.143
++	"		65	0.132

* Mean compressive strength (N/mm^2) for three samples of tomato at 2 days interval.

APPENDIX B

Average daily nand weekly experimental data for both control and the storage systems during off-harmattan period.

APPENDIX B

Table B.1: Average daily data for the control system during off-Harmattan period.+

System Design	Date	Time	Ambient Temp.°c Db	Wb	(RH)%	T_c(N)	Colour change of tomato	Colour Code
Control System	18/3/92	8am-4pm	31.3	21.4	38.4	268	Green (100%)	0
"	19/3/92	"	30.6	22.3	45.8		"	0
"	20/3/92	"	29.4	21.7	48.2	232	"	0
"	21/3/92	"	28.2	19.4	40.4		Yellow green (<50%)	1
"	22/3/92	"	27.5	18.3	37.3	157	Yellow green (50-70%)	2
"	23/3/92	"	27.7	17.5	31.4		Yellow green (>70%)	3
"	24/3/92	"	29	18.4	31.4	132	Light red (<50%)	4
"	25/3/92	"	30	19.3	32.5		Light red (50-70%)	5
"	26/3/92	"	30.6	19.4	28.9	107	Light red (>70%)	6
"	27/3/92	"	31.1	19.1	27.7		Deep red (<50%)	7
"	28/3/92	"	31.9	19.7	27.9	82	"	7
"	29/3/92	"	32.3	21.2	33.8		Deep red (50-70%)	8
"	30/3/92	"	31.5	20.4	32	72	Deep red (>70%)	9
"	31/3/92	"	31.1	18.7	25.7		"	9

Table B.1 (contd.)

System Design	Date	Time	Ambient Temp. °c Db	Wb	(RH)%	* (N)	Colour change of tomato	Colour Code
Control System	1/4/92	8am-4pm	30.7	17.4	20.7	62	Rot appearance (100%)	10
"	2/4/92	"	31.9	18.8	23.5		"	10
"	3/4/92	"	32.4	20.8	31.5	48	"	10
"	4/4/92	"	32.6	21.8	35.8		"	10
"	5/4/92	"	32.8	22.6	38.8	44	"	10
"	6/4/92	"	32.1	23.4	45.3		"	10
"	7/4/92	"	30.2	21.8	44.3	39	"	10
"	8/4/92	"	30.6	22	44.2		"	10
"	9/4/92	"	31.1	22.6	45.1	38	"	10
"	10/4/92	"	30.4	22.8	49.8		"	10
"	11/4/92	"	31.2	23	47	37	"	10
"	12/4/92	"	31.8	22.3	40.8		"	10
"	13/4/92	"	31.7	22.5	42.5	36	"	10
"	14/4/92	"	32.3	22.6	40.5		"	10
"	15/4/92	"	32	23.9	48.4	36	"	10
"	16/4/92	"	31.8	22.3	40.8	36	"	10

+Each value is the mean of 3 readings at the morning, afternoon and evening, that is between 8am - 4pm daily.

*Mean of compressive resistance for three samples of tomato at 2 days interval.

Table B.2. Average daily data for the four storage equipment during off-Harmattan period.+

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	$\bar{U}_c$ (N)**	Colour change of tomato	Colour Code
- -	18/3/92	8am-4pm	24.9	24.5	98	268	Green (100%)	0
+ -	"	"	25.5	25.3	98.6	268	"	"
- +	"	"	26.4	26.1	98.4	268	"	"
+ +	"	"	24.7	24.3	98	268	"	"
- -	19/3/92	8am-4pm	23	22.9	99		Green (100%)	0
+ -	"	"	23.7	23.4	98.4		"	"
- +	"	"	24.5	24.2	98.4		"	"
+ +	"	"	23.6	23.4	98.6		"	"
- -	20/3/92	8am-4pm	23	22.8	98.6	263	Green (100%)	0
+ -	"	"	24	23.9	99	258	"	"
- +	"	"	24.6	24.5	99	260	"	"
+ +	"	"	23.4	23.2	98.6	255	"	"
- -	21/3/92	8am-4pm	17.8	17.7	98.9		Green (100%)	0
+ -	"	"	21.8	21.5	98.4		"	"
- +	"	"	20.5	20.4	99		"	"
+ +	"	"	18.3	18.1	99		"	"
- -	22/3/92	8am-4pm	18.1	18.0	99	253	Green (100%)	0
+ -	"	"	19.2	19.1	99	248	"	"
- +	"	"	20.1	20	99	250	"	"
+ +	"	"	18.7	18.6	99	245	"	"

Table B.2 (contd.)

System* Design Matrix	Date	Time	Storage Temp. °c Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	23/3/92	8am-4pm	19.2	19.1	99		Green (100%)	0
+ -	"	"	20.1	19.9	98.6		"	"
- +	"	"	21	20.8	98.4		"	"
+ +	"	"	19.6	19.4	98.6		"	"
- -	24/3/92	8am-4pm	20.5	20.4	98.9	243	Green (100%)	0
+ -	"	"	21.2	21	99	238	"	"
- +	"	"	22.2	22	98.8	240	"	"
+ +	"	"	20.6	20.4	98.6	235	"	"
- -	25/3/92	8am-4pm	21.1	20.9	99		Yellow green (<50%)	1
+ -	"	"	21.7	21.6	99		"	"
- +	"	"	22.4	22.2	98.9		"	"
+ +	"	"	22.1	21.9	98.9		"	"
- -	26/3/92	8am-4pm	21.6	21.4	98	233	Yellow green (50-70%)	2
+ -	"	"	22	21.8	99	225	"	"
- +	"	"	22.6	22.5	98.9	230	"	"
+ +	"	"	21.3	21	98	222	"	"
- -	27/3/92	8am-4pm	20.2	20	98.9		Yellow green (50-70%)	2
+ -	"	"	21.3	21	98		"	"
- +	"	"	21.6	21.5	98		"	"
+ +	"	"	19.9	19.6	96		"	"

Table B.2 (contd.)

System* Design Matrix	Date	Time	Storage Temp. °c Db	Wb	(RH)%	$\bar{U}_c$(N)**	Colour change of tomato	Colour Code
- -	28/3/92	8am-4pm	21.7	21.5	98.6	222	Yellow green (70%)	3
+ -	"	"	21.7	21.4	98	214	"	"
- +	"	"	23	22.7	96	220	"	"
+ +	"	"	20.9	20.7	98.8	210	"	"
- -	29/3/92	8am-4pm	22.3	22.1	98		Light red (<50%)	4
+ -	"	"	21.8	21.4	97		"	"
- +	"	"	23.7	23.5	98.7		"	"
+ +	"	"	21.3	21.1	98.6		"	"
- -	30/3/92	8am-4pm	21.9	21.7	97.5	212	Light red (<50%)	4
+ -	"	"	21.7	21.4	98	204	"	"
- +	"	"	23.1	22.9	98.9	210	"	"
+ +	"	"	21.3	21.1	98.8	202	"	"
- -	31/3/92	8am-4pm	17.7	17.5	99		Light red (50-70%)	5
+ -	"	"	19.7	19.4	98		"	"
- +	"	"	20	19.8	99		"	"
+ +	"	"	18	17.8	98.8		"	"
- -	1/4/92	8am-4pm	18.7	18.6	98.6	202	Light red (>70%)	6
+ -	"	"	18.9	18.5	95	194	"	"
- +	"	"	20.3	20.1	97.4	200	"	"
+ +	"	"	18.3	18	97	192	"	"

Table B.2 (contd.)

System* Design Matrix	Date	Time	Storage Temp.°c Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	2/4/92	8am-4pm	21	20.8	98.6		Deep red (<50%)	7
+ -	"	"	21.3	20.9	95		"	"
- +	"	"	22.2	22.1	98		"	"
+ +	"	"	20.8	20.5	96		"	"
- -	3/4/92	8am-4pm	23.5	23.3	98.9	192	Deep red (<50%)	7
+ -	"	"	25.5	24	88	182	"	"
- +	"	"	24.8	24.7	98.9	190	"	"
+ +	"	"	23.7	23.4	98	180	"	"
- -	4/4/92	8am-4pm	24.4	23.8	95.1		Deep red (50-70%)	8
+ -	"	"	25.8	24.8	92		"	"
- +	"	"	25.5	25.1	98.2		"	"
+ +	"	"	24.5	24.1	98		"	"
- -	5/4/92	8am-4pm	25.1	24.8	98.0	182	Deep red (50-70%)	8
+ -	"	"	26.2	25.9	98.5	172	"	"
- +	"	"	26.5	26.3	98.5	170	"	"
+ +	"	"	25.6	25.4	98	160	"	"
- -	6/4/92	8am-4pm	24.3	24	98		Deep red (>70%)	9
+ -	"	"	25.6	25.5	98.9		"	"
- +	"	"	25.4	25.3	99		"	"
+ +	"	"	25.1	24.7	97.5		"	"

Table B.2 (contd.)

System* Design Matrix	Date	Time	Storage Temp.°c Db	Storage Temp.°c Wb	(RH)%	$\bar{\sigma}_c$ (N)**	Colour change of tomato	Colour Code
- -	7/4/92	8am - 4pm	23.1	22.8	98	172	Deep red (>70%)	9
+ -	"	"	24	23.9	98.9	162	"	"
- +	"	"	24.4	24.2	98.9	160	"	"
+ +	"	"	23.6	23.5	98.9	150	"	"
- -	8/4/92	8am - 4pm	24.2	23.8	97		Deep red (>70%)	9
+ -	"	"	25.1	24.8	98		"	"
- +	"	"	25.4	25.2	98.8		"	"
+ +	"	"	24.8	24.6	98.9		"	"
- -	9/4/92	8am - 4pm	24.8	24.7	99	162	Deep red (>70%)	9
+ -	"	"	25.8	25.6	98.5	150	"	"
- +	"	"	26	25.9	99	160	"	"
+ +	"	"	25.8	25.6	98.5	148	"	"
- -	10/4/92	8am- 4pm	24.1	24	99		Deep red (>70%)	9
+ -	"	"	25.9	25.5	97.6		"	"
- +	"	"	25.6	25.5	99		"	"
+ +	"	"	25.7	25.4	98		"	"
- -	11/4/92	8am - 4pm	24.5	24.4	98	150	Deep red (>70%)	9
+ -	"	"	25.4	25.2	98.5	138	"	"
- +	"	"	25.9	25.7	98.9	140	"	"
+ +	"	"	25.4	25.1	98	128	"	"

Table B.2 (contd.)

System* Design Matrix	Date	Time	Storage Temp. °c Db	Wb	(RH)%	σ_c (N)**	Colour change of tomato	Colour Code
- -	12/4/92	8am-4pm	23.2	23	98.9		Deep red (>70%)	9
+ -	"	"	24	23.5	96		"	"
- +	"	"	24.9	24.8	99		"	"
+ +	"	"	23.6	23.4	98.9		"	"
- -	13/4/92	8am-4pm	23.2	23	98.9	130	Deep red (>70%)	9
+ -	"	"	24	23.5	96	115	"	"
- +	"	"	24.9	24.8	99	120	"	"
+ +	"	"	23.6	23.4	98.9	105	"	"
- -	14/4/92	8am-4pm	22.3	22.1	98.6		Deep red (>70%)	9
+ -	"	"	21.8	21.4	97.5		"	"
- +	"	"	23.7	23.5	98		"	"
+ +	"	"	21.3	21.1	98.9		"	"
- -	15/4/92	8am-4pm	24.3	24	98	110	Deep red (>70%)	9
+ -	"	"	25.6	25.5	98.9	95	"	"
- +	"	"	25.4	25.3	99	100	"	"
+ +	"	"	25.1	24.7	97.5	85	"	"
- -	16/4/92	8am-4pm	23.2	23	98.9	70	Rot appearance	10
+ -	"	"	24	23.5	96	65	"	"
- +	"	"	24.9	24.8	99	60	"	"
+ +	"	"	23.6	23.4	98.9	55	"	"

+ Each Value is the mean of 3 readings at the morning, afternoon and evening, that is between 8am - 4pm.

* System Design Matrix for four storage equipment.

-- : Small size storage equipment with single layer of Hessian sack.

+- : Large size storage equipment with single layer of Hessian sack.

-+ : Small size storage equipment with double layer of Hessian sack.

++ : Large size storage equipment with double layer of Hessian sack.

** Mean of compressive resistance for three samples of tomato at 2 days interval.

Table B.3: Average weekly data for the four storage equipment during off-Harmattan period.+

System Design Matrix	Date	Time	Storage Temp. °c Db	Wb	(RH)%	σ_c(N)
- -	18 - 24th March	8am-4pm	20.9	20.8	98.8	256.75
+ -	(Week 1)		22.2	22	98.7	253
- +			22.8	22.6	98.7	254.5
+ +			21.3	21.1	98.6	250.75
- -	25 - 31st March	8am-4pm	20.9	20.7	98.4	222.3
+ -	(Week 2)		21.4	21.1	98.1	214.3
- +			22.3	22.2	98.3	220
+ +			20.7	20.5	98.3	211.3
- -	1 - 7th April	8am-4pm	22.9	22.6	97.9	187
+ -	(Week 3)		23.9	23.4	95.2	177.5
- +			24.2	24	98.4	180
+ +			23.1	22.8	97.6	170.5
- -	8 - 14th April	8am-4pm	23.8	23.6	98.5	124.4
+ -	(Week 4)		24.6	24.2	97.4	112.6
- +			25.2	25.1	98.8	116
+ +			24.3	24.1	98.6	104.2

+Each column is the mean of 7 days data

σ_c(N): Compressive resistance

(RH)% : Relative humidity

Db : Dry bulb temperature

Wb : Wet bulb temperature

Table B.4: Strength measurement data for the control samples (off-Harmattan period)

System Design	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
Control system	18/3/92	9a.m.	268	0.546
	20/3/92	"	232	0.473
	22/3/92	"	157	0.320
	24/3/92	"	132	0.269
	26/3/92	"	107	0.218
	28/3/92	"	82	0.167
	30/3/92	"	72	0.147
	1/4/92	"	62	0.126
	3/4/92	"	48	0.098
	5/4/92	"	44	0.090
	7/4/92	"	39	0.079
	9/4/92	"	38	0.077
	11/4/92	"	37	0.075
	13/4/92	"	36	0.073
	15/4/92	"	36	0.073
	16/4/92	"	36	0.073

* Mean compressive strength (N/mm^2) for three samples of tomato at 2 days interval.

Table B.5: Strength measurement data for samples in the four storage equipment (off-Harmattan period)

System Design Matrix	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
--	18/3/92	9 a.m.	268	0.546
+-	"		268	0.546
-+	"		268	0.546
++	"		268	0.546
--	20/3/92	"	263	0.536
+-	"		258	0.526
-+	"		260	0.530
++	"		255	0.519
--	22/3/92	"	253	0.515
+-	"		248	0.505
-+	"		250	0.509
++	"		245	0.499
--	24/3/92	"	243	0.495
+-	"		238	0.485
-+	"		240	0.489
++	"		235	0.479
--	26/3/92	"	233	0.475
+-	"		225	0.458
-+	"		230	0.469
++	"		222	0.452
--	28/3/92	"	222	0.452
+-	"		214	0.436
-+	"		220	0.448
++	"		210	0.428

Table B.5 (contd.)

System Design Matrix	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
--	30/3/92	9 a.m.	212	0.432
+-	"		204	0.416
-+	"		210	0.428
++	"		202	0.412
--	1/4/92	"	202	0.412
+-	"		194	0.395
-+	"		200	0.407
++	"		192	0.391
--	3/4/92	"	192	0.391
+-	"		182	0.371
-+	"		190	0.387
++	"		180	0.367
--	5/4/92	"	182	0.371
+-	"		172	0.350
-+	"		170	0.346
++	"		160	0.326
--	7/4/92	"	172	0.350
+-	"		162	0.330
-+	"		160	0.326
++	"		150	0.306
--	9/4/92	"	162	0.330
+-	"		150	0.306
-+	"		160	0.326
++	"		148	0.302

Table B.5 (contd.)

System Design Matrix	Date	Time	Compressive load, N	Compressive strength, N/mm^2 *
--	11/4/92	9 a.m.	150	0.306
+-	"		138	0.281
-+	"		140	0.285
++	"		128	0.261
--	13/4/92	"	130	0.265
+-	"		115	0.234
-+	"		120	0.244
++	"		105	0.214
--	15/4/92	"	110	0.224
+-	"		95	0.194
-+	"		100	0.204
++	"		85	0.173
--	16/4/92	"	70	0.143
+-	"		65	0.132
-+	"		60	0.122
++	"		55	0.112

* Mean compressive strength (N/mm^2) for three samples of tomato at 2 days interval.

APPENDIX C

Statistical Analysis of data and calculations of effects of the variables for the preliminary and second experiments.

APPENDIX C

Detailed calculation of the Effects of Variables for the preliminary experiment.

Table C.1: Design Matrix of variables and the average compressive resistance for the Preliminary Experiment.

Test condition Number	Size (S)	Thickness (T)	σ_c (N)*	Interr-action (S x T)
1	-	-	246.25	+
2	+	-	241.25	-
3	-	+	246.25	-
4	+	+	246.25	+

*Mean Value of compressive resistance for the first week.

$$\text{Mean} = \frac{246.25 + 241.25 + 246.25 + 246.25}{4} = \underline{245N}$$

$$\text{Size effect(s)} = -\frac{246.25 + 241.25 - 246.25 + 246.25}{2} = -\underline{2.5 \text{ n.s.}}$$

$$\text{Effect of Thickness (T)} = -\frac{246.25 - 241.25 + 246.25 + 246.25}{2} = \underline{2.5 \text{ n.s.}}$$

$$\text{Interraction (S \& T)} = \frac{246.25 - 241.25 - 246.25 + 246.25}{2} = 2.5 \text{ n.s.}$$

$$\text{Standard Error (S.E)} = \sqrt{\frac{\sum d^2}{2(4)}} = \sqrt{\frac{\sum d^2}{8}}$$

$$= \sqrt{\frac{(246.25-245)^2 + (241.25-245)^2 + (246.25-245)^2 + (246.25-245)^2}{8}}$$

$$= \sqrt{\frac{(1.25)^2 + (-3.75)^2 + (1.25)^2 + (1.25)^2}{8}} = \sqrt{2.34}$$

$$= \underline{1.53}$$

2 S.E = 3.06

Since 2 S.E > 2.5, the effect of size, thickness and interraction are not significant, the same procedure is followed in calculating the effects of variables for the second and third weeks. However, only the average value of the compressive resistance for the second and third weeks is used for these cases.

Detailed calculation of the Effects of Variables for the second Experiment.

Table C.2: Design Matrix of variables and the average compressive resistance for the second Experiment.

Test condition Number			σ_c (N)*	Interraction (S x T)
	Size (S)	Thickness (T)		
1	-	-	256.75	+
2	+	-	253	-
3	-	+	254.5	-
4	+	+	250.75	+

*Mean Value of compressive resistance for the first week.

$$\text{Mean} = \frac{256.75 + 253 + 254.5 + 250.75}{4} = 253.75\text{N}$$

$$\text{Size effect(s)} = \frac{-256.75 + 253 - 254.5 + 250.75}{2} = -3.75$$

$$\text{Effect of Thickness (T)} = \frac{-256.75 - 253 + 254.5 + 250.75}{2} = -2.25$$

$$\text{Interraction (S x T)} = \frac{256.75 - 253 - 254.5 + 250.75}{2} = 0$$

$$\text{Standard Error (S.E)} = \sqrt{\frac{\sum d^2}{2(4)}} = \sqrt{\frac{\sum d^2}{8}}$$

$$= \sqrt{\frac{(256.75-253.75)^2+(253-253.75)^2+(254.5-253.75)^2+(250.75-253.75)^2}{8}}$$

$$= \sqrt{(3)^2+(-0.75)^2+(0.75)^2+(-3)^2} = \sqrt{2.39} = 1.55$$

$2SE = 3.1$

Since the effect of size(s) (3.75) > 2SE(3.1). This implies that the effect of size has a significant effect. But the effect of thickness and interraction has no significant effect since their effects is less than 2S.E.

The same procedure is followed in calculating the effects of variables for second, third and fourth weeks. Only the average value of the compressive resistance for the second, third and fourth weeks is used for these cases.

APPENDIX D

Detailed cost analysis of the storage equipment.

APPENDIX D

Table D.1: Cost Estimate Analysis for the Large Storage equipment with single layer of the Hessian sack (b).

Material	Quantity	Unit Cost (₦)	Total Cost(₦)
Wood	4½ lenght	45.00	191.00
Hessian sack	2 bags	6.00	12.00
Wire netting	2 yards	15.00	30.00
Nails (1")	2 pounds	12.00	24.00
Hinges (1")	1 pair	3.00	6.00
Sheet metal (gauge 18; 4'x8')	1	215.00	215.00
Oil paint	1 tin	10.00	10.00
		Total	488.00

Cost of Labour = ₦200.00

Cost of Production = ₦488 + ₦200 = ₦688.00

The cost of material for the large storage equipment with double layer of the Hessian sack (d) = ₦500.00 and the cost of production = ₦500 + ₦200 = ₦700.00

The cost of labour remains the same as with the single layer of the Hessian sack.

Table D.2: Cost Estimate analysis for the small storage equipment with single layer of the Hessian sack (a).

Material	Quantity	Unit Cost(₦)	Total Cost(₦)
Wood	2¼ lenght	45.00	101.25
Hessian sack	1 bag	6.00	6.00
Wire netting	1 yard	15.00	15.00
Nails (1")	1 pound	12.00	12.00
Hinges (1")	1 pair	3.00	6.00
Sheet metal (4'x8')(gauge 18)	1	215.00	215.00
Oil paint	1 tin	10.00	10.00
		Total	365.25

Labour Cost = ₦150.00

Cost of Production = ₦365.25 + ₦150.00 = ₦515.25

The cost of material for the small storage equipment with double layer of the Hessian sack (c) = ₦371.25 and the cost of production = ₦371.25 + ₦150.00 = ₦521.25

The cost of labour remains the same as with the single layer of the Hessian sack.

APPENDIX E

Psychometric state points and the calculated values of the cooling and humidification efficiencies during harmattan and off-harmattan seasons.

APPENDIX E

Table E.1: Psychometric state points and the calculated values of the cooling and humidification efficiencies (harmattan period).

System design matrix	Temp.°C T_1+	T_2	T_s	Moisture content, kg/kg dry air W_1	W_2	W_s	Rel. Humidity* (%)	η_c (%)	η_H (%)
- -	25.15	17.15	16.6	0.0057	0.011	0.0115	90.07	93.57	91.38
+ -	25.15	18.23	15.15	0.0057	0.0091	0.0105	70.23	69.2	70.83
- +	25.15	15.65	14.9	0.0057	0.010	0.0103	91.89	92.68	93.48
+ +	25.15	17.45	14.9	0.0057	0.009	0.0103	76.2	75.12	71.74

Relative humidity for the ambient = 28.29%

Table E.2: Psychometric state points and the calculated values of the cooling and humidification efficiencies (off-harmattan period).

System design matrix	Temp.°C T_1+	T_2	T_s	Moisture content, kg/kg dry air w_1	w_2	w_s	Rel. Humidity* (%)	η_c (%)	η_H (%)
- -	30.9	22.2	22	0.010	0.0157	0.016	98.4	97.75	95
+ -	30.9	23.1	22.8	0.010	0.017	0.0175	97.4	96.3	93.3
- +	30.9	23.7	23.6	0.010	0.018	0.0185	98.6	98.63	94.12
+ +	30.9	22.5	22.3	0.010	0.0167	0.0172	98.3	97.67	93.10

Relative humidity for the ambient = 37.3%

* Mean relative humidity value for duration of the experiment.

\+ Mean dry bulb temperature for the ambient for the duration of the experiment.