EFFECTS OF POSTHARVEST HANDLING METHODS AND STORAGE CONDITIONS ON STORABILITY OF PEPPER (*Capsicum frutescens* L.) FRUITS IN SOUTHWEST NIGERIA

BY

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ABSTRACT

Pepper a perishable seasonal fruit, requires storage to extend its shelf-life. Appropriate postharvest handling and storage prolong longevity and preserve quality of Pepper Fruit (PF). However, there is dearth of information on its handling and storage in Southwest Nigeria. Therefore, the effects of postharvest handling methods and storage conditions on storability of PF were investigated.

Two hundred Pepper Fruit Marketers (PFM) were randomly selected from pepper markets in Ibadan, Oyo State (Sasa and Bodija), Iwo, Osun state (Erunmu, Odo-Ori, and Station) and Akure, Ondo State (viz: Isikan, Oja-Oba, Sasa, NEPA and Isolo). Structured questionnaire was used to determine the socioeconomic characteristics of PFM and postharvest handling methods. *Capsicum frutescens* grown on the Teaching and Research Farm, University of Ibadan was harvested with and without pedicels at 10 and 100% ripeness. Postharvest handling was evaluated by comparing packaging in perforated polyethylene, non-perforated polyethylene and aluminium-foil before storing in either Ambient Conditions (AC) of 21.9-33.5°C and 58-62% Relative Humidity (RH); Refrigerator (4.0°C and 40-45% RH) or Evaporative Coolant Structure (ECS) (18 - 20°C and 70-75% RH). Pepper fruits were heat-sterilised, parboiled and unparboiled before oven-drying or sun-drying in order to determine the effect of processing on proximate and Vitamin C Content (VCC). Percentage Weight Loss (WL) was calculated. Firmness (FM) and Decay Level (DL) were evaluated on a scale of 1 to 4 and General Appearance (GA) on scale of 1 to 5. Data were analysed using descriptive statistics, correlation coefficient and ANOVA at $p < 0.05$.

The average age of PF marketers was 45 years with male predominance (56%). Majority (69.0%) spread PF on cemented floor to minimise deterioration; Sixty-six percent removed spoilt fruits to reduce infection. Seventy-four percent sourced PF from middlemen these were inappropriately transported in commuter vehicles with used grain sack. Fruits were marketed at 100% ripeness without pedicels. Evidence of deterioration due to presence of insect larvae and rottenness was observed from the 5th day after storage. The shelf-life of PF harvested with pedicels at 10% ripeness and stored in refrigerator, ECS and AC was 27, 20 and 6 days, respectively, while shelf life of PF harvested at 100% ripeness was 21, 14, and 3 days, respectively. In contrast, the shelf-life of PF harvested without pedicel at 10% ripeness was 21, 18 and 5 days while for 100% ripeness, it was 18, 15 and 2 days respectively. The WL, DL, GA and firmness of fruits harvested at 10% with pedicels and stored in refrigerator was 14.3%, 3.2, 4.0 and 3.5. The PF packaged in the aluminium-foil had significantly longer shelf life (30 days) than those packaged in perforated polyethylene (21 days) and non-perforated polyethylene (15 days). Parboiled-sundried pepper was significantly higher in crude protein (15.2%), fat (11.3 %), capsaicin (27.8%), and VCC (9.6 mg/100 g) compared to oven-dried pepper. Heat-sterilised fruits had the lowest nutrient contents.

Storability of PF was best at 10% ripeness with pedicel. Parboiled-sundried method conserved nutrients better than other techniques.

Keywords: Pepper storability, Postharvest handling, *Capsicum frutescens.*

Word count: 487

DEDICATION

This thesis is dedicated to our Lord Jesus Christ, the Almighty and the all sufficient God and to the family of Femi Michael Adewoyin.

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O.B. Adewoyin

CERTIFICATION

I certify that this work was carried out by Mrs O.B. Adewoyin in the Department of Agronomy, University of Ibadan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Peppers (*Capsicum* spp.), members of the family *Solanaceae*, are widely distributed throughout temperate and tropical regions. Pepper is derived from the Greek word “Kapsimo,” meaning to “bite” in allusion to the pungent property of the fruit (Bosland and Votava, 2000). The world production of pepper in 2001 was estimated to be 21.3 million tonnes from a harvested area of 1.6 million hectares. Nigeria is known to be one of the major producers of pepper in the world accounting for about 71.5 % of the African production (Grubben and Tahir, 2004).

Pepper is an essential ingredient in the food sector all over the world. After the discovery of the spice, it replaced black pepper (*Pepper nigrum*) as prime spice and basic ingredient in everyday cuisine all over the world (Whitmore and Turner, 2002). It can be dried, ground and packaged for export. It is used as colouring agent, pharmaceutical ingredient and a rich source of Vitamins A, C, and E (Bosland and Votava, 2000).

Postharvest losses are measurable reduction in quality or quantity of harvested pepper. They arise from the fact that harvested agricultural produce consist of living tissues that respire and undergo physiological changes caused by conditions such as high temperature, low atmospheric humidity, physical injury, biotic contamination and enzyme actions (Mrema and Rolle, 2002). The phenomenon could result in unpleasant flavours, erratic ripening and other changes in the living processes of fruits, making it unfit for use. Internal causes of deterioration include high respiration rate, ethylene production and action, rates of compositional changes associated with colour, texture, flavour, and nutritive value, water stress, sprouting and rooting, physiological disorders, and pathological breakdown (Kader, 2003). A major undesirable physical change in produce is due to the absorption of moisture in the atmosphere as a result of inappropriate packaging material. It can occur either as a result of poor selection of packaging material or failure of the package integrity during storage. Loss is not synonymous with damage, which is the visible sign of deterioration. Damage restricts the use of a produce, whereas loss makes it unusable

(Mrema and Rolle, 2002). Every unit of produce conserved translates to added unit available for productive utilisation and food security. Postharvest handling encompasses the delivery of a crop from the time and place of harvest to the time and place of consumption, with minimum loss, maximum efficiency, and maximum returns for all involved (Jobling, 2002).

Inappropriate postharvest handling results in postharvest losses, reduction of fruit shelf-life, hastened postharvest decay and reduced marketability of produce (Kader, 2003). Handling is an integrated systematic approach aimed at preserving quality of the final produce. Postharvest processes which include cleaning, grading, cooling, storing, packaging, transporting and marketing bridge the time and distance gap between producer and the consumer (Usman, 2009). The system of handling pepper fruits in Nigeria comprises of indigenous techniques practiced by growers, traders, and processors which result in considerable deterioration in the physical and nutritional compositions of the fruits. The inappropriate practices include harvesting unripe or over-ripe fruits, use of rough field packaging materials (strawed baskets or used grain sacks) and poor transportation methods (Hardenburg *et al.*, 1990). These problems could be considerable in magnitude and vary depending on climatic conditions, government policies, cultural practices of stakeholders, market demand, road condition, level of knowledge and awareness on appropriate postharvest handling methods (Hodges *et al*., 2010).

Considerable publicity has been given to the need to produce more food in Nigeria by successive government agencies. The Agrarian Revolution with the launching in Nigeria of the Operation Feed the Nation in 1976 sensitised the populace on the importance of achieving successful food security for the country. However, pests, diseases, natural disasters, inadequate storage and processing techniques are problems that still pervade the various food value chains in the country. During the main crop harvest period, surpluses often occur. In such situations, storage of fresh pepper is of great importance since it helps to stabilise prices by carrying over produce from period of high production (June) to period of low production (March). Without storage, the producer would be forced to market the produce soon after harvest regardless of demand thereby leading to market glut. In addition to storage of fresh pepper, drying the fruits is another option capable of reducing wastages, enhancing availability of pepper through out the year, and also stabilise price.

Food problems in the Third World countries, Nigeria inclusive, are not due to only underproduction but inappropriate postharvest handling methods (Adegbola and Awagu, 2013).

The objectives of this study were to:

i. Conduct a survey on postharvest handling methods of pepper (*Capsicum frutescens*) fruits and seasonal price pattern in southwest Nigeria.

ii. Evaluate the effects of levels of ripeness at harvest, harvesting methods and storage conditions on storability of pepper (*Capsicum frutescens*) fruits.

iii. Evaluate the effects of different packaging materials on the storability of pepper (*Capsicum frutescens*) fruits;

iv. Evaluate the effects of processing techniques on nutrient composition of pepper (*Capsicum frutescens*) fruit.

CHAPTER 2

LITERATURE REVIEW

2.1 Horticultural food losses

Postharvest loss is the reduction in quantity (weight or volume) and quality (altered physical condition or characteristics) between maturity of crop and the time of its final consumption (Usman, 2009). Food losses refer to any change in the availability, wholesomeness, edibility, acceptability or quality of that food that reduces its value to human being. There can be indirect loss through spillage or consumption by insects, rodents, birds and accidents. There can be direct loss by lowering of quality leading to rejection of food. There can be rejection due to custom, norms or human's preferences (Bhat *et al*., 2010). Losses may also occur at any level from the food chain between planting and preparation for immediate consumption. Three general periods have been identified.

i. Pre-harvest losses: This occurs during field operations before harvesting due to insects, rodents, drought, weeds, and diseases.

ii. Harvest losses**:** This occurs during harvesting which may be through shattering, lateness in harvest, disease infections, punctures, bruises, and cuts.

iii. Postharvest losses: This occurs after harvest due to poor handling, inappropriate transportation, inappropriate packaging methods, bad roads, inadequate storage and processing methods.

Despite the remarkable progress made in increasing food production at the global level, approximately half of the population in the third world does not have access to adequate food supplies. There are many reasons for this; one of which is food losses, particularly those occurring in the postharvest and marketing system of horticultural crops. Evidences suggest that these losses tend to be highest in those countries where the need for food is greatest. Both quantitative and qualitative food losses of extremely variable magnitude occur at all stages in the postharvest system from harvesting, through handling, storage, processing and marketing to final delivery to the consumer (Adegbola and Awagu, 2013). Estimate of postharvest losses in developing countries are hard to judge but some authorities stated that losses on sweet potatoes, plantain, tomatoes banana, and citrus, are sometimes as high as 50 percent (Satin, 1997). Reduction of these wastages, particularly if it can be economically avoided would be of great significance to growers and consumers alike. Postharvest losses vary greatly, by crop, by country, and by climatic region, and partly because there is no universally applicable method of measuring losses (Mazuad, 1997). Consequently, estimates of total postharvest food loss are controversial and range widely, generally from about 10% to as high as 40%. During postharvest period, about 5-21 % of food produce disappear in drying, storage and processing. Total estimated losses, not counting later losses by retailers and consumers run, from 10-37 % of all crops grown (Satin, 1997).

2.2 Problem of Postharvest Food Losses

Consumers demand for cosmetically perfect produce; this often means much of the food successfully harvested is wasted. It is observed that the importance of qualitative factors is growing and food that might have been accepted before may become lost now because they do not meet the current market higher standard for acceptability. A recent review of food waste in the United States reported that some 43 billion kilograms of food or 27 % of food available for consumption in the United States were lost in only three stages of the marketing process, retailing food services, and consumers. The total did not include losses elsewhere in the food harvesting and distribution system (Kantor *et al.*, 1997).

Addressing the problem of postharvest loss is complicated in so many ways, yet some recent efforts have shown promise, a number of strategies have targeted losses during food storage especially directly after harvest when food internal moisture is being reduced and they are prone to attack by insects and other pathogens (Agoda *et al.*, 2011). The level of losses of some specific fruits and vegetables in Nigeria is indeed a source of major concern to many Nigerians. The losses when translated to monetary value surely run into millions of naira. The complex and long chain of marketing systems between the producer and consumers make it difficult to accurately assess the level of damage in many food crops.

According to FAO (2003), postharvest handling system can be grouped as follows:

i. Technical activities: harvesting at proper maturity stage, field drying, threshing, cleaning, additional drying, storage, processing;

ii. Economic activities: transporting, marketing, quality control, nutrition, extension,

iii. Management activities: Information, communication and administration.

2.3 Losses Assessment

There are no generally accepted methods for evaluating postharvest losses of fresh produce (Mazuad, 1997), whatever evaluation method may be used, and the result can only refer to the described situation in the appraisal of an existing marketing operation. The accurate evaluation of losses occurring is a problem. It may be suspected that losses are too great, but there may be no figure to support this view because

1. Records do not exist in many cases;
2. Records if available do not cover a long enough period of time;
3. The figures available are only estimates made by several observations;
4. Records may not truly represent a continuing situation (for example, losses may have been calculated only when it is usually low or high).
5. Loss figures may be deliberately over or underestimated for personal gain or to avoid embarrassment.

If accurate record of losses at various stage of market operation has not been kept over a period of time, a reliable assessment of the potential cost effective ways to improve handling method is virtually impossible, and the marketing position of the grower is difficult to strengthen. It is evident that the grower, marketers, consumers, and all stakeholders in the food chain who wants to reduce their postharvest losses must maintain reliable record. The estimate of postharvest losses involves quantitative and qualitative losses occurring in horticultural crop between harvest and consumption. The goal is to minimise these losses, and to do so, the following is essential.

i. Understanding the biological and environmental factors involved in postharvest deterioration.

ii. The use of appropriate postharvest technology procedures that will slow down deterioration and maintain quality and safety of the commodities.

iii. Undertaking appropriate cultural farming procedure with pest and weed management regimes.

iv. Appropriate stage of maturity must be attained before harvest and harvesting should be done during low temperature periods of the day (morning and evening).

v. Proper harvesting methods and careful postharvest handling.

Qualitative losses, such as loss in edibility, nutrient contents, and consumer acceptance of the products are much more difficult to assess than quantitative losses. Food loss assessment provides basis for programmes aimed at reducing postharvest losses (Atanda *et al.*, 2011). Assessment may be made by survey of both traditional and improved method and be followed by quantitative, technical and financial assessment to determine acceptability of storage structure or method of operation.

Importance of Proper Postharvest Handling is as follows:

1. Proper handling, packaging, transportation and storage reduce the postharvest losses of fruits and vegetables.
2. Processing and preservation technology helps to save excess fruits and vegetables during the glut season.
3. The technology has become a necessity to improve the food safety and strengthen nation's food security.
4. The technology helps to boost export of agricultural commodities in the form of preserved and value added products.

2.4 Market price behaviour, structure, conduct and performance of horticultural crops

The information on market price of commodities is important to producers, traders, consumers and policy makers; it is particularly useful for planning, decision making and policy formulation. Many food crops are harvested at a particular time and the quantity harvested must be sufficient for an entire year. There is a perpetual cycle of short period of boom which occur immediately after harvest and a long period of dearth which occurs during cultivation and harvesting. A substantial part of harvest must therefore be stored for use later in the year. The prices of agricultural commodities are then dictated by the forces of supply and demand. At harvest period, the supply of a commodity is in abundance and as time elapses between harvest and new planting the supply dwindles. In the face of a constant demand and varying levels of supply at different periods of the year, a definite commodity price pattern emerges during the year. At harvest period, prices are low because of large supply while at planting when supply is almost depleted prices are high because of low level of commodity supply (Trap, 1991).

At harvest period when supply is in abundance, the price of a commodity is low thus giving rise to low price index. As the level of supply dwindles in a crop year, price rises and the price index also rises accordingly. The concept of agriculture marketing and storage of produce is very important in production. Production is said to be incomplete until the produce reaches the ultimate consumer hence marketing and storage are very important aspects of the production system. Marketing according to America Marketing Association, consist of the performance of business activities that directs free flow of goods and services from producers to consumers or users. Marketing channel is the path in which goods are taken through from producers to final consumer. The marketing channel for agricultural produce in Nigeria is mainly a decentralised type in which wholesalers purchase either directly from producers or from small production area of selling point.

2.5 Pre-harvest factors influencing postharvest quality of fruits and vegetables

2.5.1 Maturity stage

Maturity is one of the major factors that determine the compositional quality of vegetables. (Howard *et al.*, 1994) observed that total AA content of red pepper was about 30 % higher than that of green pepper. Tomato fruits harvested green and ripened at 20 ^{o}C to table-ripeness contain less Ascorbic Acid (AA) than those harvested at the table ripe stage. Tomato fruit analysed at the 'breaker' stage contained only 69 % of their potential AA concentration. Ascorbic acid content increased with ripening in apples and mangoes while large and more mature peas contained less ascorbic acid than smaller and immature peas. Various workers reported that immature citrus fruits contained the highest concentration of AA, whereas ripe fruits contained the least (Wilson *et al.*, 1995). Although AA concentration decreases during maturation of citrus fruits, the total AA content per fruit tended to increase because the total volume of juice and fruit size increased with advancing maturity.

2.5.2 Harvesting Method

The method of harvest can determine the extent of physical injuries and consequently influence nutritional composition of fruits and vegetables. Mechanical injuries such as bruising, surface abrasions and cuts can result in accelerated loss of nutrient composition in produce. The incidence and severity of such injuries are influenced by the method of harvest and handling operations (Kader, 2003). During postharvest handling of produce, mechanical damage can be inflicted on produce, causing the enzymes contained in the cell tissues to be released leading to enzymatic breakdown of cellular materials. The chemical reactions catalysed by the enzymes result in the degradation of food quality, such as development of off-flavours, deterioration of texture, and loss of nutrients. Since enzymes are mainly protein, they are sensitive to heat, therefore if temperatures are not controlled during postharvest handling this may cause the produce to deteriorate at an accelerated rate. Careless handling of fresh produce causes internal bruising, which results in physiological damages, thus rapidly increasing water loss and rate of physiological breakdown. Skin breaks also provide sites for infection by disease-causing organisms leading to decay.

2.5.3 Climatic conditions

The climatic conditions such as temperature, humidity and light intensity are essential for the synthesis of AA in plants; the amount and intensity of light during the growing season have definite influence on the amount of AA formed. AA is synthesised from sugars supplied through photosynthesis in plants. Outside fruit exposed to maximum sunlight contains higher amount of AA than shaded fruit on the same plant. Temperature also influences the nutrient composition of plant tissues during growth and development. Total available heat and the extent of low and high temperature are very important factors in determining growth rate and chemical composition of horticultural crops.

2.5.4 Cultural Practices

Lisiewska and Kmiecik (1996) reported that increasing amount of nitrogen fertilizer from 80 – 120 kg ha^{-1} decreased the AA content by 7 % in cauliflower. Reduced level of AA in juices of oranges, lemons, grapefruits and mandarins resulted from the application of high levels of nitrogen fertilizer to those crops while increased potassium fertilizer increased AA content. Because of nitrogen's involvement in protein synthesis, soil nitrogen deficiencies may lead to lower protein concentrations in vegetables, thereby affecting the nutritional composition of the crop. Adequate soil nitrogen supplies allow for optimal development of vegetable colour, flavour, texture, and nutritional quality. Deficiencies in soil calcium have been associated with a number of postharvest disorders including blossom end rot of tomato and pepper. High soil calcium concentrations reduce these disorders and are associated with other postharvest benefits, including increased AA content, extended storage life, delayed ripening, increased firmness, and reduced respiration and ethylene production (Freeman *et al.*, 1991). High levels of soil potassium often have a positive effect on the quality of vegetables. Increased soil potassium concentrations have been shown to increase the AA content and improve vegetable colour. Potassium also decreases blotchy ripening of tomato (Freeman *et al.*, 1991).

Leeks grown with less frequent irrigation showed increased concentration of dietary fibre, AA, protein, calcium, magnesium and manganese (Sorensen *et al.*, 1995). High AA content may serve as a protective strategy against drought and injury, therefore, from a nutritional point of view; horticultural crops grown under low nitrogen supply and irrigated less frequently may be preferred due to high concentrations of vitamins C and low concentration of nitrate (Toivonen *et al.*, 1994). Cultural practices such as pruning and thinning determine the crop load and fruit size which can influence the nutritional composition of fruits. Also the use of agricultural chemicals such as pesticides and growth regulators may indirectly affect the nutritional quality of fruits and vegetables (Liang *et al.*, 1996).

2.6 Postharvest Factors

Fresh fruits and vegetables, as living tissues, are subject to continual changes after harvest. Such changes cannot be stopped but can be controlled within certain limits by using various postharvest procedures. Postharvest factors that affect fruits and vegetables include the following:

2.6.1 Temperature

Temperature is the most important tool to extend shelf-life and maintain quality of fresh fruits and vegetables. Delays between harvesting and cooling or processing can result in direct loss due to water loss and decay; also indirect losses can occur as a result of changes in appearance, taste, texture and deterioration in nutritional quality. The environment for safe and prolonged storage of fruits and vegetables must therefore be one of high humidity and low temperature because postharvest water loss of fruits and vegetables results in fruit softening, and reduced shelf life.

2.6.2 Bruising, Trimming and Cutting

Bruising significantly affects the chemical composition of pericarp and locular tissues of tomato fruit. AA content was about 15 % lower in bruised locular tissue than unbruised fruits. Green peas and green lima beans retain their nutrient better if left in the pods than if shelled (Moretti *et al.*, 1998).

2.6.3 Chemical Treatments

Calcium dips may be used to reduce physiological disorders and maintain firmness in apples and cherries. Dehydrated pineapples and guava pre-treated with cysteine hydrochloride had increased AA retention and reduced colour change during storage (Mohammed *et al.*, 1993). Kiwi fruit slices stored in ethylene-free air contained 3-fold more AA than control when kept in an ethylene-free atmosphere, slices had a slightly higher AA content than those treated with 10 % $CaCl_2$ (Agar *et al.*, 1999).

2.6.4 Irradiation

Ionizing radiation may be used for sprout inhibition, insect control, or delay of ripening of certain fruits and vegetables. Irradiation of horticultural crops at relatively low doses of 75 - 100 krad irreversibly inhibited sprouting of potatoes regardless of storage temperature. Losses in AA were lower in potato irradiated for sprout control and subsequently stored at 15 ^{o}C than in non-irradiated tubers stored at 2 - 4 ^{o}C (Joshi *et al.*, 1990). In general doses of 2 - 3 krad combined with refrigeration were useful for extending the shelf life of strawberries (Graham and Stevenson, 1997).

2.6.5 Controlled Atmosphere (CA) and Modified Atmosphere Package (MAP)

In general, atmospheric modification reduced physiological and chemical changes of fruits and vegetables during storage. Loss of AA can be reduced by storing apples in a reduced oxygen atmosphere Veltman *et al.* (1999) discovered that storage of pepper for 6 days in CO_2 enriched atmosphere resulted in a reduction in AA content of sweet pepper kept at 13 ^oC.

Retention of AA in Jalapeno pepper reduced after 12 days storage at 4 ^oC and in additional 3 days at 13 ^oC was 83 % in modified atmosphere packaging (MAP) and 56 % under ambient condition. Modified atmosphere packaging retarded the conversion of AA to DHA that occurred in air stored peppers. Other qualities of pepper were maintained better in MAP than in air (Howard and Hernandez-Brends, 1998).

2.6.6 Processing methods

Ascorbic acid is very susceptible to chemical and enzymatic oxidation during processing, cooking and storage of produce. Blanching and pasteurisation prevent the action of AA oxidase. Other plant enzymes, including phenolase, cytochrome, oxidase and peroxidase are indirectly responsible for AA loss. Electromagnetic energy had advantage over conventional blanching by reducing processing time, energy and water usage and improvement of product quality. Howard *et al.* (1999) reported that steam blanching green beans resulted up to 30 % loss of total AA. Microwave cooking had minimal effect on AA content. Unblanched beans and pepper lost more than 97 % of their AA within 1 month of freezing at 23^oC, blanching reduced AA content by 28 %, vacuum-sealed sample decreased by 3 % while non vacuum-sealed 10 % in 12 month of storage (Oruna-Concha *et al.*, 1998).

2.7 Storage of horticultural crops

The need for storage of agricultural produce has been dictated by the alteration of favourable and unfavourable periods for the optimum growth and production of crops as characterised by the dry and rainy seasons in the tropics. Also by disasters such as draught, famine, major pest and disease outbreak confronting crop production. Tropical vegetables are stored at higher temperature than temperate vegetables. The higher temperature leads to increase in metabolic activities, respiratory rate, microbial infection, loss of moisture content, and increased rate of ripening; all these reduce the shelf life of tropical fruits more rapidly (Bechmann and Earles, 2000).

Various authorities have estimated 25 - 70 % of fresh fruits and vegetables produced lost after harvest (Daramola and Okoye, 1998). These losses have been found to be due to loss of moisture, changes in composition during metabolism, pathogen attack, temperature and relative humidity of the storage environment. Other factors that contribute to deterioration include initial quality of crop, mechanical injury, transportation method, maturity stage and harvesting method. The storage life of produce is highly variable and can be related to the wide range of respiration rate among different plant tissues. Peppers stored above 7.5 °C suffer more water loss and shrivel. Dried pepper are allowed to equalise in moisture content, they are then packed tightly into sacks and stored in non-refrigerated warehouses for up to 6 months. Storage under low temperature aids loss of red colour and slows down insect activities (Willis *et al.*, 1998). The moisture content of pepper should be low enough (10 - 15 %) to prevent mould growth. A relative humidity of 60 - 70 % is desirable with a higher moisture content; the pod may be too pliable for grinding and may have to be re-dried with lower moisture content (under 10 %), pods may be too brittle that they shatter during handling; this causes losses and the release of dust, which is irritating to the skin and respiratory system (Wills *et al.*, 1989). The use of polyethylene bags provides better storage, ensures pods maintain constant moisture content during storage up till the time of grinding and reduces dust problem (Banaras *et al.,* 2005). Pepper can also be preserved effectively in the evaporative coolant structure for 2 weeks without facing the problems associated with cold storage (Babatola *et al.*, 2005).

The control of relative humidity in postharvest environment is often as important as the control of temperature. In some situation, the effects of the two factors are difficult to separate because of the capacity of air to hold moisture which varies with temperature. A humidity of 60 - 70 % is usually recommended for fresh hot pepper while 90 - 95 % relative humidity is recommended for sweet or bell pepper. The relative humidity in the postharvest environment affects moisture loss from fruit or vegetables and the activities of decay causing agent (Sinchez *et al.*, 2006).

2.8 Evaporative Coolant Structure

The evaporative coolant structure works on the principle of cooling which is based on transfer of heat from the storage chamber to the riverbed sand which forms the cooling medium from where the heat is also sent out across the outer wall of the structure by evaporation. The evaporative coolant structure (ECS) is a portable model (pot-in-pot), described by Babarinsa and Nwagwa (1986). It consists of two burnt clay pots which are placed inside each other and the space in-between them was filled with riverbed sand and is constantly kept wet. There are many other examples of evaporative coolant structure, they are as follows:

a. Bamboo Coolant Structure

The base of the cooler is made by a large diameter tray that contains water. Bricks are placed within this tray and an open ware cylinder of bamboo or similar materials is placed on top of the bricks. Hessian cloth is wrapped around the bamboo frame, ensuring that the cloth is dipped into the water to allow water to be drawn up the cylinder's wall. Food kept in the cylinder with a lid placed on the top.

b. Charcoal Cooler

The charcoal cooler is made from an open timber frame of approximately 0.50 mm x 0.25 mm in section. The door is made by simply hinging one side of the frame. The wooden frame is covered in mesh, inside and out leaving 9.25 mm cavity, this filled with pieces of charcoal.

The charcoal is sprayed with water and when wet provides evaporative cooling effect. The framework is mounted outside the house on a pole with a metal to deter rat and a good coating of grease to prevent ant from getting to the food stored.

c. An Almirah Cooler

The Almirah cooler is a more sophisticated cooler that has a wooden frame covered with white cotton cloth. There is a water tray at the base and on top of the frame into which the cloth dips, thus keeping it wet. A hinged door and internal shelves allow easy access to the stored produce.

Pot Designs and uses

There are simple designs of evaporative coolers that can be used in the homes. The basic design consists of a storage pot placed inside a bigger pot that holds water. The inner pot stores food that is kept cool. One adaptation on the basic double pot design is Janata cooler, developed by the Food and Nutrition Board of India. A storage pot is placed in an earthenware bowl containing water. The pot is covered with a damp cloth that is dipped into the reservoir of water. Water drawn up the cloth evaporates keeping the storage pot cool. The bowl is placed on wet sand to isolate the pot from the hot ground.

In the Department of Agronomy, University of Ibadan various researches were carried out to investigate the effectiveness of the evaporative coolant structure in prolonging shelf-life of horticultural crop. Babatola and Adewoyin (2005) observed that *Cucumis sativus* stored best for 3 weeks under the refrigerator followed by evaporative coolant structure and then open shelf. The evaporative coolant stored cucumber fruit effectively for 2 weeks. Babatola and Adewoyin (2006) also investigated the effect of storage conditions on nutrient composition and quality of *Capsicum frutescens* under three storage conditions. Observations were made on colour, firmness, weight loss, disease incidence and pungency level of pepper fruit. It was observed that pepper fruits kept well for 21 days in the evaporative coolant structure at a temperature of 20 - 22^{o}C. Babatola and Adewoyin (2007) further investigated the effect of NPK fertilizer levels on growth, yield and storage of pepper on *Capsicum annuum*. The result showed that fruits stored in the refrigerator stored best for 3 weeks, followed by evaporative coolant structure which stored for 2 weeks while fruits under the ambient condition deteriorated rapidly after 4 days.

2.9 Harvesting index for horticultural crops

The principles dictating at which stage of maturity a fruit or vegetable should be harvested are crucial to its subsequent storage, marketability and quality. Postharvest physiology distinguishes three stages in the life span of fruit and vegetables – maturation, ripening and senescence. Maturation is indicative of fruits and vegetables readiness for harvest. At this point the edible part of the fruit or vegetable is fully developed in size. Ripening follows or overlaps maturation rendering the produce edible as indicated by taste. Senescence is the last stage characterised by natural degradation of fruit as in loss in texture and flavour. The quality of fruit and vegetable cannot be improved but it can be preserved. Good quality is obtained when harvesting is done at the proper stage of maturity. Immature fruit when harvested will give poor quality and erratic ripening. Delay in harvesting of fruits however may increase their susceptibility to decay, resulting in poor quality and low market value (Brecht *et al.,* 1992).

The decision on when to harvest a crop is very important to farmers and growers of vegetables and fruits. Some fruits are harvested when still very tender like green beans, egg plant, and okra before developing high fibre and lignin, green beans are usually harvested green when still succulent, and green pepper is also harvested green. Normally any type of fresh produce is ready for harvest when it has developed to the ideal condition for consumption. This condition is usually referred to as harvest maturity. Confusion may arise because of the word maturity, since in botanical sense, this refers to the time when the plant has completed its active growth and arrived at the stage of flowering and seed production (physiological maturity). Therefore, harvest maturity refers to the time when the fruit is ready for harvest and must take into account the time required to reach market and how it will be managed en route. This time indicates that harvesting is done earlier than the physiological or ideal maturity time (Steven and Celso, 2005).

2.10 Preservation techniques for pepper fruit

In recent years, developing countries have been asking for rural techniques for preservation of fruits and vegetables in order to increase the rural and urban population self sufficiency as well as their contribution to agricultural development. One of the main obstacles to the development of these techniques is the lack of modern literature adapted to the socio-economic condition of the countries (FAO, 2003).

The preservation of horticultural crops involves checking enzymatic actions as well as destroying or retarding the growth of micro-organisms. To achieve the latter, conditions should be made unbearable for micro-organisms by ensuring a high or low temperature, reducing moisture levels, keeping out air, destroying enzymes and application of the combination of these measures.

These conditions can be accomplished by the use of high or low temperatures or by chemical means. Processing is a postharvest activity carried out to maintain or change the form or characteristics of fresh produce. To achieve these, spoilage agents must be eliminated without destroying the nutritive value or palatability of the produce. Produce that have been processed can also be stored to prevent spoilage and extend storage life; hence we have the term preservation. Preservation controls the physical, chemical or biological changes in foods. These include physical changes (colour, flavour, texture and taste etc.) chemical changes (carbohydrate, fats, proteins, vitamins and minerals), and biological changes (mould, yeasts and bacteria). Processing and preservation aim at achieving the following goals:

i. To increase shelf-life of the produce by the use of preservation techniques, which inhibit microbiological and biochemical changes; hence moulds, bacteria and enzymes should be destroyed.
ii. To increase variety in the diet by providing a range of attractive flavours, colours, aromas and textures.
iii. To increase the economic value of the product by transforming it from one form to another.
iv. To create new products.
v. To remove inedible parts of produce.

2.10.1 Drying of foods

Drying is another method of food preservation that involved the removal of moisture from food to the level at which micro-organisms cannot grow. Sun drying is generally done where sunshine is available for long period (Mepba *et al.*, 2007). Mechanical drying involves application of heat by a mechanical dryer under the controlled conditions of temperature, humidity and air flow. In vacuum drying temperature of food and the rate of water removal are controlled by regulating the degree of vacuum and intensity of heat input on the produce. Freeze-drying is done by sublimation process, converting food into ice without passing through the liquid form of water by means of vacuum and heat applied in the drying chamber. In this method, produce is first frozen then water is removed by vacuum and application of heat which occurs simultaneously in same chamber binding the moisture in food. The use of high concentration of sugar binds up the moisture and makes the food have a certain level of moisture at which micro-organisms are not able to grow. Also the use of salt which result in high concentration of salt that causes high osmotic pressure and tie up the moisture which inhibit the growth of micro-organisms. It dehydrates the food by drying out and tie up moisture as it dehydrates the microorganism's cells. Salt reduces the solubility of oxygen in the food by reducing the moisture (Barbosa *et al*., 2003).

2.10.2 Use of low temperature

Low temperature retards the microbial growth and enzyme reaction because it retards the chemical reactions **(**Davey *et al*, 2000). This is not a permanent method because some micro-organisms can also grow at low temperature. Semi-perishables such as potatoes, apples etc. can be stored in the commercial cold storage with proper ventilation, automatic controlled temperature for one year. Freezing (-18 to -40 ^{o}C) ties up the moisture and increases the concentration of dissolved substances in the food. But, sometimes enzymes are active even below the 0 ^{o}C. In this case before freezing, 'Blanching' is necessary for vegetable freezing.

2.10.3 Boiling and Cooking

The primary objective of cooking is to produce a palatable food. Cooking results in destruction or reduction of micro-organisms and inactivation of undesirable enzymes; destruction of potential hazard in the foods which are present naturally through micro-organisms; improvement of colour, flavour, texture of food and digestibility of food components (Mepba *et al.*, 2007).

2.10.4 Packaging

The main objective of packaging is to keep the fruits and vegetables in good condition until they are sold and consumed. The packaging of fruits and vegetables should protect them from injury and water loss, and be convenient for handling and marketing (Mordi and Olorunda, 2003). Packages should also provide information about the produce, including the grade, handling instructions, and appropriate storage temperatures. Plastic film bags are widely used for consumer size packs in fruit and vegetable marketing. It retains water vapour so as to reduce water loss from the content.

Plastic boxes are rigid containers most suited for packaging soft and delicate commodities. Net or mesh bags are widely used for packing fruits like apple, citrus, guava, *Poulteria sapota*. Sleeve packs are immobilisation of packed fruits, superior visibility that gives a good sales appeal. Plastic film are ideal packaging for low water vapour transmission rate with high gas permeability. Shrink film or stretch film – Stretching the film under controlled temperature and tension, the film which is wrapped over the produce, stretches and then contract by cooling. It is actively involved with produce interaction with internal atmosphere of packaging material to extend shelf life by maintaining quality and safety (Banaras, 2005). Antimicrobial packaging involved incorporating antimicrobial agents into polymer surface coating sand surface attachments. Wooden packagings are used for packing fruits and vegetables. They are similar to plastic crates. Modified atmosphere packaging is the packaging of perishable produce whereby the atmosphere surrounding the produce is regulated to extend shelf life of the produce. Bamboo mat holed boxes is suitable for transportation of apple. Polypropylene boxes are highly suitable for long markets, and they can be reused. Corrugated fibre boards are suitable for fruits and vegetables and very economical (FAO, 2003).

CHAPTER 3
MATERIALS AND METHODS

3.1 Survey of postharvest handling methods of pepper fruit by farmers and marketers in Southwest Nigeria

Surveys were conducted in Oyo and Ondo states (Fig 3.1 & 3.2) to investigate the postharvest methods of handling pepper fruits by farmers using structured questionnaire (Appendix 1). A purposive sampling technique was used to select fifty pepper farmers each in the state capital of Oyo and Ondo. The sampled areas were predominantly farming communities in Ibadan and Akure. The annual rainfall distribution in Ibadan is 1,100 - 1,800 mm distributed over nine months with temperature range of 21.9 °C to 35 °C and relative humidity of 75 % to 90 %. The geographical location for Oyo state is between latitude 7° 22.51 N and longitude 3° 50.51E. The geographical location of Akure is within latitude 7° 16N and longitude 5° 14E. The soil is sandy loam. The annual rainfall distribution varies from 1,100 – 1,300 mm with relative humidity of 75 % and a mean temperature range of 27 ^{o}C to 32 ^{o}C.

Surveys were also conducted on the postharvest handling methods of pepper fruits by marketers in Ibadan, Akure, and Iwo using structured questionnaire (Appendix 2). The questionnaire was designed to elicit information on the socio-economic characteristics of pepper fruit handlers, sources of their pepper fruits, current methods of storage, observed signs of deterioration, storage duration before spoilage, methods used for prolonging pepper fruit shelf-life, methods of preventing damage during transportation, methods of package for transportation and storage, effect of various handling methods on storability and quality of pepper fruits, causes of deterioration and problems encountered during handling (Appendix 2).

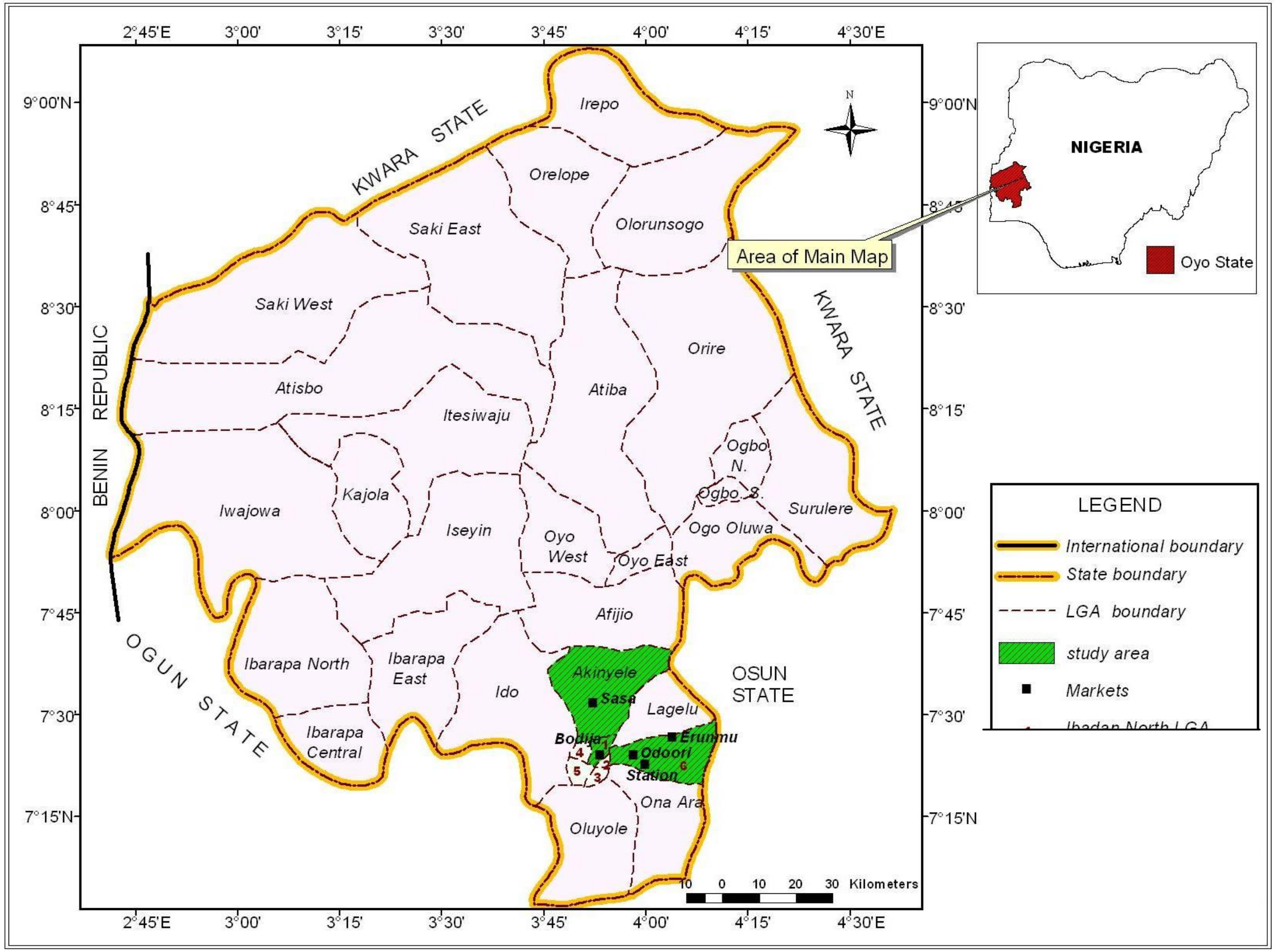

Fig 3.1. Map of Oyo state showing the local government area for markets surveyed

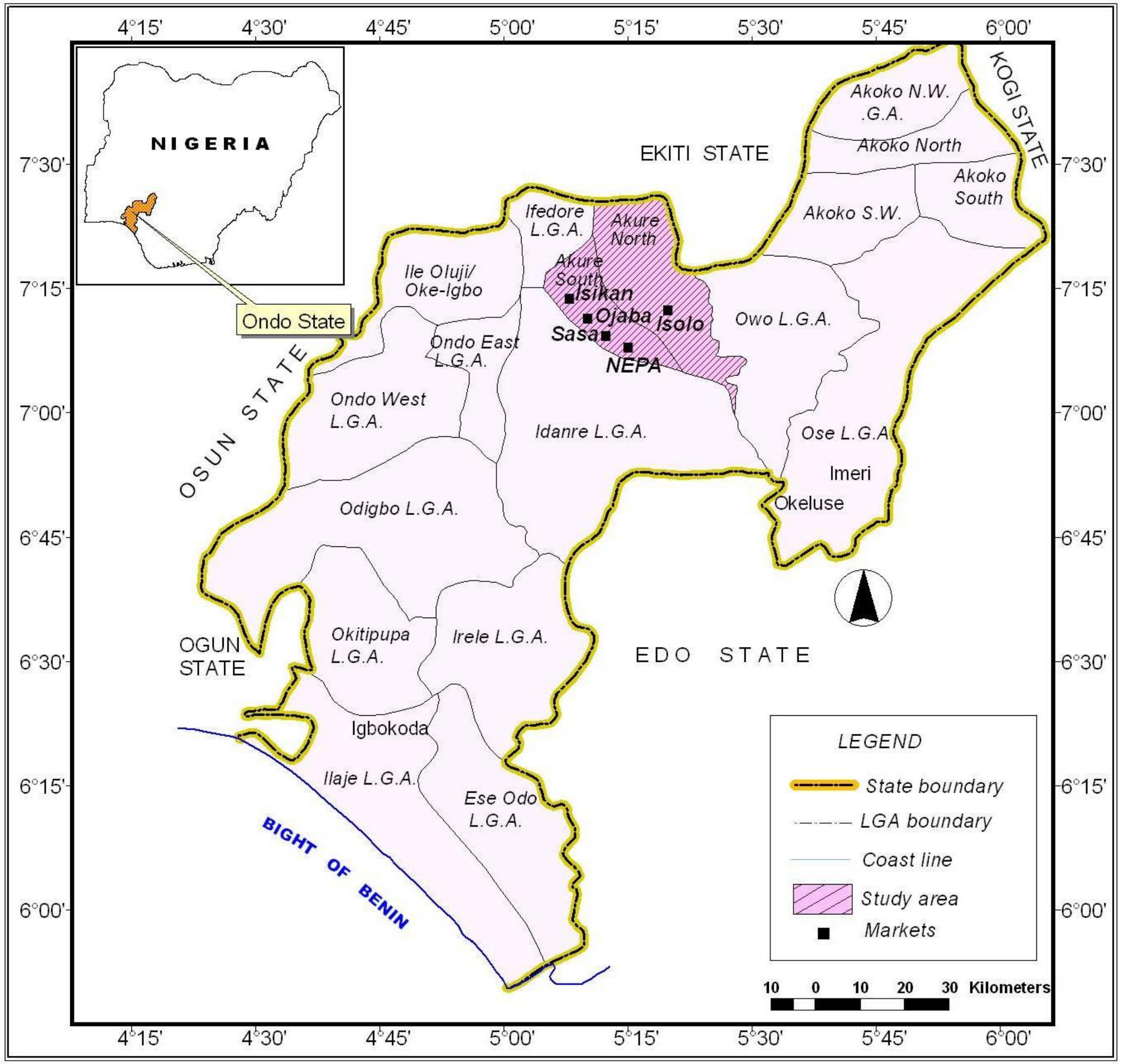

Fig 3.2: Map of Ondo state showing the local government area for markets surveyed.

The survey was carried out using multistage sampling technique which involved an initial purposive sampling to identify major pepper fruit markets in Ibadan, Iwo and Akure. Twenty pepper marketers were randomly selected from each market. The markets were Sasa, and Bodija (Ibadan), Erunmu, Odo-Ori, and Station (Iwo), and Isikan, Oja-Oba, NEPA, Isolo, and Sasa in Akure.

Data collected were analysed using frequency and percentages.

3.1.2 Seasonal price pattern of pepper fruit in urban and rural markets of Oyo and Ondo states from 2004-2009

The objective of the study was to obtain information on seasonal price pattern of pepper fruits in Oyo and Ondo states. The rural markets are those located at the rural areas (Sasa). The results can be used by producers for planning, decision making and policy formulation (Appendix 3). A price index is a normalised average price of produce in an area during a given interval of time. It is designed to compare variation in monthly prices of a produce over time periods at a given location. Adequate storage of produce could lead to price stability, enables farmers to maximise profit and encourage increase in production. In this study the seasonal price pattern of pepper fruits in Oyo and Ondo states was estimated using six-year average monthly price index from 2004 to 2009. Monthly Price Index was calculated for each year thus (Afolami, 1998).

$$\text{Monthly Price Index} = \frac{\text{Monthly Price}}{\text{Annual Average Price}} \times \frac{100}{1}$$

3.2 Experiment 1

Effects of ripeness at harvest, harvesting methods and storage conditions on storability of pepper fruit

The objective of this experiment was to evaluate the effects of ripeness at harvest, harvesting methods, and storage conditions on storability of pepper fruits. Ripeness was determined according to USDA (1991). The treatments were harvesting methods (with and without pedicels) and ripeness at harvest (10 % and 100 % ripeness). The storage conditions were refrigerator, evaporative coolant structure

(ECS), and ambient. The experimental design was a factorial in completely randomised design replicated three times.

3.2.1 Experimental site location

The experimental site was located at the Teaching and Research Farm, University of Ibadan. The area falls within the rainforest zone of Nigeria with temperature mean range of 25 - 35 ^{o}C and rainfall of about 1,150 mm - 1,800 mm per annum. Maize was grown on the land previous to this experiment. The farmer's site was located at Elepe village in Akinyele Local Government Area of Oyo State. The area falls within the rain forest zone of Nigeria. Crops commonly grown were maize, cassava, *Amarantus, Celosia*, pepper and okra.

Cultural practices

The existing vegetation was cleared from the Teaching and Research Farm experimental plot manually with the use of cutlass and hoe. Stumping was done in preparation for planting. The vegetable beds were prepared manually; each bed was 2.5 m x 1.5 m. Pepper fruit *(Capsicum frutescens)*, long cayenne, was procured in August 2005 from the seed section of Department of Agronomy, University of Ibadan and raised for four weeks in the nursery. Seeds were planted by broadcasting. Germination commenced 5-10 days after sowing. Two seedlings were planted per stand at a spacing of 70 x 50 cm. The plant population was 13,636 plants/ha. The seedlings were thinned to one per stand after two weeks. Weeding was done five times at two weeks intervals.

The pre-planting operation in farmer's field involved clearing, burning, stumping and removal of refuse. Beds were prepared manually with the aid of hoe. In farmer's field, nursery operation included clearing, preparation of beds, broadcasting of seeds and covering with palm fronds to enhance germination. Germination takes place within 5-10 days after sowing. The seedlings were transplanted to the field after six weeks of germination. Two seedlings were planted per stand at a spacing of 45 x 30 cm. Two weeks after transplanting, the seedlings were thinned to one per stand.

Harvesting

Fruits were harvested at 8 weeks after transplanting in two batches (10 % and 100 % ripeness) according to the recommended technique during the cool time of the day (7-9 am) by holding the pedicel and turning it in opposite direction to the angle of repose of the fruit in order to achieve easy detachment and prevent rupturing of the pedicel (Mohammed, 2000). Fruits were harvested with pedicel (+P) and without pedicel (-P), at 10 % and 100 % ripeness.

3.2.3 Postharvest Operations

Freshly harvested pepper fruits were sorted according to uniformity of size (6 - 8cm), freedom from diseases and defects. Infected fruits and those with defects were discarded. The fruits were rinsed with water and air dried. Transparent polyethylene bags (30 cm long and 20 cm wide and 0.04 mm in thickness) perforated at 10 points with holes of 0.5 cm was used to package the pepper fruits. 500g of pepper fruits harvested with pedicel and without pedicel at 10 % and 100 % ripe stages were packaged in the transparent polyethylene bags and sealed. The pepper fruits were stored under three storage conditions viz: ambient (21.9 °C – 33.5 °C; 58 – 62 %RH), evaporative coolant structure (18 °C – 20 °C; 70 – 75 %RH) and refrigerator (4 °C; 40 - 45 %RH).

For the ambient condition treatments, the polyethylene bags with the fruits were placed on open shelves in the Agronomy Departmental laboratory. The evaporative coolant structure used was a portable model described by Babarinsa and Nwagwa (1986). It consisted of two burnt clay pots, one placed inside the other and the space in between them was filled with riverbed sand and was kept constantly wet. The cooling effect resulted from the transfer of heat from the storage chamber to the wet riverbed sand which formed the cooling medium from where the heat was also sent out across the outer wall of the structure by evaporation (Fig. 3.3).

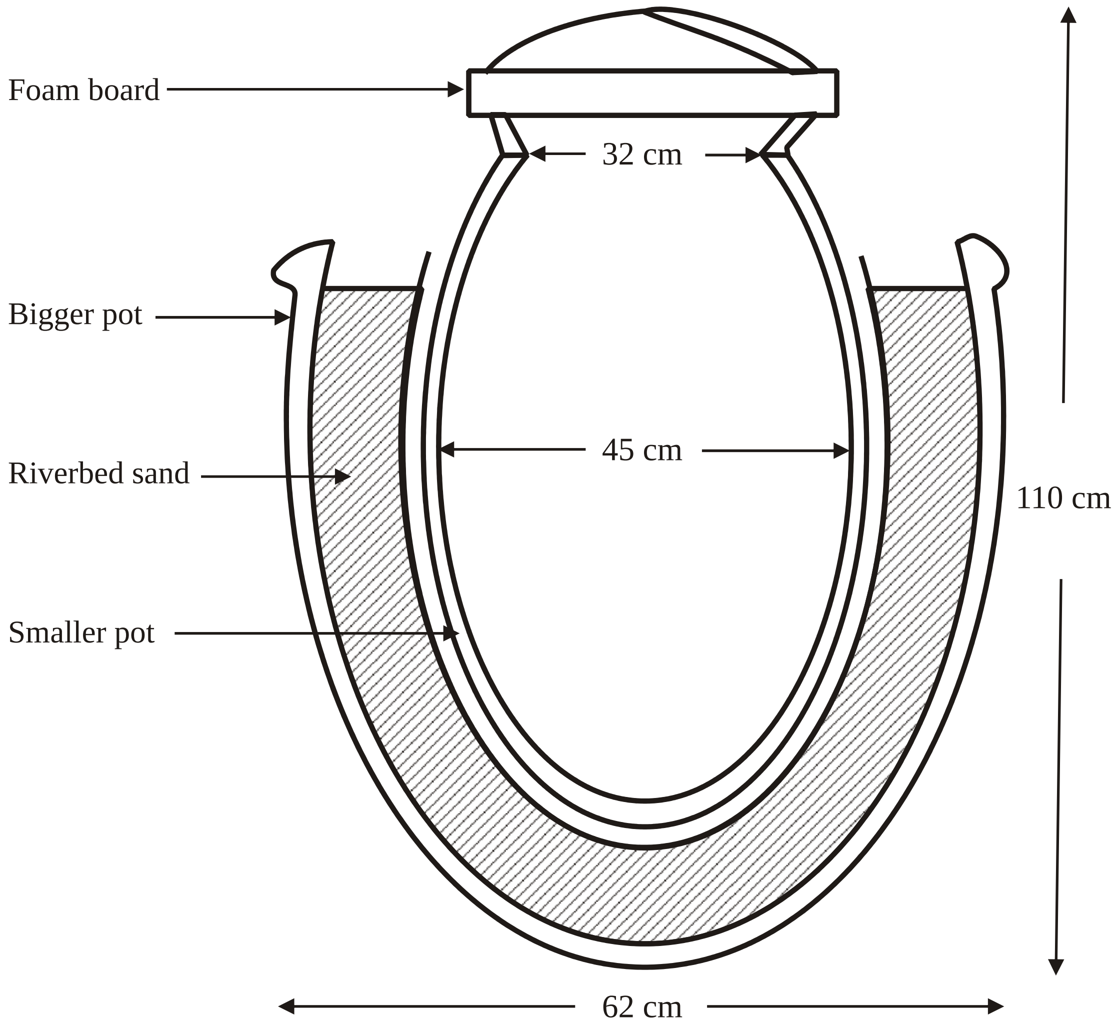

Fig. 3.3: Evaporative coolant structure (ECS)

3.2.4 Data Collection

The parameters assessed were weight loss, decay level, firmness and general appearance.

Weight loss: Fruits in each replicate were weighed at the beginning of the experiment using an electronic balance and then at six days intervals during the storage period. The percentage weight loss was calculated as: $\frac{A-B}{A}$ x 100 where A = Original weight before storage and B = Change in weight at six days interval

Decay level: Visual observation was made at six days intervals to determine the decay level on a scale of 1 to 4. 1 = wholesome, 2 = very slight decay 3 = moderate decay, , and 4 = high decay (Babatola and Adewoyin, 2002).

Firmness: Observation was made at six days intervals by hand feel to determine the level of firmness of pepper fruit. Firmness was also rated on a scale of 1 to 4. 1 = Not firm, 2 = slightly firm, 3 = Firm and 4 = very Firm (Babatola and Adewoyin 2002).

General appearance: Visual observation was carried out on a scale of 1 to 5 to assess wilting and shrivelling where 1 = extremely poor, 2 = poor, 3 = fair, 4 = good and 5 = excellent (Troncoso *et al.*, 2005).

3.2.5 Data Analysis

Data were subjected to analysis of variance (ANOVA). Means were separated using Duncan Multiple Range Test (DMRT) at $p < 0.05$. Multidimensional analysis was used to estimate the appropriate harvesting method, ripeness at harvest and storage condition of pepper fruits. Correlations analysis was used for comparison among the treatments.

3.3 Experiment 2

Effects of packaging materials and storage conditions on storability of pepper fruits

The objective of this experiment is to evaluate the effectiveness of packaging materials and storage conditions on storability of pepper fruits (*Capsicum frutescens* L). The experimental design was a factorial experiment in completely randomised design replicated three times.

3.3.1 Packaging and Storage

Pepper fruits of uniform sizes (6 -8cm) harvested with pedicels at 10 % ripeness were randomly selected for the experiment. Pepper fruits weighing 500 g were packaged into the different packaging materials that were sealed before placing in the different storage conditions. The packaging materials evaluated consisting of transparent non-perforated polyethylene bag, perforated polyethylene bag, aluminium foil paper, and unpackaged fruits (control). The storage conditions were ambient (21.9 - 33.5 °C; 58 - 62 %RH), evaporative coolant structure (10 - 15.8 °C; 70 - 75 %RH), and refrigerator (4 °C; 40 - 45 %RH).

3.3.2 Data Collection

Observations were made at six days intervals on the following parameters for 30 days.

Weight loss and Firmness: Percentage, weight loss and firmness were evaluated as indicated earlier in this section from experiment 1.

Freshness: Pepper fruit freshness was assessed at six days intervals of storage using a scale of 0 - 4 as described by IPGRI/IITA (1998) where 0 = Poor (musty odour, turns brown, slimy and decayed), 1 = Unacceptable (no freshness, fruit with black streak), 2 = Acceptable (appearance of limited acceptability), 3 = Good (overall appearance good), and 4 = Excellent (overall appearance excellent).

3.3.3 Data Analysis

Data were subjected to Analysis of Variance (ANOVA) and Correlation analysis. Means were separated using Duncan Multiple Range Test (DMRT) at $p < 0.05$.

3.4 Experiment 3

Effect of processing techniques on proximate composition of pepper fruits

The objective of this experiment was to investigate the effects of a number of processing techniques (parboiled sundried, sundried, parboiled oven dried, oven dried and heat sterilisation) on the nutrient composition of pepper fruits. The experimental design was Completely Randomised Design (CRD) replicated three times.

3.4.1 Processing Techniques

500 g of pepper fruits harvested with pedicels were used for each of the various processing techniques investigated. The fruits were spread on a tray and sundried for 3 days and then blended. Sampled fruits were parboiled in water at 75 °C for 3 minutes before spreading on a tagged tray and then sundried for 2 days to facilitate blending. Parboiled and Oven-dried fruits were parboiled in water at 75 °C for 3 minutes, then removed and spread on a tagged tray in the oven at 60 °C. For oven dried sample, fruits were oven dried to a constant weight at 60 °C to reduce the moisture content. It was blended to a smooth texture. The fresh blended and heat sterilised sampled fruits were blended into a smooth texture, boiled for 25 minutes, cooled to room temperature and then placed in a bottle and sealed. The bottle was sterilised by boiling the tightly covered bottles under low heat for 45 minutes.

3.4.2 Laboratory Analyses:

Proximate analysis

Moisture content, ash content, fat and crude protein content were determined according to AOAC (1990). Mineral elements such as Potassium, Zinc, Magnesium, Calcium, Iron, Phosphorus, Capsaicin**,** and Sodium were determined using spectrophotometer

Determination of oleoresin

The oleoresin content of pepper fruit harvested with pedicels at 10% ripeness was determined by weighing 5.0 g of well ground pepper fruits into 250 ml beaker. 50 ml acetone was added and the mixture was shaken very well on a Vortex mixer to obtain a homogenous solution. The homogenous mixture was filtered through a filter paper into a 250 ml beaker. 50 ml methanol-chloroform mixture was added to the filtrate and shaken vigorously to obtain a homogenous solution. This was transferred to a 50 ml beaker with a separate funnel to separate the organic mixture containing the oleoresin into a 100 ml volumetric flask. The absorbance or optical density of the oleoresin standard solution and each sample extract were read on a Cecil 404 spectrophotometer at a wavelength of 515 nm. The percentage oleoresin was calculated using the following formula:

$$\% \text{ oleoresin} = \frac{\text{Absorbance of sample x Average Gradient x Dilution factor}}{\text{Weight of sample}}$$

(AOAC, 1990)

Determination of ascorbic acid (AA) (mg) content: 30 ml of pepper extract was transferred into 250 ml volumetric flask, made up with 0.4 % oxalic acid and then filtered. Fifteen millilitres of oxalic acid (0.4 %) was added to 5 ml aliquot of the filtrate and treated with standardised 0.4 % dye (sodium 2, 6-dicholorphenol-indo-phenol) and titrated to obtain a faint pink end point.

$$\text{Ascorbic acid per 100g sample} = \frac{\text{dye equivalent x titre x dilution}}{5} \text{ x } 100$$

Dye equivalent (sodium 2,6-dichlorophenol – indophenol) = 0.189 $\pm$ 0.005

(AOAC, 1990)

3.4.3 Data Analysis

Data were subjected to analysis of variance (ANOVA). Means were separated using Duncan Multiple Range Test (DMRT) at $p < 0.05$.

CHAPTER 4

RESULTS

4.1 Survey of postharvest handling methods of pepper fruits by farmers in southwest Nigeria

The results of the survey indicated that men were more involved in pepper fruits farming (71.0 %) compared to women (29.0 %). Most of the farmers (70.0%) were married and between the ages 40 and 50 years (Plate 4.1). Majority (63.0 %) of them had basic education. About 86.0 % had household size range within one to six. About 53.0 % of the pepper fruits farmers were solely involved in farming (Table 4.1).

Most of the farmers (74.0 %) obtained their seeds from previous harvests. About (88.0 %) cultivated 1 to 3 ha of land for pepper production. Majority of farmers (65.0 %) had 6 to10 years experience in farming. The farmers harvest either with basket, plastic bucket, or used grain sack at 100 % ripeness from May to July. The handling of pepper fruits by majority of the farmers (55.0 %) were resulting in huge postharvest losses. Sorting of infected fruits from harvest was only carried out by 23% of the farmers. About 55.0 % of the farmers employed family labour during harvest while others hired paid labour on daily basis; these labourers were not given any training on harvesting and postharvest handling of pepper fruits. In all cases, the harvests were exposed to direct sunlight without any provision of shade. Most of the respondents observed deterioration of the fruits 3 to 5 days after collection. The harvests were transported to the market with the use of commuter vehicles (Plate 4.3). In the markets, the produce was either sold to retailers or directly to the consumers at differential prices which were usually high around December. The leftovers were spread on cemented floor. Some of the challenges faced by farmers include inadequate transportation due to poorly maintained roads and vehicles which caused physical damages to fruits, price fluctuations, unskilled personnel in postharvest handling, and unavailability of storage systems. (Table 4.2)

Table 4.1: Socio-economic characteristics of pepper fruit farmers

Socio-economic characteristics	%
Gender	
Male	71.0
Female	29.0
Age (years)	
31-40	20.0
41-50	70.0
51 above	10.0
No Formal Education	37.0
Primary school	38.0
Secondary school	17.0
Post secondary	8.0
Marital Status	
Single	5.0
Married	91.0
Divorce	4.0
Household Size	
0-6	86.0
7-11	19.0
Occupation	
Other crops (cassava, maize, yam)	41.0
Okada	20.0
Farming	22.0
Civil servant	12.0
Source of seed for planting	
Previous harvest	59.0
ADP	23.0
Farm size	
1-3ha	88.0
4-5ha	12.0

Table 4.2: Postharvest handling of pepper fruit by farmers

Postharvest handling	%
Time of harvest	
January	10.0
May	51.0
June	26.0
July	13.0
Method of Harvest	
With Pedicels	66.0
Without Pedicels	34.0
Ripening stage	
Fully ripe (100 %)	62.0
Slightly ripe (10 %)	38.0
Storage Duration	
2 days	15.0
3-5	85.0
Separation of infected fruit	
Sort unwholesome ones	23.0
No Sorting	77.0
Handling of leftover fruits	
Spread on cemented floor	47.0
Kept in bags	38.0
Kept in baskets	15.0
Transportation methods	
Commuter vehicles	49.0
Truck	34.0
Motorcycle	17.0
Sales of fruits	
Fruits sold directly to market	
Yes	64.0
No	36.0

4.1.1 Survey of postharvest handling methods of pepper fruits by marketers in southwest Nigeria

The result of the survey indicated that men, mainly Hausas from the Northern part of the country (Plate 4.1), were more involved in the handling of pepper fruit sales (56.0 %) compared to women (44.0 %). However, about 37.0 % of the marketers were fully involved in the trade without any other means of livelihood. Majority (70%) of the pepper marketers in the study area were between 31 and 50 years of age. Most of the marketers were married (67.0 %). About 45.0 % of the marketers had basic education. Large proportion of the respondents (55.0 %) had household size of 7 to 20. Seventy-four percent of the marketers obtained their fruits from middlemen while twenty-six percent obtained theirs from farmers (Table 4.3).

Majority of the respondents (68.0 %) engaged in fresh pepper sales. The marketers try to prevent deterioration by spreading the fruits on concrete floor. Most marketers (87.0 %) detect worms and moulds which would normally start from the fifth day. After harvest most marketers usually package their fruits in used grain sack (Plate 4.2). Fifty-nine percent of the marketers indicated that over 20 % of their produce was lost during marketing while 31% indicated a loss of 11 - 20 %, and only 10 % reported a loss of 10 % (Table 4.4). The vehicles used for transporting pepper fruits by about 96 % of the marketers were usually hired at high cost, the fruits were always loaded tightly (Plate 4.3). Sixty-six percent of the marketers would prefer to separate damaged and spoilt fruits from the wholesome ones before sales. The marketers had between 10 - 20 years of experience and belong to an association which fixes price for pepper fruits. About 91.0 % of the marketers obtained loan from cooperative society for the trade (Appendix 2). The marketers faced many challenges similar to the farmers in postharvest handling of pepper fruits.

Table 4.3: Socio-economic characteristics of pepper fruit marketers

Socio-economic characteristics	%
Gender	
Male	56.0
Female	44.0
Age (in years)	
< 30	19.0
41-50	37.0
51 above	11.0
No Formal Education	19.0
Primary School Education	45.0
Secondary School	30.0
Post Secondary	6.0
Marital Status	
Single	26.0
Married	67.0
Divorce	7.0
Household size	
0-6	45.0
7-11	39.0
12-20	16.0
Occupation	
No other occupation	36.0
Artisan	30.0
Farming	22.0
Civil servant	12.0
Source of Pepper	
Farmer	26.0
Middle Men	74.0
Type of Pepper	
Processed	32.0
Fresh	68.0

Table 4.4: Postharvest handling, storage and preservation of pepper fruit by marketers

Signs of Deterioration	%
Mouldy	43.0
Maggot	44.0
Odour	13.0
Method of Preservation	
Spreading on mat	31.0
Spreading on cement floor	69.0
Method of Storage	
Bags	65.0
Baskets	35.0
Storage Duration	
< 3	10.0
3-5	31.0
75	59.0
Prevention of damages	
Avoidance of Overstocking	34.0
Sorting of wholesome from unwholesome fruits	66.0
Percentage loss of Pepper	
<10%	10.0
11-20%	13.0
>20%	59.0
Marketing experience (years)	
< 9	18.0
10-20	76.0
>21	6.0

Plate 4.1: Display of pepper fruits by Hausa men in Sasa market, Ibadan, Oyo State

Plate 4.2: Packaged pepper fruits ready for transportation by marketers

Plate 4.3: Compression of fruits caused by inappropriate transportation method

4.1.2 Seasonal Price Pattern of Pepper in the Urban and Rural Markets in Southwest Nigeria from 2004-2009

The six-year mean monthly price indices in the urban (Bodija) and rural (Sasa) markets from 2004 to 2009 showed that the price of pepper attained its peak in June and December in Oyo and Ondo states respectively for both urban and rural markets. The lowest prices occurred in March and November for urban and rural markets respectively in Oyo State and in January for both rural and urban markets in Ondo State. The lowest price indices were 49 and 86 for urban and rural markets of Oyo State and the corresponding value for Ondo State were 87 and 80 this rose to 117 and 142 for the rural markets and urban markets respectively in Oyo State correspondingly to 122 and 121 in Ondo State (Tables 4.5 & 4.6).

4.2 Effects of ripeness at harvest, harvesting methods and storage conditions on storability of pepper fruit

The results on the storability of pepper fruits as influenced by levels of ripeness at harvest, harvesting methods and storage conditions on weight loss (WL), decay level, firmness and general appearance (GA) of pepper fruits are contained in Tables 4.7 to 4.19.

4.2.1 Weight loss

Pepper fruits kept in the refrigerator consistently had significantly lower WL of 3.6 to 15.8 % at 3 DIS (Days in storage) to 30 DIS compared with corresponding values of 4.1 to 17.4 % and 4.0 to 16.5 % for ambient and ECS, respectively. The effect of methods of harvest was significant on WL of pepper fruits with those harvested with pedicel having significantly lower weight loss of 5.6 to 15.3 % at 9 to 30 DIS compared to those without pedicels with corresponding values of 6.1 to 17.8 %. Furthermore, fruits harvested at 10 % ripeness had significantly lower WL of 3.1 to 16.0 % compared to 4.7 at 3 DIS to 17.1 % at 30 DIS for those harvested at 100 % ripeness during the corresponding period (Table 4.7)

The interactions of ripeness at harvest and storage conditions on WL of pepper fruits were significant at 3, 15, and 30 DIS. The fruits harvested at 10 % ripeness and stored in refrigerator consistently had the lowest WL of 2.4 %, 7.6 % and 14.7 % at 3, 15, and 30 DIS respectively (Table 4.8). Conversely, the fruits harvested at 100 % ripeness and kept under the ambient condition had the maximum WL of 4.6 and 17.3 % at 3 and 30 DIS respectively. At 30 DIS, for fruits harvested at 100 % ripeness, the WL of those kept in the refrigerator and ECS were similar and significantly lower than those of fruits kept in the ambient condition. At 3 DIS, pepper fruits harvested at 100 % ripeness had similar WL under the three storage conditions. However, at 30 DIS the same pepper kept in refrigerator and ECS had similar WL values which were significantly lower than those fruits left in the ambient condition.

The interaction of harvesting methods and storage conditions was significant at 3, 15, 21, 27 and 30 DIS (Table. 4.9). In all cases fruits harvested with pedicel and kept in the refrigerator consistently had the lowest WL while those harvested without pedicel under ambient condition had the highest values at 15, 21, 27 and 30 DIS. At 3 DIS, while WL did not differ significantly among storage conditions in fruits harvested without pedicel, the values followed this order: refrigerator < ECS < ambient in those harvested with pedicel.

The interaction of ripeness at harvest, harvesting methods and storage conditions was significant for WL of pepper fruits at 15, 21 and 30 DIS (Table 4.10). At 15 DIS pepper fruits harvested with and without pedicels at 10% ripeness and kept in the refrigerator had similar WL values with fruits harvested with pedicel, kept in the ECS and also with fruits harvested with pedicels at 100% ripeness. Fruits harvested with pedicel at 10% ripeness had the lowest WL, while those harvested without pedicels at 100 % ripeness kept in the ambient had the highest WL.

Table 4.5: Average price indices for fresh pepper fruits in rural and urban markets of Oyo State from 2004 to 2009

Average Price Indices	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rural	94	91	49	109	115	117	80	77	69	80	82	109
S.E	3	7	6	9	9	9	3	7	7	3	2	9
Urban	116	94	90	103	110	142	91	86	89	87	86	101
S.E	9	3	9	8	9	9	3	2	3	3	2	8

Table 4.6: Average price indices for fresh pepper fruits in rural and urban areas of Ondo State from 2004 to 2009

Average Price Indices	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rural	87	97	95	88	98	91	94	113	118	110	96	122
S.E	7	9	8	7	9	8	9	9	10	9	7	10
Urban	80	93	90	87	98	94	94	110	120	114	98	121
S.E	8	9	8	7	9	6	7	9	10	9	8	10

Table 4.7: Effects of ripeness at harvest, harvesting methods and storage conditions on percentage weight loss of pepper fruit

	Days in Storage					
Treatments	3	9	15	21	27	30
Storage Conditions (SC)			(%)			
Ambient	4.1a	6.0a	10.2a	13.2a	15.5a	17.4a
Evaporative coolant structure	4.0a	5.9ab	9.7b	12.5b	14.7b	16.5b
Refrigerator	3.6b	5.7b	9.2bc	12.5b	13.8c	15.8c
SE	0.10	0.09	0.09	0.13	0.11	0.13
Harvesting Methods (HM)						
With Pedicel	3.8	5.6b	9.1b	12.1b	14.0b	15.3b
Without Pedicel	4.0	6.1a	10.3a	13.4a	15.3a	17.8a
SE	0.07	0.07	0.06	0.09	0.09	0.09
Ripeness (R)						
10% ripeness	3.1b	5.3b	8.0b	11.3b	13.6b	16.0b
100% ripeness	4.7a	6.4a	11.5a	14.2a	15.7a	17.1a
SE	0.08	0.06	0.08	0.08	0.09	0.09
Interaction SE						
R×HM	0.07ns	0.07ns	0.06ns	0.08ns	0.08ns	0.10ns
SC× HM	0.12*	0.17ns	0.12*	0.14*	0.15*	0.13*
SC × R	0.12*	0.17ns	0.11*	0.19ns	0.17ns	0.12*
SC × R× HM	0.16ns	0.17ns	0.12*	0.12*	0.26ns	0.12*

ns = Not Significant, * = significant at $p < 0.05$.

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$.

Table 4.8: Interactions of ripeness at harvest and storage conditions on weight loss (%) of pepper fruits

Storage conditions	Days in storage					
	3		15		30	
	10 % ripeness	100 % ripeness	10 % ripeness	100 % ripeness	10 % ripeness	100 % ripeness
Ambient	3.6b	4.6a	8.3d	12.1a	15.7c	17.3a
Evaporative Coolant Structure	3.3b	4.7a	8.1d	11.4b	15.9c	16.8b
Refrigerator	2.4c	4.9a	7.6a	10.9c	14.7d	16.9b
SE	0.12		0.11		0.12	

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$.

Table 4.9: Interactions of harvesting methods and storage conditions on weight loss (%) of pepper fruits

Storage conditions	Days in storage									
	3		15		21		27		30	
	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel
Ambient	4.3a	3.9b	9.5cd	10.9a	12.7b	13.7a	14.6cd	16.3a	13.7f	19.3a
Evaporative Coolant Structure	3.9b	4.1ab	9.2d	10.2b	11.9c	13.1b	14.4c	15.2b	16.9c	17.8b
Refrigerator	3.3c	4.0ab	8.7e	9.8c	11.6c	13.3b	13.2d	14.3c	15.3e	16.3d
SE	0.12		0.12		0.14		0.15		0.13	

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

Table 4.10: Interactions of ripeness at harvest, harvesting methods and storage conditions on weight loss (%) of pepper fruits

Storage conditions	Days in storage											
	15				21				30			
	10% ripeness		100% ripeness		10% ripeness		100% ripeness		10% ripeness		100% ripeness	
	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel
Ambient	7.5e	9.1c	11.5b	12.7a	11.2d	12.5c	14.2b	14.9a	16.7d	17.9c	18.7b	20.1a
Evaporative coolant structure	7.3e	8.8cd	11.1bc	11.6b	10.4e	11.4d	13.5b	14.7a	15.4e	16.5d	16.9d	19.1b
Refrigerator	6.9e	7.1e	7.3e	8.2d	9.1f	9.2f	9.3f	9.4f	14.3g	15.0ef	14.9f	17.5c
SE	0.12				0.12				0.12			

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

4.2.2 Decay level

The lowest decay level score of 3.1 to 1.2 from 3 to 30 DIS was obtained on pepper fruits stored in the refrigerator. Fruits kept in the ECS also had significantly lower decay level score of 3.3 to 1.6 from 3 to 30 DIS than those under ambient conditions with corresponding values of 3.8 to 2.7. Methods of harvesting and ripeness at harvest had significant effects on decay of pepper fruits with those harvested with pedicels, and at 10 % ripeness being more wholesome than those harvested without pedicel, and at 100 % ripeness (Table. 4.11).

The interaction of method of harvest and storage condition on decay level score of pepper fruit was significant at 9, 15 and 30 DIS. Pepper fruits harvested with pedicel and stored in the refrigerator had lower decay level score compared to fruits harvested with pedicel kept in ECS and ambient. Except at 30 DIS, pepper fruits harvested with and without pedicel and kept in the refrigerator had similar but lower decay level score than other storage conditions. At 30 DIS pepper fruits harvested without pedicel had lower value than those with pedicel when both were in the refrigerator. However, under the ambient and ECS conditions pepper fruits harvested with pedicel consistently had lower decay level score than those without pedicel. Fruits harvested with pedicel consistently had lower decay level score when in ECS compared with ambient condition while the difference was not significant in those harvested without pedicel at 9 and 15 DIS (Table. 4.12).

The interactions of ripeness at harvest and storage condition had significant effect on decay level at 15, 21, 27 and 30 DIS. Fruits harvested at 10 % ripeness kept in the refrigerator consistently had lower decay level score compared to those harvested at 100 % ripeness kept under the ambient condition. Fruits harvested at 10 % ripeness and kept in the ECS had similar value to those in the ambient condition at 15 and 21 DIS but differed significantly at 27 and 30 DIS (Table. 13).

The interaction of storage condition, ripeness at harvest and method of harvest was significant on decay level at 9, 15 and 30 DIS. Fruits harvested with pedicel at 10 % ripeness kept in ECS and refrigerator as well as those harvested without pedicel at 10 % ripeness in the refrigerator had the lowest decay level score at 9 DIS. Those harvested at 10 % with and without pedicel and kept in the refrigerator also had significantly lower decayed level score than all the other combination of treatment at

9 DIS. Under ambient and ECS conditions pepper fruits harvested with pedicel at 10 or 100 % ripening had lower decay level score than the corresponding ones without pedicel. However, when kept in the refrigerator, pepper fruits harvested at 10 % ripeness with and without pedicel had similar decay level score that were lower than those harvested at 100 % ripeness with and without pedicel at 9 DIS. Under all storage condition, fruits harvested with pedicel had lower decay level when harvested at 10 % ripeness compared with 100 % (Table 4.14).

Table 4.11: Effects of ripeness at harvest, harvesting methods and storage conditions on decay level of pepper fruit

Treatments	Days in Storage					
	3	9	15	21	27	30
Storage Conditions (SC)						
Refrigerator	3.1c	2.6c	2.3c	1.8c	1.6c	1.2c
Evaporative coolant structure	3.3b	3.3b	2.6b	2.1b	1.8b	1.6b
Ambient	3.8a	3.6a	3.2a	2.9a	2.7a	2.7a
SE	0.03	0.03	0.03	0.03	0.03	0.03
Harvesting Methods (HM)						
Without Pedicel	3.5a	3.3a	2.9a	2.4a	2.1a	2.0a
With Pedicel	3.3b	3.0b	2.5b	2.1b	1.9b	1.7b
SE	0.01	0.10	0.10	0.01	0.15	0.15
Ripeness (R)						
100% ripeness	3.6a	3.4a	2.9a	2.6a	2.4a	2.1a
10% ripeness	3.2b	2.8b	2.5b	1.9b	1.7b	1.5b
SE	0.02	0.02	0.05	0.03	0.02	0.02
Interaction SE						
R × HM	0.01ns	0.01ns	0.01ns	0.01ns	0.01ns	0.01ns
SC × HM	0.70ns	0.04*	0.08*	0.50ns	0.60ns	0.04*
SC × R	0.80ns	0.70ns	0.20*	0.40*	0.40*`	0.30*
SC × R × HM	0.70ns	0.06*	0.12*	0.70ns	0.70ns	0.06*

ns =Not Significant, * = Significant at $p < 0.05$

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$.

Table 4.12: Interactions of harvesting methods and storage conditions on decay level of pepper fruit

Storage conditions	Days in storage					
	9		15		30	
	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel
Refrigerator	2.8c	2.4d	2.5c	2.1d	1.3e	1.2e
Evaporative coolant structure	2.9b	2.4d	2.8b	2.3cd	1.7c	1.5d
Ambient	3.7a	3.6a	3.4a	3.1a	2.7a	2.5b
SE	0.04		0.08		0.04	

Decay level score scale of 1 to 4: 1= wholesome, 2 = very slight decay, 3 = moderate decay and 4 = high decay

Means with the same letters in columns under 'each days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

Table 4.13: Interactions of ripeness at harvest and storage conditions on decay level of pepper fruit

Storage conditions	Days in storage							
	15		21		27		30	
	100 % ripeness	10 % ripeness	100 % ripeness	10 % ripeness	100 % ripeness	10 % ripeness	100 % ripeness	10 % ripeness
Ambient	2.6b	1.9c	2.4c	1.3d	1.9d	1.2f	1.4d	1.0f
Evaporative coolant structure	2.7b	2.4c	2.4c	1.9d	2.2bc	1.4e	1.9c	1.2e
Refrigerator	3.4a	3.0b	3.2a	2.6b	2.9a	2.3b	2.9a	2.3b
SE	0.20		0.40		0.40			0.30

Decay level score of 1 to 4: Decay level score scale of 1 to 4: 1= wholesome, 2 = very slight decay, 3 = moderate decay and 4 = high decay

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at p< 0.05

Table 4.14: Interactions of ripeness at harvest, harvesting methods and storage conditions on decay level of pepper fruit

Storage conditions	9				15				30			
	100% ripeness		10% ripeness		100% ripeness		10% ripeness		100% ripeness		10% ripeness	
	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicle
Ambient	3.1cd	2.6e	2.4f	2.2f	2.8cd	2.5d	2.1e	1.8f	1.5d	1.3cd	1.0d	1.0f
ECS	3.9a	3.2c	3.0d	2.7e	3.1bc	2.9c	2.4de	2.4de	2.0c	1.8c	1.3cd	1.1d
Refrigerator	3.9a	3.8a	3.5b	3.4b	3.5a	3.3ab	3.1bc	3.0bc	3.2a	2.7b	2.5b	2.2b
SE	0.06				0.12				0.06			

Decay level score scale of 1 to 4: 1= wholesome, 2 = very slight decay, 3 = moderate decay and 4 = high decay

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

4.2.3 Firmness

The effects of ripeness at harvest, harvesting methods and storage conditions were significant on firmness rating of pepper fruits at 9, 15, 21, 27 and 30 DIS. Pepper fruits firmness rating declined over time reaching lowest value of 2.8 at 27 DIS in the refrigerator as well as 1.8 and 1.3 at 30 DIS for ECS and ambient respectively, it followed the order, refrigerator > ECS > ambient (Table 4.15).

Fruits harvested at 10 % ripeness had significantly higher firmness ratings of 3.7, 3.5, 3.1, 2.7, 2.4 and 2.2 at 3, 9, 21, 27 and 30 DIS respectively compared with those harvested at 100 % ripeness. The corresponding firmness ratings for fruits harvested at 100 % ripeness were 3.7, 3.3, 2.7, 2.3, 2.0 and 1.8 at 3, 9, 15, 21, and 30 DIS, respectively. Pepper fruits harvested with pedicels had significantly higher firmness rating compared to those fruits harvested without pedicel at 9, 15, 27 and 30 DIS respectively (Table 4.16).

The interaction of ripeness and storage conditions was significant on firmness rating of pepper fruits at 9, 15 and 27 DIS. The highest firmness rating was obtained on fruits harvested at 10 % ripeness kept in the refrigerator. Firmness rating of pepper fruits followed the order, refrigerator > ECS > ambient (Table 4.17).

The interaction of ripeness at harvest, harvesting methods and storage conditions were significant at 9 and 15 DIS. Fruits harvested at 10 % ripeness with pedicel at 9 DIS and fruits harvested at 10 % with and without pedicel at 15 DIS kept in the refrigerator as well as those harvested at 10 % ripeness with pedicel in the ECS at 15 DIS had the highest firmness score among various combinations. (Table 4.18)

At 9 DIS, under the ambient condition, pepper fruits harvested at 10 % ripeness with pedicel had significantly higher firmness than those of other harvesting method and ripeness combination in the same storage condition while that harvested at 100 % ripening without pedicel had the least (Table 4.18). However under ECS, fruits harvested at 10% ripening with and without pedicel, as well as those harvested at 100 % ripening with pedicels had similar scores that were higher than that of fruits harvested at 100 % ripeness without pedicels. For fruits in the refrigerator, those harvested at 10 % ripeness with pedicels had higher score than similar ones of other combinations. At 15 DIS, fruits harvested with and without pedicels at 10 % ripeness had similar firmness score that were significantly higher than those fruits harvested at

100 % when kept under the ambient and refrigerator. In the ECS, only those fruits harvested with and without pedicel at 100 % ripening were similar while those harvested at 10 % ripeness with pedicel had significantly higher firmness level than those of other harvesting method and ripeness combination in the same storage condition. At 10 % ripening fruits harvested without pedicel kept in the ECS and refrigerator had similar firmness score.

4.2.4 General Appearance

The effect of storage conditions on general appearance (GA) of pepper fruits are contained in Table 4.18. Pepper fruits in refrigerator had higher GA than those in ambient and ECS conditions at 3, 9, 21 and 27 DIS.

The GA of pepper fruits harvested with pedicel was significantly higher than those fruits harvested without pedicels at 3, 15 and 30 DIS. Similarly, fruits harvested at 10 % ripeness had higher GA than those harvested at 100 % at 3 DIS (Table 4.18).

The interaction of storage conditions, ripeness at harvest and harvesting methods on general appearance of pepper fruits were significant at 9 and 15 DIS. Pepper fruits harvested with or without pedicel, at 10 % or 100% ripeness, stored in refrigerator and ECS had significantly higher GA values compared with those stored under ambient condition. There were no significant differences at 15 DIS for fruits harvested without pedicels at 100 % ripeness kept under the various conditions (Table 4.19).

Table 4.15: Effects of ripeness at harvest, harvesting methods and storage conditions on firmness of pepper fruit

Treatment	Days in Storage					
	3	9	15	21	27	30
Storage Conditions(SC)						
Ambient	3.5c	3.2c	2.3c	2.0c	1.6c	1.3c
Evaporative coolant structure	3.7b	3.3b	3.0b	2.6b	2.2b	1.8b
Refrigerator	3.9a	3.7a	3.3a	3.0a	2.8a	2.8a
SE	0.02	0.02	0.02	0.02	0.02	0.02
Harvesting Methods (HM)						
With Pedicel	3.7ns	3.5a	2.9a	2.5a	2.3a	2.1a
Without Pedicel	3.7ns	3.3b	2.8b	2.5b	2.1b	1.9b
SE	0.02	0.03	0.05	0.03	0.03	0.02
Ripeness						
10% ripeness	3.7a	3.5a	3.1a	2.7a	2.4a	2.2a
100% ripeness	3.7a	3.3b	2.7b	2.3b	2.0b	1.8b
SE	0.01	0.01	0.01	0.02	0.02	0.02
Interaction SE						
R × HM	0.02ns	0.02ns	0.40ns	0.02ns	0.03ns	0.03ns
SC× HM	0.02ns	0.02ns	0.60ns	0.03ns	0.03ns	0.04ns
SC × R	0.14ns	0.50*	0.08*	0.14ns	0.04*	0.16ns
SC × R× HM	0.13ns	0.60*	0.12*	0.16ns	0.16ns	0.18ns

Firmness scoring scale (1 to 4): 1=Not firm; 2=Slightly firm; 3 = Firm; 4 = very firm

ns = Not significant, * = Significant at $p < 0.05$

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at P<0.05.

Table 4.16: Interactions of ripeness at harvest and storage conditions on firmness of pepper fruits

Storage conditions	Days in storage					
	9		15		27	
	10 % ripeness	100 % ripeness	10 % ripeness	100 % ripeness	10% ripeness	100 % ripeness
Ambient	3.2c	3.1d	2.6c	2.1d	1.8c	1.4d
Evaporative coolant structure	3.5b	3.1d	3.2b	2.8c	2.5b	1.9c
Refrigerator	3.9a	3.5b	3.5a	3.1b	2.9a	2.6b
SE	0.05		0.08		0.04	

Firmness scoring scale (1 to 4): 1=Not firm; 2=Slightly firm; 3 = Firm; 4 = very firm

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p< 0.05$.

Table 4.17: Interaction of ripeness at harvest, harvesting methods and storage conditions on firmness

Storage conditions	Days in storage							
	9				15			
	10 % ripeness		100% ripeness		10% ripeness		100% ripeness	
	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedicel	Without pedicel
Ambient	3.4b	3.3c	3.1c	2.7d	2.6d	2.5d	2.2e	2.0e
Evaporative coolant structure	3.5b	3.4b	3.5b	3.1c	3.2b	3.1b	2.8c	2.7c
Refrigerator	3.9a	3.8a	3.6b	3.5b	3.5a	3.1b	3.1b	3.1b
SE	0.60				0.12			

Firmness scoring scale (1 to 4) : 1=Not firm; 2=Slightly firm; 3 = Firm; 4 = very firm

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$.

Table 4.18: Effects of ripeness at harvest, harvesting methods and storage conditions, on general appearance of pepper fruit

Treatments	Days in Storage					
	3	9	15	21	27	30
Storage Conditions (SC)						
Refrigerator	4.2a	4.1a	4.0a	3.6a	3.6a	3.5ns
Evaporative coolant structure	4.0b	4.0b	3.9ab	3.5ab	3.5ab	3.5ns
Ambient	4.0b	4.0b	3.8b	3.4b	3.2b	3.2ns
SE	0.02	0.01	0.04	0.04	0.04	0.05
Harvesting Methods						
With Pedicel	4.1a	4.0ns	3.9a	3.6ns	3.5ns	3.4a
Without Pedicel	4.0b	4.0ns	3.8b	3.5ns	3.5ns	3.3b
SE	0.01	0.01	0.04	0.45	0.35	0.04
Ripeness						
10% ripeness	4.1a	4.0ns	3.9ns	3.5ns	3.5ns	3.5ns
100% ripeness	4.0b	4.0ns	3.8ns	3.6ns	3.5ns	3.3ns
SE	0.01	0.01	0.05	0.04	0.04	0.05
Interaction SE						
R × HM	0.40ns	0.30ns	0.30ns	0.30ns	0.30ns	0.40ns
SC× HM	0.50ns	0.40ns	0.30ns	0.40ns	0.40ns	0.40ns
SC × R	0.50ns	0.40ns	0.50ns	0.40ns	0.50ns	0.40ns
SC × R× HM	0.02ns	0.20*	0.11*	0.09ns	0.08ns	0.10ns

General appearance scale of 1 to 5: 1=extremely poor, 2=poor, 3=fair 4=good and 5=excellent

ns = Not significant, * = Significant at $p < 0.05$

For each factor means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$.

Table 4.19: Interaction of ripeness at harvest, harvesting methods and storage conditions on general appearance of pepper fruits

Storage conditions	Days in storage							
	9				15			
	10% ripeness		100% ripeness		10% ripeness		100% ripeness	
	With pedicel	Without pedicel	With pedicel	Without pedicel	With pedice l	Withou t pedicel	With pedicel	Without pedicel
Ambient	4.0b	3.8b	3.5c	3.0c	3.8b	3.5c	3.0d	2.5d
Evaporative coolant structure	4.9a	4.7a	4.5a	4.3b	3.9b	3.7b	3.3d	3.3d
Refrigerator	5.0a	4.9a	4.8a	4.6a	4.0a	3.8b	3.5c	3.3d
SE	0.20				0.11			

General appearance scale of 1 to 5: 1=extremely poor, 2=poor, 3=fair 4=good and 5=excellent

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$.

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4.2.5 Multidimensional analysis of parameters measuring storability of pepper fruits

The results of the multidimensional analysis of the various parameters measuring storability of pepper fruits are contained in Table 4.20. This is a summary of all combinations of parameters taken to determine the appropriate ripening stage, harvesting method and best storage condition. The results indicated that fruits stored in refrigerator after harvesting at 10 % ripening with and without pedicel ranked first and second respectively. Pepper fruits kept in the refrigerator after harvesting at 100 % ripening with and without pedicel ranked fourth and eighth respectively. Pepper fruits harvested at 10 % ripening with pedicels and stored in ECS ranked third, while those harvested without pedicel at 100 % ripening and kept at ambient condition ranked twelfth.

Table 4.20: Multidimensional analysis of parameters measuring storability of pepper fruits

Parameter	Weight loss (%)	Firmness level	Decay level	General appearance	Σi.RWT	Ranking
Ambient×10% ripeness × with pedicel	16.7	1.5	1.6	2.0	0.64	9
Ambient ×10% ripeness × without pedicel	17.9	1.4	1.3	1.5	0.63	10
Ambient×100% ripeness × with pedicel	16.7	1.2	1.0	1.3	0.60	11
Ambient×100% ripeness × without pedicel	20.1	1.1	1.1	1.0	0.43	12
Evaporative coolant structure ×10% ripeness ×with pedicel	15.4	2.3	2.0	2.5	0.77	3
Evaporative coolant structure ×10% ripeness ×without pedicel	16.5	2.1	1.8	2.3	0.74	5
Evaporative coolant structure ×100% ripeness× with pedicels	18.5	1.9	1.3	2.0	0.71	6
Evaporative coolant structure ×100% ripeness× without pedicel	19.4	1.6	1.1	1.5	0.66	7
Refrigerator × 10% ripeness × with pedicel	14.3	3.1	3.1	3.0	1.10	2
Refrigerator × 10%ripeness without pedicel	15.0	2.9	2.8	2.9	1.73	1
Refrigerator × 100% ripeness ×with pedicel	14.3	2.6	2.5	2.8	0.73	4
Refrigerator × 100% ripeness× without pedicel	19.1	2.5	2.2	2.5	0.65	8

RWT = Relative weight, i = index number

4.26 Correlation of weight loss, firmness, decay level and general appearance on pepper fruits

Correlation of weight loss, firmness, decay level and general appearance of pepper fruits were significant on pepper fruit storability (Table 4.21). Negative correlation was obtained for weight loss and other parameters (firmness, decay level and general appearance) from 3 to 30 DIS. Firmness at 9 to 30 DIS were negatively correlated to weight loss from 3 to 27 DIS with r values range of 0.5 to 0.8. Furthermore decay level was also negatively correlated with weight loss at 3 to 27 DIS, r values ranged from 0.6 to 0.9. General appearance was negatively correlated to WL at 3 DIS. Decay level and firmness were positively correlated from 3 to 30 DIS with minimum r value of 0.7 and maximum of 1.0.

Table 4.21: Correlation Coefficient (r) among weight loss, firmness, decay and general appearance of pepper fruits (n= 36)

	Weight loss						Firmness						Decay						General appearance					
	3	9	15	21	27	30	3	9	15	21	27	30	3	9	15	21	27	30	3	9	15	21	27	30
WL 9 DIS	0.8***																							
WL 15 DIS	0.9***	1.0***																						
WL 21 DIS	0.8***	0.9***	1.0***																					
WL 27 DIS	0.8***	0.9***	0.9***	0.9***																				
WL 30 DIS	0.3ns	0.4ns	0.4ns	0.4ns	0.5*																			
FM 3 DIS	-0.3ns	-0.3ns	-0.3ns	-0.3ns	-0.5**	-0.1ns																		
FM 9 DIS	-0.5**	-0.6***	-0.6***	-0.6**	-0.8***	-0.7***	0.7***																	
FM 15 DIS	-0.6*	-0.6***	-0.6***	-0.6***	-0.8***	-0.2ns	0.9***	0.8***																
FM 21 DIS	-0.6**	-0.6***	-0.6***	-0.6***	-0.8***	-0.1ns	0.8***	0.8***	1.-0***															
FM 27 DIS	-0.6**	-0.6***	-0.6***	-0.6***	-0.9***	-0.3ns	0.9***	0.8***	1.0***	0.1***														
FM 30 DIS	-0.5**	-0.5**	-0.5**	-0.5**	-0.7***	-0.3ns	0.9***	0.9***	1.0***	1.0***	1.0***													
Decay 3 DIS	-0.7***	-0.8***	-0.8***	-0.8***	-0.9***	-0.4ns	0.8***	0.9***	0.9***	0.8***	0.9***	0.9***												
Decay 9 DIS	-0.7**	-0.8***	-0.7***	-0.7***	-0.8***	-0.3ns	0.8***	0.8***	1.0***	0.9***	1.0***	0.9***	0.9***											
Decay 15 DIS	-0.5*	-0.6***	-0.7***	-0.6***	-0.8***	-0.3ns	0.7***	0.8***	0.8***	0.1***	0.9***	0.9***	0.9***	0.9***										
Decay 21 DIS	-0.7***	-0.7***	-0.8***	-0.7***	-0.9***	-0.3ns	0.8***	0.8***	0.9***	0.9***	0.9***	0.9***	0.9***	0.9***	0.9***									
Decay 27 DIS	-0.7***	-0.7***	-0.8***	-0.7***	-0.9***	-0.4ns	0.]8***	0.9***	0.9***	0.9***	0.9***	0.9***	1.0***	1.0***	0.1***	1.0***								
Decay 30 DIS	-0.6**	-0.6**	-0.6**	-0.6**	-0.8***	-0.3ns	0.9***	0.9***	0.9***	0.8***	0.9***	1.0***	1.0***	0.9***	0.9***	0.9***	1.0***							
GA 3 DIS	-0.6**	-0.5**	-0.4ns	-0.6**	-0.5**	-0.3ns	0.4ns	0.5*	0.4*	0.5*	0.5*	0.5*	0.5*	0.4ns	0.5*	0.5*	0.5**	0.6**						
GA 9 DIS	-0.3ns	-0.3ns	-0.3ns	-0.3ns	-0.3ns	-0.2ns	0.2ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.3ns	0.4ns	0.5*					
GA 15 DIS	-0.2ns	-0.3ns	-0.3ns	-0.3ns	-0.3ns	0.1ns	0.3ns	0.2ns	0.4ns	0.4ns	0.4ns	0.4ns	0.4ns	0.4ns	0.4ns	0.3ns	0.3ns	0.4ns	0.5*	0.3ns				
GA 21 DIS	0.0ns	-0.0ns	-0.1ns	-0.0ns	-0.1ns	0.2ns	0.3ns	0.ns	0.2ns	0.2ns	0.3ns	0.2ns	0.2ns	0.2ns	0.3ns	0.2ns	0.2ns	0.3ns	0.1ns	-0.1ns	0.0***			
GA 27 DIS	0.1ns	0.1ns	-0.0ns	0.0ns	-0.1ns	0.2ns	0.2ns	0.0ns	0.1ns	0.2ns	0.2ns	0.2ns	0.2ns	0.2ns	0.3ns	0.2ns	0.2ns	0.3ns	0.0ns	-0.0ns	0.7***	0.7***		
GA 30 DIS	0.1ns	0.1ns	0.0ns	0.0ns	-0.0ns	0.2ns	0.1ns	-0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.1ns	0.ns	-0.0ns	0.7***	0.8***	0.9***	

DIS = Days in storage, WL = Weight loss, FM = Firmness, GA = General appearance

*, **, *** Significant at p< 0.05, p< 0.01, respectively

4.3 Effects of packaging materials and storage conditions on pepper fruit

4.3.1 Percentage weight Loss

Pepper fruits kept in the refrigerator had the lowest WL of 2.8 to 11.8 % from 3 to 30 DIS compared with the corresponding values of 6.4 to 23.5 % and 3.5 to 20.9 % for ambient and ECS respectively. However WL of fruits kept in the ECS were lower than those in the ambient condition (Table 4.22).

Pepper fruits packaged in aluminium foil had significantly lower WL of 3.2 to 13.6 % from 3 to 30 DIS compared with the corresponding values of 3.5 - 14.6 % for fruits packaged in perforate polyethylene, 4.8 to 22.4 % for non-perforated polyethylene and 5.4 to 24.4 % for unpackaged fruits respectively (Table 4.22).

The interactions of packaging materials and storage conditions were significant on weight loss at 3, 9, 15, and 27 DIS (Table 4.23). Pepper fruits packaged in aluminium foil and stored in the refrigerator had lower weight loss of 2.1 % at 3 DIS to 7.2 % at 27 DIS compared to those packaged in perforated polyethylene with a weight loss of 2.6 % at 3 DIS to 9.2 % at 27 DIS followed by non-perforated polyethylene package with a weight loss value of 3.2 % at 3 DIS to 10.4 % at 27 DIS. Unpackaged pepper fruits had the highest weight loss of 3.8 % at 3 DIS to 14.2 % at 27 DIS. Pepper fruits packaged in aluminium foil, perforated polyethylene, non-perforated polyethylene, and unpackaged fruits and stored in the ECS had weight loss value of 2.9 % to 11.6 %, 3.1 % to 16.6 %, 3.8 % to 10.4 % and 4.3 % to 22.1 % respectively at 3 to 27DIS. In all cases unpackaged pepper fruit stored at ambient condition had the maximum WL compared to all other combination. At 3 DIS, pepper fruits packaged in aluminium foil and those packaged in perforated polyethylene kept in the ECS and refrigerator were similar at 9, 15, and 27 DIS. Similar response was obtained for pepper fruits packaged in non-perforated polyethylene kept in the refrigerator.

Table 4.22: Effects of packaging materials and storage conditions on weight loss (%) of pepper fruit

Treatment	Days in Storage					
	3	9	15	21	27	30
			%			
Storage Conditions						
Ambient	6.4a	11.2a	17.0a	20.5a	22.7a	23.5a
Evaporative coolant structure	3.5b	8.2b	12.6b	16.0b	18.8b	21.0b
Refrigerator	2.8c	6.7c	7.9c	8.9c	10.3c	11.8c
SE	0.09	0.07	0.11	0.12	0.12	0.11
Packaging Methods						
Aluminium foil	3.2d	5.9d	7.9d	10.6d	12.0d	13.6d
Perforated Polyethylene	3.5c	8.2c	10.7c	13.4c	14.7c	14.6c
Non-perforated Polyethylene.	4.8b	9.7b	14.8b	17.4b	19.7b	22.4b
Unpackaged (control)	5.4a	11.1a	16.5a	19.2a	22.0a	24.4a
SE	0.04	0.09	0.13	0.13	0.14	0.13
SE (Packaging × Storage)	0.09*	0.13*	0.23*	0.24ns[3]	0.11*	0.1ns

ns = Not significant, * = Significant at $p < 0.05$

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$.

Table 4.23: Interactions of packaging material and storage conditions on percentage weight loss (%) of pepper fruit

Storage Conditions	3 Days in storage				15 Days in storage				27 Days in storage			
	Foil	Perforated polyethylene	Non Perforated Polyethylene	Unpackaged fruits	Foil	Perforate Polyethylene	Non Perforated polyethylene	Unpackaged fruits	Foil	Perforated Polyethylene	Non Perforated Polyethylene	Unpacked fruits
Ambient	4.7d	5.3c	7.5b	8.1a	15.3f	16.4e	24.1b	26.3a	17.2d	18.3e	24.5b	26.1a
ECS	2.9h	3.1g	3.8f	4.3e	10.2h	15.6f	17.3d	19.1c	11.6g	16.6e	17.4d	22.5b
Refrigerator	2.1j	2.6i	3.2g	3.8f	6.2j	8.2i	10.1h	12.1g	7.2j	9.2i	10.4h	14.2f
SE	0.09				0.23				0.11			

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$.

4.3.2: Pepper Fruit Firmness

Firmness of pepper fruits differed significantly among the three storage conditions: refrigerator, ECS and ambient following the order refrigerator > ECS > ambient from 3 to 30 DIS (Table 4.24). Fruits kept in refrigerator had the highest firmness values of 4.0 to 1.7 from 3 to 30 DIS compared to corresponding values of 3.7 to 1.1 and 3.3 to 1.1 for ECS and ambient respectively. Firmness of pepper fruit was significantly affected by packaging materials at 3 to 30 DIS, those fruits packaged in aluminium foil had the highest values (3.8 to 1.6) compared with all the other treatments at 3 to 30 DIS, also fruits packaged in the perforated polyethylene had higher values (3.0 to 1.3) compared to those fruits in the non-perforated polyethylene at 9 to 30 DIS. The unpackaged fruits as well as those in the non-perforated polyethylene had lower values which were similar at 27 and 30 DIS (Table 4.24).

The interaction of packaging materials and storage conditions on firmness score of pepper fruits was significant at 3, 9, 15, 21, 27 and 30 DIS (Table.4.25). Pepper fruits packaged with aluminium foil kept in refrigerator consistently had the highest firmness score of 3.4 to 2.6 at 9 to 27 DIS while the unpacked fruits kept under ambient condition had the lowest values (2.7 to 1.5). At 3 DIS, fruits kept in the refrigerator after packaging with foil and perforated polyethylene had score of 4.0 that was highest while the unpacked fruits had the lowest value (3.5). Firmness of pepper fruits followed the order ambient < ECS < refrigerator for storage condition, with respect to packaging materials, pepper fruit firmness followed the order aluminium > perforated polyethylene > non-perforated polyethylene > unpackaged fruits in all the storage conditions from 9 to 30 DIS. Similarly at 30 DIS, fruits packaged in perforated polyethylene kept in the refrigerator had firmness score (2.3) that was comparable to values of those fruits packaged with aluminium foil (2.6) while the unpackaged fruits had the lowest value (1.5) in the same storage condition. At 3 to 30 DIS, pepper fruits packaged in aluminium foil kept in the ECS had values (3.8 to 2.0) comparable to those fruits packaged in perforated polyethylene in the same condition at 30 DIS which was also similar to those fruits packaged in perforated polyethylene (3.4) kept in the refrigerator at 15 DIS.

Table 4.24: Effects of packaging methods and storage conditions on firmness of pepper fruits

Treatments	Days in Storage					
	3	9	15	21	27	30
Storage Conditions						
Ambient	3.3a	2.6a	2.2a	1.9a	1.5a	1.1a
Evaporative coolant structure	3.7b	3.1b	2.7b	2.3b	2.8b	1.1a
Refrigerator	4.0c	3.7c	3.1c	2.4c	2.9c	1.7c
SE	0.01	0.01	0.01	0.01	0.02	0.01
Packaging Methods						
Aluminium foil	3.8a	3.2a	2.9a	2.5a	2.1a	1.6a
Perforated Polyethylene	3.6b	3.0b	2.6b	2.3b	1.9b	1.3b
Non-perforated Polyethylene	3.6b	2.8c	2.4c	2.2c	1.4c	1.1c
Unpackaged (control)	3.5c	2.6d	2.2d	1.9d	1.4c	1.1c
SE	0.01	0.01	0.01	0.01	0.02	0.21
SE (Packaging × Storage)	0.04*	0.02*	0.03*	0.04*	0.08*	0.02*

Firmness scoring scale =1 to 4 (1=Not firm; 2=Slightly firm; 3=Firm; 4=Very Firm)

* = Significant at $p < 0.05$

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$

Table 4.25: Interactions of packaging materials and storage conditions on firmness of pepper fruits

Storage Conditions	3 Days in storage				15 Days in storage				30 Days in storage			
	Foil	Perforated polyethylene	Non-Perforated polyethylene	Unpackaged fruits	Foil	Perforated Polyethylene	Non Perforated Polyethylene	Unpackaged Fruits	Foil	Perforated Polyethylene	Non Perforated Polyethylene	Unpackaged fruits
Ambient	3.5d	3.3e	2.9fg	2.5h	2.4g	2.2h	2.1i	2.0j	1.5cde	1.4de	1.2e	0.6f
Evaporative coolant structure	3.8b	3.6cd	3.0f	2.8g	3.5b	2.8e	2.5f	2.2h	2.0bc	1.8bcd	1.6cde	1.4de
Refrigerator	4.0a	4.0a	3.7bc	3.5d	3.8a	3.4c	3.2d	2.8e	2.6a	2.3ab	2.0bc	1.5cde
SE	0.04				0.03				0.2			

Firmness scoring scale of 1 to 4 (1=Not firm; 2=Slightly firm; 3=Firm; 4=Very Firm)

Means with the same letters in columns under each ‘days in storage’ treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

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4.3.3 Fruit Freshness

Freshness of pepper fruits was significantly affected by storage conditions at 3 to 27 DIS. Freshness score were highest on the fruits stored in the refrigerator at 3, 15, and 21 DIS and maximum at 9, 27, and 30 DIS. Freshness score of pepper fruits with respect to storage also followed the order refrigerator > ECS > ambient condition at 3 and 21 DIS while the ones in ECS had values comparable to the maximum at 9, 27, and 30 DIS. Pepper fruits stored in the refrigerator had higher freshness score of (3.8 to1.8) compared to ECS (3.5 to 1.5) and ambient (2.6 to 1.0) from 3 to 30 DIS. Pepper fruits freshness reduced as storage duration increased from the 3rd to 30th day in storage. Pepper fruits packaged in aluminium foil had significantly higher freshness than all other packaging treatments at 3, 9 and 15 DIS and those fruits in non-perforated P.E and unpackaged fruits at 21 and 27 DIS. Furthermore, fruits packaged in perforated P.E had higher firmness score than those without packaging and those in non perforated P.E at 3, 9, 21 and 27 DI S as well as the unpackaged fruits at 15 DIS. Fruits in the non perforated P.E also had higher pepper fruit freshness than the unpackaged fruits at 9 and 15 DIS. At 21 and 27 DIS no difference was observed in fruits packaged with aluminium foil and perforated P.E

The interaction of packaging materials and storage conditions on freshness score of pepper fruits was significant at 15, 21 and 27 DIS (Table 4.27). Fruits packaged in aluminium foil, kept in the refrigerator had the highest freshness value among various other combinations while the unpackaged fruits kept in the ambient had the lowest values. The freshness values of fruits packaged with perforated P.E under the ambient was comparable to that of unpackaged fruits in ECS at15 DIS. Fruits packaged with aluminium foil kept in the ambient also had freshness value comparable to those packaged with non-perforated P.E kept in the refrigerator at 21 DIS. However at 27 DIS the fruits packaged with foil kept in the ambient condition had similar freshness to those in non-perforated P.E kept in the ECS, furthermore freshness score of fruits packaged with aluminium foil kept in the ECS was comparable to those packaged in perforated P.E kept in the refrigerator.

4.3.4 Correlation of firmness, freshness and weight loss of pepper fruits

Freshness and firmness of pepper fruit were positively correlated at 3 to 30 DIS while both parameters were negatively correlated with weight loss of pepper fruits at the corresponding DIS.

Table 4.26: Effects of packaging methods and storage conditions on freshness of pepper fruits

Treatment	Days in storage					
	3	9	15	21	27	30
Storage Conditions						
Ambient	2.6c	2.5b	2.2c	1.8c	1.6b	1.0b
Evaporative Coolant Structure	3.5b	3.0ab	2.7b	2.4b	2.1ab	1.5ab
Refrigerator	3.8a	3.6a	3.4a	2.8a	2.5a	1.8a
SE	0.05	0.34	0.07	0.09	0.20	0.18
Packaging Methods						
Aluminium foil	3.8a	3.5a	3.2a	2.8a	2.5a	1.6a
Perforated Polyethylene.	3.3b	3.1b	2.8b	2.6a	2.2a	1.3a
Non-perforated Polyethylene.	3.0c	2.9c	2.6c	1.8b	1.4b	1.2a
Unpackaged (control)	2.9c	2.6d	2.3c	2.1b	1.1b	1.0a
SE	0.06	0.04	0.08	0.11	0.24	0.21
SE (Packaging × Storage)	0.04ns[4]	0.20ns	0.03*	0.02*	0.03*	0.07ns

Freshness scoring scale of 0 to 4 (0 = poor, 1= unacceptable, 2 = acceptable 3 = good, 4 = excellent)

ns = Not significant, * = Significant at $p < 0.05$

For each factor, means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $P < 0.05$

Table 4.27: Interactions of packaging material and storage conditions on freshness of pepper fruit

Storage conditions	Days in storage											
	15				21				27			
	Foil	Perforated polyethylene	Non-Perforated polyethylene	Unpackaged fruits	Foil	Perforated polyethylene	Non-Perforated polyethylene	Unpackaged fruits	Foil	Perforated polyethylene	Non-Perforated polyethylene	Unpackaged fruits
Ambient	2.4g	2.2h	2.1i	2.0j	2.1e	2.0f	1.4j	1.2k	1.8e	1.6g	1.4i	1.3j
Evaporative Coolant Structure	3.5b	2.8e	2.5f	2.2h	3.0c	2.6d	1.8h	1.5i	2.7b	2.4c	1.8e	1.5h
Refrigerator	3.8a	3.4c	3.2d	2.8e	3.3a	3.1b	2.1e	1.9g	3.0a	2.7b	2.0d	1.7f
SE	0.03				0.02				0.03			

Means with the same letters in columns under each 'days in storage' treatment are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

Table 4.28: Correlation coefficient (r) among fruit quality traits in pepper (n = 36)

	Days in Storage																	
	3	9	15	21	27	30	3	9	15	21	27	30	3	9	15	21	27	30
	Freshness						Firmness						Weight loss					
Freshness 3 DIS																		
Freshness 9 DIS	0.8***																	
Freshness 15 DIS	0.7***	1.0***																
Freshness 21 DIS	0.8***	1.0***	1.0***															
Freshness 27 DIS	0.7***	0.9***	1.0***	1.0***														
Freshness 30 DIS	0.7***	0.9***	0.9***	1.0***	1.0***													
Firmness 3 DIS	0.8***	0.9***	0.9***	0.8***	0.7***	0.8***												
Firmness 9 DIS	0.9***	0.8***	0.8***	0.9***	0.8***	0.8***	0.7***											
Firmness 15 DIS	0.9***	0.9***	0.8***	0.9***	0.9***	0.8***	0.8***	1.0***										
Firmness 21 DIS	0.8***	0.8***	0.8***	0.9***	0.8***	0.8***	0.8***	0.9***	0.9***									
Firmness 27 DIS	0.8***	0.7***	0.7***	0.9***	0.8***	0.74***	0.5*	0.8***	0.8***	0.7***								
Firmness 30 DIS	0.5*	0.7***	0.7***	0.9***	0.7***	0.7***	0.6*	0.6**	0.6**	0.5*	0.6**							
Weight loss 3 DIS	-0.9***	-0.9***	-0.8***	-0.9***	-0.8***	-0.8***	-0.9***	-0.9***	-0.9***	-0.9***	-0.7***	-0.5*						
Weight loss 9 DIS	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-1.0***	-0.9***	-0.8***	-0.6**	0.9***					
Weight loss 15 DIS	-0.8***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.7***	-0.6**	0.9***	1.0***				
Weight loss 21 DIS	-0.8***	-1.0***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.8***	-0.8***	-0.9***	-0.7***	-0.7***	0.9***	0.9***	1.0***			
Weight loss 27 DIS	-0.7***	-1.0***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.8***	-0.8***	-0.8***	-0.7***	-0.7**	0.9***	0.9***	1.0***	1.0***		
Weight loss 30 DIS	-0.6***	-0.9***	-0.9***	-0.9***	-0.9***	-0.9***	-0.8***	-0.7***	-0.8***	-0.8***	-0.7***	-0.7**	0.8***	0.9***	0.9***	0.9***	1.0***	

DIS = Days in storage

*, **, *** Significant at p< 0.05 and p< 0.01 respectively

4.4 Effect of processing techniques on proximate composition of pepper fruit in storage

The effect of processing techniques on proximate composition of pepper fruits are contained in Table 4.29. Parboiling before sun-drying of pepper fruits resulted in the highest percentage ash, crude protein, fat and capsaicin content of pepper fruits while parboiled oven-drying resulted in the highest carbohydrate and oleoresin content. Sun-drying of pepper fruits resulted in the highest percentage crude fibre and ash content of pepper fruits while blending of fresh fruits resulted in the highest ash and moisture content of pepper fruits. Conversely, pepper fruits blended fresh had the lowest crude protein, fat, carbohydrate, capsaicin and oleoresin contents while those parboiled before oven drying had the lowest ash and crude fibre content.

Moisture content of fruits processed by all the other techniques was significantly lower than those blended fresh. Oven-dried pepper fruits had high ash, capsaicin and oleoresin content while that sun dried also had high crude protein and carbohydrate contents. Fruits parboiled before drying and those blended fresh had high fat and crude fibre contents respectively. Pepper oven dried alone or after parboiling however had significantly low ash content than those subjected to other processing techniques while those pepper subjected to sun drying alone after parboiling generally had significantly higher ash, crude protein content than those correspondingly oven dried. In contrast sun drying pepper fruit either alone or after parboiling resulted in lower oleoresin content than the corresponding oven dried ones, fruits blended fresh had the lowest proximate compositions, except for moisture content, crude fat, and ash content.

Table 4.29: Effect of processing techniques on proximate composition of pepper fruit in storage

Processing Technique	Ash	Moisture contents	Crude protein	Fat	Crude fibre	Carbohydrate	Capsaicin	Oleoresin
					%			
Parboiled Oven Dried	6.0c	6.3b	14.1c	11.0b	22.1e	36.6a	21.2c	1.2a
Oven Dried	6.6b	6.2b	13.3d	10.6d	24.8a	34.0d	22.4b	1.0b
Parboiled Sun Dried	7.9a	6.2b	15.2a	11.3a	24.4d	35.6c	27.8a	0.9c
Sun Dried	8.0a	6.3b	15.0b	10.9c	24.5c	36.5b	20.1d	0.8d
Fresh Blended	7.9a	11.4a	12.6e	8.8e	24.6a	33.6e	19.9e	0.5e
SE	0.06	0.05	0.03	0.02	0.03	0.03	0.02	0.01

Means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $p<0.05$

4.4.1 Effect of processing techniques on nutrient elements and Vitamin C contents of Pepper Fruit in storage

The effect of processing techniques on nutrient elements and vitamin C content of pepper fruits was significant on nutrient element of pepper fruit (Table 4.30). Pepper fruits parboiled before sun-drying or oven drying had the maximum content of the entire nutrients while only those that were sun-dried after parboiling had maximum vitamin C of 9.8 mg/kg. Except magnesium, fruits blended fresh had the lowest contents of all the nutrients and vitamin C content. Although not comparable to the maximum pepper oven dried after parboiling had high vitamin C content of 8.5 mg/kg. Similarly, pepper oven-dried and sun-dried had high phosphorus, calcium, magnesium, and zinc content while high iron and sodium content were observed in those sun-dried and oven-dried, respectively.

Table 4.30: Effect of processing techniques on nutrient elements and vitamin C content of pepper fruit in storage

Processing technique	Phosphorus	Calcium %	Potassium	Magnesium	Zinc	Iron mg/kg	Sodium	Vit. C
Parboiled (Oven Dried)	0.3a	0.3a	0.1ab	0.3a	1.4a	77.1a	160.0a	8.4b
Oven Dried	0.2b	0.2b	0.1bc	0.2b	1.3b	74.0c	158.0b	7.3c
Parboiled (Sun Dried)	0.3a	0.3a	0.1a	0.3a	1.4a	77.1a	159.0ab	9.6a
Sun Dried	0.2b	0.2b	0.1bc	0.2b	1.3b	76.0b	155.3c	9.7a
Fresh Blended	0.1c	0.1c	0.1bc	0.2b	1.2c	70.0d	149.8d	7.3c
S.E	0.01	0.01	0.01	0.03	0.01	0.08	0.37	0.07

Means followed by the same letter(s) in columns are not significantly different by Duncan Multiple Range Test (DMRT) at $p < 0.05$

4.4.2: Correlation for proximate composition, nutrient elements and vitamin C content of pepper fruits

The relationship of each of the nutrient element evaluated indicated significant correlation among the treatments (Table 4.31). Phosphorus content was significantly correlated with calcium (r = 0.9), zinc (r = 0.8), iron (r = 0.9), sodium (r = 0.9) and, potassium (0.6). Calcium was significantly correlated with zinc (r = 0.9), iron (r = 0.9), potassium (r = 0.8), and sodium (r = 0.9) while magnesium was significantly correlated with zinc and iron with r values of 0.5 and 0.6 respectively. Vitamin C was significantly correlated with potassium (r = 0.6) and was only significantly correlated with all other nutrients (r = 0.5 to 0.6) with the exception of sodium with non-significant relationship. Vitamin C was significantly correlated with potassium (r = 0.6). The relationship among nutrient element and vitamin C were all positive. Zinc was also significantly correlated with iron, potassium and sodium with r values of 0.7, 0.9 and 0.8 respectively while potassium correlated to sodium (r = 0.7).

Oleoresin was positively correlated with all proximate contents of pepper fruits except crude protein and fat content. Furthermore, carbohydrate was correlated with crude protein, fat, and crude fibre content while crude fibre was also correlated to ash content. Fat content was also correlated with moisture content and crude protein (Table 4.32).

Table 4.31: Correlation Coefficient (r) among mineral elements in pepper fruits (n=24)

	P	Ca	Mg	Zn	Fe	K	Na
Ca	0.9***						
Mg	0.4ns	0.4ns					
Zn	0.8***	0.9***	0.5*				
Fe	0.9***	0.9***	0.6**	0.9***			
K	0.6**	0.8**	0.2ns	0.7***	0.7***		
Na	0.9***	0.9***	0.4ns	0.9***	0.9***	0.7*	
Vit C	0.6*	0.6*	0.6*	0.6*	0.8*	0.5*	0.4ns

*, **, *** Significant at p< 0.05, p< 0.01 and p< 0.001, respectively

Table 4.32: Correlation Coefficient (r) among proximate composition in pepper fruits (n=24)

	Ash	Moisture content	Crude protein	Fat	Crude fibre	Carbohydrate	Capsaicin
Moisture content	0.3ns						
Crude protein	0.3ns	0.7**					
Fat	0.2ns	1.0**	0.8**				
Crude fibre	0.7*	0.3ns	-0.1ns	-0.3ns			
Carbohydrate	0.1ns	0.7**	0.8***	0.7*	0.6*		
Capsaicin	0.2ns	-0.4ns	0.6*	0.5*	0.1ns	0.1ns	
Oleoresin	0.8*	0.8**	0.4ns	0.8**	0.7*	0.6*	0.3ns

*, **, *** Significant at p< 0.05, p< 0.01 and p< 0.001, respectively

CHAPTER 5

DISCUSSION

The bulk of pepper produced gets damaged during the process of handling, transportation and marketing due to absence of proper postharvest management system. In addition, infection by pathogen from the field which may not be apparent at harvest could latter cause severe damage as a result of high temperature and humidity with consequent huge postharvest losses (Bhat *et al*., 2010). Olayemi *et al.* (2010) reported losses of 10 - 30 % during harvesting and transportation stages for tomatoes, bell and hot pepper. Furthermore, unavailability of storage structures resulted in farmers selling their produce at very low prices. In order to avert the problem of transporting unsold produce at high cost, farmers sold their pepper fruits at low price near the market area (Udugbe *et al.*, 2012).

The farmers involved in pepper fruit cultivation were mostly married males with average family size of one to six, who were basically between ages 40 to 50 and were energetic to source for inputs for improved production practices. This is in agreement with the findings of Mohammed *et al*. (2013) whose study revealed that the average age of farmers was 45 years with a mean household size of 10 persons in Ethiope west local government area of Delta State, Nigeria. In this study, most respondent had primary school education, engaging solely in pepper farming and cultivating between one to three hectares of land. The farmers used previous year seeds for production while they harvest fruits with baskets, plastic bucket, or used grain sack at full ripening as earlier observed by Olayemi *et al.* (2010). These harvest and postharvest techniques were inappropriate for the protection of fruits from damage and deterioration. The situation was further aggravated by the failure of farmers to sort out infected fruits from wholesome ones before transporting to market which could have reduced infection of healthy fruits and subsequent postharvest losses. Other causes of high losses include the use of unskilled labour for harvest, careless loading and unloading of harvested fruits, exposure of fruits to direct sunlight resulting in heat build-up, poor roads and road networks, inappropriate packaging and transportation method, lack of shade or precooling facilities to remove field heat in order to reduce rate of respiration and consequent deterioration rate. On the whole, none of the marketers and farmers used the plastic crate which was designed by Food and Agriculture Organization (FAO) and Nigerian Stored Product Research Institute (NSPRI) to prevent physical damage to produce. This corroborates the findings of Olayemi *et al.* (2010) on assessment of postharvest challenges of small scale farm holders of tomatoes, bell and hot pepper in some local government areas of Kano State who observed that pepper were normally harvested at fully ripe stage (90 %) and that most farmers still use the traditional basket and sack as their packaging material in conveying produce which resulted in massive postharvest losses of about 62.5 %.

Survey of postharvest handling of pepper fruits by marketers showed that Hausa men were more involved in marketing of pepper fruits compared to women. This could be attributed to the rigorous demand of the business that required constant transportation of pepper fruits from the north to the southwest, the religious back ground, and custom in the north also restricted women to more of domestic activities within the home environment. Most marketers were married, within the age range of 31 to 50 years and had average household size of 6. This implied viable economic activities which generate enough returns to sustain the family. Most respondents engaged in fresh pepper rather than processed pepper trade due to lack of access to simple processing technology and storage methods as earlier reported by Adewoyin *et al*. (2011). The results of this study further revealed that the major challenges facing the marketers were inadequate and inappropriate transportation with poor road networks resulting in high transportation cost. This claim was supported by Abbot and Makehem (2002) that most pepper marketers face the problem of high cost of transportation.

The sign of deterioration recognised by most marketers were the presence of fly larvae in the pepper fruits, discolouration, off flavour, and unpleasant odour which occurred within 3-5 days, as earlier reported by Babatola *et al.* (2012) for pepper fruits marketers in Ibadan metropolis. This is attributable to deterioration due to poor handling methods by marketers and exposure to unhygienic conditions. In order to prevent further deterioration and enhance the value of produce, marketers normally separated rotten fruits from the wholesome ones before sales, and then spread leftover fruits on cement floors or mats. This implied that, to some extent, pepper marketers made serious effort to prevent deterioration, but this method needs improvement (FAO, 2007). Polypropylene sack which was widely used by marketers was inappropriate and caused damage to fruits. The adoption of harvesting crates would be more appropriate to reduce mechanical damage, microbial infection and heat build-up, thereby extending the shelf life of pepper fruits (FAO 2007). The high economic loss in pepper as a result of inappropriate handling methods by marketers necessitates improvement in the existing technique.

Pepper price peaked in June for both urban and rural markets while the trough price occurred in March for urban markets and November for rural markets in Oyo State. The low price index in March may be attributed to the transportation of pepper fruits produced through irrigation system from the North directly to the urban centre by the Hausa trader while trough price experienced in the rural market may be attributed to the Fadama production of pepper fruits. Increase in supply resulting in decrease in price in the rural area but added cost of handling would have increased price before getting to the urban centre. Seasonal price indices provide a summary of average monthly historical pattern of price trends (Trap, 1991). The other months with price indices above 100 were April, May and December for rural markets as well as January, April, May and December for urban markets. The seasonal monthly price indices of 117 and 142 for rural and urban markets respectively indicated that the price of pepper in June was 17 % and 42 % higher than the annual average price in the two markets in Oyo State. Likewise, the March trough index value of 49 in rural market and 85 in urban markets indicated that price of pepper were 15 and 51 % below annual average in rural and urban markets respectively.

In Ondo State, the peak price index occurred in December for both urban and rural markets and trough price index occurred in January for urban and rural markets. Most farmers in Akure, Ondo state who concentrates mainly on production of cash crops like cocoa and rubber. The consumers depend mostly on pepper fruits from the northern part of the country. Increase in cost of transportation and high demand for pepper fruits during the festive period account for the high price of the produce in December. This result corroborates the earlier findings of Babatola *et al. (*2010) that most pepper consumed in the state first arrived at urban markets before transportation to the rural markets at higher price. The price index then rose in December to 122 for rural markets and 121 for urban markets. The monthly price indices were above 100 in August, September, October and December for rural and urban markets.

Amplitude of the seasonal price indices, given as the difference between highest and lowest price indices (Afolami, 1998), for this study were 68 and 57 for Oyo State and the corresponding value for Ondo State were 35 and 41. This implied large price fluctuation. The estimated average monthly percentage price increase for urban and rural areas were 22.7 and 11.4 % respectively in Oyo State while the corresponding values for Ondo State were 5.0 and 5.9 % respectively. Durojaiye and Aihonsu (1988) had earlier estimated average monthly rise in seasonal price to be 3.43 and 2.50 percent for grain seeds for urban and rural markets, respectively in Ogun State.

The cumulative weight loss (WL) of pepper fruits were significantly reduced in the refrigerator compared to evaporative coolant structure (ECS) and ambient conditions. The most important function of refrigeration was to control respiration rate. Respiration generates heat as sugars, fats, and proteins in the cells of the crop are oxidized. The loss of these stored food reserves through respiration causes reduction in food value, flavour, firmness and general appearance of the produce. The respiration rate of a produce strongly determines its quality in transit and postharvest life (Fan *et al.*, 2008).).

The high temperature at ambient condition increases the rate of water loss from fruits through transpiration and decrease turgor in cells which begins to shrink and collapse thus leading to loss in weight (Nyanjage *et al.*, 2005). The lower weight loss in fruits kept in the refrigerator could be attributed to the lower temperature (4 °C) which reduced physiological processes compared to the other storage conditions evaluated in this study. Bechmann and Earles (2000) have also attributed the slowing down of physiological processes such as respiration fruits to the combine effects of low temperature and higher relative humidity in the refrigerator. Davey *et al.* (2000) further affirmed that temperature and relative humidity were important factors in maintaining quality of fruits after harvest. In a similar development, Wilson *et al.* in their report on postharvest handling and cooling of fresh fruits and vegetable, asserted that deterioration of fresh commodities can result from physiological breakdown due to ripening, water loss, physical damage, or/and invasion by micro-organisms and their interactions with temperature and relative humidity of the storage conditions

(Wilson *et al.*, 1995). Pepper fruits kept in the ECS (18 °C – 20 °C; 70 - 75 %RH) had lower WL compared to ambient condition (21.9 °C – 33.5 °C; 58 – 62 %RH). Mordi and Olorunda (2003) in their study on storage of tomatoes in Evaporative cooler environment reported a drop of 8.2 °C from ambient condition of 33 °C while the relative humidity increased by 36.6% over an ambient condition of 60.4%. In this study, the shelf-life of fruits kept in the ECS was 21 DIS.

In this study, pepper fruits harvested at 10 % ripening had lower WL compared to those harvested at 100 % ripening. This is in contrast to the findings of Brecht *et al.* (1992), on the effects of ripeness and storage temperature on matured and immature water chestnut which stored for 1 to 2 month at 0 to 2°C and relative humidity (Rh) of 98 to 100 % but immature corms became injured within 10 days at 1°C and Rh of 98 %. Furthermore, Juan *et al.* (2007) reported that the rate of water loss in bell pepper fruits was highest in immature fruit and showed no differences between mature green and red fruit. Maturation is indicative of fruits and vegetables readiness for harvest. At this point the edible part of the fruit or vegetable is fully developed in size. Ripening follows or overlaps maturation rendering the produce edible as indicated by taste.

The WL of pepper fruits harvested with pedicels was lower than those harvested without pedicels in all the trials because of the opening created on the fruit by pedicel removal which served as openings for microbial infection and transpiration. Tissue wounding due to the removal of pedicels will also result in numerous physiological and biochemical changes in fruit that contribute to reduced shelf life. The combination of pepper fruits at 10 % ripening with pedicels and thereafter storing in the refrigerator had the lowest weight loss. The WL at 15 DIS for fruits harvested with pedicels at 10 % ripeness kept in the ECS was comparable to those fruits harvested without pedicel at 10 % ripeness and fruits harvested with pedicels at 100 % ripeness kept in the refrigerator. At 30 DIS, WL of fruits harvested at 100 % ripeness were similar when kept in the refrigerator and ECS but significantly higher for fruits under the ambient condition

Decay level is a quality index that measured the rate of deterioration of fruits and vegetables, especially pepper. The lower decay level scores in this study indicate high quality and low level of deterioration. Fruits harvested with pedicels at 10 % ripening, stored in refrigerator had lower decay score than the corresponding other treatments while combination of the two treatments promoted fresh and firm fruits up to 30DIS. However, when fruits were harvested with pedicels, at 10 % ripeness kept in the ECS, the firmness was sustained for 21 DIS compared with 9 DIS under ambient conditions. This is in agreement with the findings of Sinchez *et al.* (2006) who emphasised that fruit deterioration is predominantly governed by storage condition, and that high temperature hastened the process of deterioration. Temperature and relative humidity played key roles in fruit decay. The control of relative humidity in the postharvest environment is often as important as the control of temperature as these two factors are closely interrelated. High moisture content favoured decay hence, rate of decay was dependent on storage method and duration of storage. Pepper fruits harvested with pedicel at 10% ripening, kept in ECS and refrigerator as well as those harvested without pedicel at 10% ripening and stored in the refrigerator had the lowest decay level score at 9 DIS. Those harvested at 10 % ripening with and without pedicel and kept in the refrigerator also had significantly lower decay level score than all the other combination of treatment at 9DIS under ambient and ECS conditions. The storability of pepper fruits harvested without pedicels at 100 % ripe was lower; it was 21DIS in refrigerator, 12 DIS in ECS and 3 DIS under ambient condition.

Firmness which describes the level of turgidity of a fruit after harvest reduces as the length of storage increases and is affected by the storage technique. In this study, pepper fruits kept in the refrigerator with low temperature and high relative humidity contributed to the retention of its firmness. Fruits harvested with pedicels at 10 % ripening and stored in refrigerator remained significantly firmer for 30DIS and 21DIS for fruits in the ECS while fruits stored under ambient conditions lost firmness rapidly after 5 DIS. This is in agreement with the findings of Steven and Celso (2005) that the principal causes of postharvest losses were external damages incurred during handling and harvesting at improper stage of ripeness. The characteristic high temperature and relative humidity of the humid tropics influenced storage under ambient conditions which hastened deterioration process and loss of firmness. Also fruit harvested with pedicels exhibited higher firmness compared to those harvested without pedicels. Significant interactions were observed among ripeness, harvesting methods and storage condition of pepper fruits. Fruits harvested at 10 % ripening with pedicels, stored in the refrigerator had the highest firmness while pepper fruits harvested at 100% ripening without pedicels stored under ambient conditions had the lowest firmness.

The rating in general appearance (GA) of pepper fruits under the refrigerator was significantly higher than those in other storage conditions. This is in agreement with Sealand (1991) that a temperature of 4°C together with relative humidity of 90 to 95 % maintained pepper quality satisfactorily for a period of 12-18 days in storage. In this study, fruits harvested with pedicels at 10 % ripening and stored in refrigerator remained significantly higher in general appearance rating for 30 DIS and 21 DIS for fruits in the ECS while fruits stored under ambient conditions were reduced in general appearance rating after 5 DIS. This is in agreement with the findings of Steven and Celso (2005) that ensuring high quality required harvesting fruits with pedicels, firm fruit, uniform and shiny colour, devoid of mechanical injury and shrivelling would be more acceptable for storage than those of poor quality. The storability of pepper fruits harvested without pedicels at 100 % ripeness was lower. The shelf life was 21 DIS in refrigerator, 12 DIS in ECS and 3 DIS under ambient conditions.

The multidimensional analysis of all the measured parameters taken together to evaluate the best ripening stage, harvesting method and storage conditions further confirmed that pepper fruits harvested at 10% ripening with pedicel and stored in refrigerator (4°C) ranked first in storability, followed by fruits harvested without pedicel at 10 % ripeness and stored in refrigerator and then fruits harvested at 10 % ripeness with pedicels, stored in ECS while fruits harvested without pedicels at 100% ripening stored under ambient condition ranked 12th and had the lowest storability. Hence, pepper fruits storability was best prolonged by harvesting with pedicels at 10 % ripeness and stored in the refrigerator. The ECS therefore serves as alternative storage techniques which can be effective if fruits are handled properly by harvesting with pedicels at 10 % ripening.

Negative correlation was observed for WL from 3 to 30 DIS while firmness and decay were positively correlated. GA was only correlated to firmness and decay at the initial storage period (3 DIS) when the effects of deterioration were minimal. Immediately deterioration occurred, quality cannot be restored; hence quality can only be maintained before deterioration occurred. It is therefore apparent that all the parameters considered except GA were related and could serve as quality index in measurement of pepper fruit storability. The determination of GA includes many exogenous factors based on perceptive measure which could be influenced by many other quality factors.

Pepper fruits packaged in aluminium foil and placed in ECS extended shelf-life to 21 days. Fruits packaged in aluminium foil and stored under ambient conditions with the temperature fluctuating between 21.9 °C and 33.5 °C and relative humidity of 58 – 62 % lost moisture very rapidly after five days. The characteristic high temperature and relative humidity of the tropics have been extensively reported as the most important environmental conditions in determining shelf life of fruits and vegetables (Willis *et al.*, 1998). The high temperature led to increased rate of metabolic processes that caused depletion of substrates like sugar and protein resulting in increased weight loss. Fruits packaged in perforated polyethylene bag, placed in refrigerator extended shelf life to 21 DIS. Moisture saturated atmosphere within the packaging material decrease moisture loss thereby extended postharvest longevity of pepper fruits (Banaras *et al.*, 2005). Horticultural crops continue their living process after harvesting therefore, there is a need for air circulation to maintain the CO_2/O_2 ratio within the packaging material, hence the essence of perforation in this study. Pepper fruits packaged in perforated polyethylene bag was stored in ECS for 18 DIS while fruits placed under ambient deteriorate rapidly after 3 DIS (Babatola and Adewoyin, 2009).

This study showed that weight loss, firmness and freshness of pepper fruits were maximally conserved in fruits packaged in aluminium foil and placed inside refrigerator (4°C) which remained firm, fresh with reduced WL for a longer period (30 DIS) compared to those in the ECS (27 DIS) and ambient (9 DIS). Fruits packaged in perforated polyethylene bag however remained firm for 21 DIS in the refrigerator, 15 DIS in the ECS and 5 DIS under ambient condition showing corresponding difference in period between aluminium foil and perforated polyethylene of 9, 12 and 4 DIS shelf-lives respectively. Fruits packaged in non-perforated polyethylene bag and unpackaged fruits were lower in firmness, freshness and had higher WL. Mordi and Olorunda, (2003) reported shelf-life of unpackaged fresh tomatoes in evaporative cooler environment as 11 days while ambient conditions was 4 days; on the other hand, combination with sealed but perforated polyethylene bags was 18 DIS in ECS and 13 DIS under the ambient condition. In this study, when packaged in a non-perforated polyethylene bag, pepper fruits placed in refrigerator appeared more wholesome with shelf-life of 12 DIS compared to 9 and 3 DIS for those in the ECS and ambient condition respectively. Pepper fruits without packaging materials lost weight more rapidly in all storage conditions with shelf-life of 12, 9 and 3 DIS for refrigerator, ECS and ambient condition respectively. The higher WL observed for the unpackaged pepper fruits throughout the various storage conditions could be attributed to air movement which tend to sweep away the layer of air (at equilibrium vapour pressure with the tissues) adjacent to the surface of the produce thus increasing vapour deficit (Willis *et al.*, 1998).

Freshness of pepper fruits was obviously sustained by low temperature and higher relative humidity in this study. Pepper fruits packaged in aluminium foil and placed inside refrigerator (4°C) remained significantly higher in freshness for 30 DIS compared to those in ECS (27 DIS) and ambient condition (9DIS) respectively. Higher temperature gives rise to higher physiological activities, and increase in respiration rate in plants. Willis *et al* (1998) observed that at high temperature water evaporates from the tissue, turgor pressure decreases and the cell begins to shrink and collapse thus leading to loss of freshness. Pepper fruits packaged in non-perforated polyethylene bag placed in refrigerator were less wholesome after 18 DIS compared with aluminium foil and perforated polyethylene. The lower period of freshness observed with pepper in non-perforated polyethylene package in the refrigerator is due to the confinement of moisture in the non-perforated packaging materials. Fruits stored in non-perforated polyethylene bag placed in ECS kept for 12 DIS. Freshness and firmness of pepper fruit were positively correlated at 3 to 30 DIS while both parameters were negatively correlated with weight loss of pepper fruits at the corresponding DIS

Pepper fruits parboiled at 75 °C for 3 minutes before sun-drying had the highest nutrient composition with respect to fat, protein and capsaicin contents among various treatments evaluated. The efficient conservation of nutrient could be attributed to the inactivation of the enzyme system and retardation of physiological processes by parboiling which consequently prevent deterioration and nutrients losses. Parboiling has been found to reduce period of drying and the maintenance of the red colour of fresh pepper (Dandamrongrak *et al.*, 2003). During drying, two processes occur viz application of heat and evaporation of moisture from sample. Nutrient losses were due more to application of heat than removal of moisture which increased the concentration of nutrient in the fruit. The use of oven to dry parboiled pepper fruits accelerated the process of moisture removal but resulted in lower nutritional composition compared to sun drying. Pepper fruits subjected to heat sterilisation had high crude fibre, ash content, moisture content and lowest crude protein, fat, carbohydrate, capsaicin and oleoresin content. The ash content was highest in sun-dried pepper fruit. This agreed with the findings of Mepba *et al.* (2007) who observed that ash content of sun dried vegetables was higher compared to the blanched samples. The parboiled pepper fruits in this present study were higher in oleoresin and capsaicin content. The crude fibre content of pepper fruits parboiled before oven drying or sun drying were significantly higher than those of the respective ones dried without parboiling. Oleoresin was positively correlated with all proximate content of pepper fruits except crude protein and fat content. Furthermore carbohydrate was correlated with crude protein, fat, and crude fibre content while crude fibre was also correlated to ash content. Fat content was also positively correlated with moisture content and crude protein.

In this study mineral elements content varied among treatments; Pepper parboiled before either sun-drying or oven-drying had maximum values for all the mineral elements viz: phosphorus, zinc, iron, potassium, calcium and sodium content. The mineral elements and Vitamin C composition of pepper parboiled before sun drying were significantly higher than those of the corresponding treatments. Heat-sterilised samples had the lowest phosphorus, calcium and Vitamin C content than those subjected to various drying methods. Babatola and Adewoyin, (2012) reported losses of vitamin C during parboiling or cooking which may vary between 40 and 70 % in some cooked vegetables when processed at 100 °C for 15 minutes. Solanke and Awonorin (2002) reported losses of 62 to 93 % of vitamin C in cooked vegetables. The high solubility of vitamin C in water and relative ease with which it is oxidised renders it susceptible to deterioration in the course of processing. The route and rate of oxidation of vitamin C is influenced by several factors including pH, trace metals, enzymes, presence of oxygen as well as time and temperature. The relationship of each of the nutrient element evaluated indicated strong correlation among the treatments (Table 4.31). Phosphorus content was significantly correlated with calcium, Zinc, Iron, potassium and Sodium. Calcium was significantly correlated with zinc, iron, potassium, and sodium while magnesium was positively correlated with zinc and iron. Vitamin C was significantly correlated with potassium. The relationship among nutrient element and Vitamin C were all positive. Zinc was also significantly correlated with iron, potassium and sodium while potassium was positively correlated to sodium. This implied that the various processing techniques affected the nutrient composition of pepper fruits

CHAPTER 6

SUMMARY AND CONCLUSIONS

This study was conducted to evaluate the levels of ripeness at harvest, methods of harvesting, storage conditions, packaging materials and processing techniques in order to develop an integrated system for reducing postharvest losses in fresh pepper fruit. Market price pattern and postharvest handling methods of pepper fruits by farmers and marketers were also assessed. The result of the study revealed that the shelf-life of Pepper Fruits (PF) harvested with pedicels at 10% ripeness and stored in refrigerator, ECS and AC were 27, 20 and 6 days while those harvested at 100 % ripeness were 21, 14, and 3 days respectively. The corresponding shelf-life of PF harvested without pedicel at 10% ripeness was 21, 18 and 5 days and 100 % (18, 15 and 2). Deterioration was significantly higher in fruits harvested without pedicels compared to those harvested with pedicels. Fruits harvested with pedicels at 10 % ripeness and kept in the ECS were comparable to those fruits harvested without pedicel at 10 % ripeness and fruits harvested with pedicels at 100 % ripeness kept in the refrigerator. The ECS is an alternative storage technique which can be effective if fruits are handled properly by harvesting with pedicels at 10 % ripeness. It is available locally and requires no power input and can be adapted to any level of production.

Pepper fruits exhibited more acceptable quality indices such as higher freshness, firmness and lower WL for fruits packaged in aluminium foil compared to perforated polyethylene bag and then non-perforated polyethylene bag while the unpackaged lot deteriorated faster and had reduced shelf-life. This showed that good packaging is imperative in extending shelf life of pepper fruits.

Parboiling pepper fruits before sun-drying was better in retaining flavour, colour and nutrient contents of pepper fruits compared to other processing methods. Pepper fruits subjected to sterilisation lost their nutritional composition as a result of prolonged heat treatment.

In this study, over 20% loss was obtained during marketing due to improper postharvest handling procedures. Polypropylene sack which was widely used by marketers was inappropriate and caused extensive damage to fruits. The following conclusion can be deduced:

i. Deterioration of pepper, (*Capsicum frutescens* L.) was significantly higher in fruits harvested without pedicels at 100 % ripeness compared to those harvested with pedicel at 10 % ripeness.

ii. Pepper (*Capsicum frutescens* L.) fruits exhibited more acceptable quality indices such as higher freshness, firmness, lower weight loss for fruits packaged in aluminium foil compared to perforated polyethylene bag and non-perforated polyethylene bag.

iii. Parboiling pepper (*Capsicum frutescens* L.) fruits before sundrying was better in retaining flavour, colour and nutrient contents of pepper fruits compared to other processing techniques like sterilisation.

iv. The data generated on survey of postharvest handling of pepper fruit by marketers serves as baseline information for planning and management on postharvest of pepper fruits.

v. The evaluation of the seasonal price pattern for pepper in the rural and urban markets of Oyo and Ondo states provides information on strategies to be adopted on storage of excess produce at low price period and marketing at peak price period.

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APPENDIX 1

POSTHARVEST HANDLING OF PEPPER FRUITS BY FARMERS

DEPARTMENT OF AGRONOMY

UNIVERSITY OF IBADAN

Dear respondents, this questionnaire intends to collect information on the market conduct and performance of pepper marketing.

Your honest responses to these questions to shall be appreciated as it meant for academic purpose only; your responses shall be treated confidentially.

Please tick (✓) and fill in the appropriate space where applicable.

SECTION A

(1) What is your name?____

(2) What is your age (in years)____

(3) What is your gender (a) Male ( ) (b) Female

(4) What is your religion? (a) Christianity ( ) (b) Islam ( ) (c) Traditional ( )

(5) W hat is your tribe? (a) Yoruba ( ) (b) Igbo (c) Hausa ( ) (d) Others specific

(6) What is your marital status? (a) Married ( ) (b) Single ( ) (c) Divorce. ( )

(7) What is your highest level of educational attainment?

(a) No formal education ( ) (b) Primary school ( ) (c) other specify

(8) What is your household size

No of Husband/wives _________________

No of children ________________________

Other dependents _____________________

Total ________________________________

(9) Apart from pepper farming, do you have any other occupation?___________

(10) How long have you been in this business in years? ________________________

SECTION B

(1) How do you source for pepper seed for planting?

(a) Seed stores (b) ADP (c) Previous harvest (d) Research institute.

(2) Do you separate bruised fruits from the wholesome ones?

(3) Estimated income from pepper sales in a year……………………………..

(4) Farm size………………………………………………………………………..

(5) What time of the year do you harvest………………………………………….

(6) How do you harvest? (a) With pedicels (b) without pedicels

(7) Ripening stage of harvest. (a) Fully ripe (b) Slightly ripe (c) Unripe

(8) What container was used for harvesting?(a) Basket (b)Plastic Bucket(c)Bags

(9) How do you handle pepper during harvesting?

(a) Throw into bucket (b) place gently (c) Others specify

(10) Type of labour (a) Family labour (b) Hired labour

(11) If hired labour, how do you pay labour?

(a) Quantity harvested (b) Daily payment.

(12) Is there any provision of training for the labourers?

(13) What do you in handling large quantity of harvest?

(a) Heap each batch (b) Package in sack (c) Package in basket

(14) Is there any provision of shade for harvested fruits? (a) Yes (b) No

(15) How do you handle the unsold fruits?

(a) Spread on cemented floor (b) kept in basket (c) kept in bags

(16) How do you transport your pepper to the market?

(a) Commuter vehicles (b) Truck (c) Motorcycle (d) others specify

(17) What time of the year is pepper price lowest?..

(18) What time of the year is pepper price highest?...

(19) Do you sell to market directly or to wholesaler?...

(20) How many days does the pepper stay before spoilage?................................

APPENDIX 2

POSTHARVEST HANDLING OF PEPPER FRUITS BY MARKETERS

DEPARTMENT OF AGRONOMY

UNIVERSITY OF IBADAN

Dear respondents, this questionnaire intends to collect information on the market conduct and performance of pepper marketing.

Your honest responses to these questions to shall be appreciated as it meant for academic purpose only; your responses shall be treated confidentially.

Please tick (✓) and fill in the appropriate space where applicable.

SECTION A

(1) What is your name?____

(2) What is your age (in years)______________________________________

(3) What is your gender (a) Male ( ) (b) Female

(4) What is your religion? (a) Christianity ( ) (b) Islam ( ) (c) Traditional ( )

(5) W hat is your tribe? (a) Yoruba ( ) (b) Igbo (c) Hausa ( ) (d) Others specific

(6) What is your marital status? (a) Married ( ) (b) Single ( ) (c) Divorced ( )

(7) What is your highest level of educational attainment?

(a) No formal education ( ) (b) Primary school ( ) (c) other specify

(8) What is your household size

No of Husband/wives _______________

No of children _____________________

Other dependents ___________________

Total ______________________________

(9) Apart from selling pepper, do you have any other occupation, if any________

(10) How long have you been in this business (in years)? ____________________

SECTION B

(1) Where is the source of your pepper?

(a) Seed stores (b) market stalks (c) Others specify ______________________

(2) How, many bags/baskets do you buy at once? (a) 1 (b) 2 (c) Others specify

(3) Do you buy directly from the farmer (a) Yes (b) No(c) other specific

(4) Which type of pepper do you buy? (a) Processed (b) Fresh (c) Others specify

(5) Do you carry out processing on your produce before sales (a) Yes (b) No

(6) If yes, how do you process it? (a) Parboiling (b) Drying (c) Grinding

(7) How long does the processed one stay before going bad? (a) 1 month (b) 2 month

(8) How long do you keep the produce in storage before sale ________________

(9) Do you process the one that is going bad? (a) Yes (b) No (c) Others specify

(10) When purchased fresh, how long does it keep before going bad?

(a) 1 week (b) 2 weeks

(11) What signs do you observe on the bad or deteriorating ones?

(a) Mould (b) Maggot (c) Odour

(12) How do you prolong the shelve life of the fresh ones?

(a) Spreading on a mat (b) Spreading on a cemented floor (e) Others specify

(13) How do you prevent damage during transportation?

(a) Avoidance of overstocking (b) Separation of produce from other ones

(14) Do you separate the damaged freshness from the good ones before sales?

(a) Yes (b) No (e) Others specify

(15) If you separate the damaged from good one which one commands better market value or enjoy higher demand? (a)Damaged (b) undamaged

(16) What is the unit price of your produce per *kongo* (in naira)

i. Fresh undamaged ₦__________

ii. Fresh damaged ₦ ____________

iii. Processed (Dried) ₦ __________

(17) What is the level of profit made from the business? (a) High (b) Moderate (c) Low

(18) Is the market seasonal? (a) Yes (b) No

(19) Do you belong to pepper marketers association (a) Yes (b) No

(20) If yes, what is the role of the association in your pepper business? __________

(21) How do you determine the market price of your produce?

(a) association fixed price (b) self fixed price

(22) What measures do you use in selling your produce?

(a) Kongos (b) Baskets (c) Bags

(23) How do you transport your pepper to the market?

(a) Hired vehicle (b) Own vehicle (c) Others specify

(24) How much do you spent on transporting your pepper from place of supply to the market?

(25) What type of labour are you using? (a) Hired labour (b) Family labour (c) Others specify

(26) If hired labour, how much do you spent on labourers annually?____________

(27) What is your source of capital for financing your business?

(a) Cooperative society ( ) (b) Bank loan ( ) (e) Personal savings ( ) (d) Money lenders ( ) (e) Other specify ( )

(28) What are the problems confronting you as the pepper marketer?__________

(29) What do you think are the likely solution to the mentioned problems_________

(30) What quantity of the following types of produce do you buy in a week?

i. Fresh undamaged ______________

ii. Fresh damaged ________________

iii. Processed (Dried) ______________

APPENDIX 3

SEASONAL PRICE PATTERN OF PEPPER (₦/kg) IN ONDO STATE

Urban/Rural market retail prices (₦) (2004-2009)

	2004		2005		2006		2007		2008		2009	
	Urban	**Rural**	**Urban**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Rural**	**Urban**	**Rural**
Jan.	86.33	85.55	89.50	134.13	132.72	126.00	132.50	126.00	132.50	96.50	125.75	89.90
Feb.	84.00	94.00	89.90	133.60	137.98	162.50	165.75	162.50	165.75	106.20	127.50	106.20
Mar.	87.50	102.00	113.30	191.20	193.95	114.50	104.15	114.50	104.15	119.58	113.30	117.58
April.	94.00	96.00	86.00	188.50	183.50	88.35	85.85	154.80	158.33	101.50	109.50	116.50
May	85.50	95.75	166.12	104.20	104.20	103.50	107.25	245.43	246.68	172.46	92.50	105.70
June	84.25	104.50	104.50	132.00	140.80	91.65	100.00	240.50	267.50	112.00	104.50	112.00
July	85.15	83.50	92.50	111.38	113.05	100.75	110.05	231.50	224.20	105.70	151.25	161.00
August	90.45	99.55	107.01	121.00	122.30	110.85	120.42	314.03	291.25	111.92	188.00	197.00
Sep.	92.40	98.98	109.01	116.10	150.00	147.92	151.43	420.41	421.25	111.92	128.73	138.07
Oct.	93.00	95.00	118.96	145.20	148.70	149.75	149.25	244.09	249.59	128.04	137.53	178.53
Nov.	90.45	99.55	133.25	119.46	124.58	125.25	135.25	215.75	236.25	146.25	94.50	101.40
Dec.	94.00	101.75	126.60	187.88	192.88	157.25	155.13	299.00	313.10	125.50	129.17	143.17
Average	**88.92**	**96.09**	**111.45**	**140.39**	**145.39**	**123.19**	**126.42**	**225.37**	**226.12**	**120.11**	**122.05**	**133.94**

APPENDIX 4

SEASONAL PRICE PATTERN OF PEPPER (₦/kg) IN OYO STATE

Urban/Rural market retail prices (₦) (2004-2009)

	2004		2005		2006		2007		2008		2009	
	Urban	Rural	Urban	Urban	Rural	Urban	Rural	Urban	Rural	Rural	Urban	Rural
Jan.	91.70	85.70	108.01	152.08	450.00	82.09	92.85	126.00	132.50	113.39	533.62	609.23
Feb.	90.86	86.98	109.33	105.36	96.84	111.77	99.24	162.50	165.75	110.16	564.14	577.41
Mar.	95.70	87.40	123.39	96.13	98.59	121.75	105.93	114.50	104.15	131.82	710.00	603.93
April.	99.00	91.77	165.25	113.94	101.79	118.12	130.52	154.80	158.33	112.54	599.34	564.56
May	86.79	98.09	190.73	169.84	109.59	116.85	114.86	245.43	246.68	169.26	547.28	510.91
June	93.86	101.90	126.60	194.74	151.52	141.61	159.96	240.50	267.50	131.88	338.19	380.42
July	79.08	90.90	95.79	108.45	123.70	97.64	103.27	231.50	224.20	96.61	452.65	536.03
August	74.51	74.15	89.60	100.01	111.70	109.40	100.84	214.03	291.25	102.95	321.58	325.81
Sep.	76.65	77.28	97.50	25.00	-	109.54	94.50	240.41	221.24	109.36	321.58	325.81
Oct.	74.00	75.40	111.26	98.60	109.74	77.22	84.23	244.09	249.59	134.80	525.34	556.06
Nov.	74.48	89.65	110.39	78.27	87.73	97.00	90.28	215.75	236.25	113.71	525.34	556.14
Dec.	93.39	99.84	162.12	124.002	101.205	130.19	108.38	298.00	295.10	164.33	523.45	556.14
Average	**85.83**	**88.25**	**124.23**	**113.87**	**140.22**	**109.43**	**107.07**	**225.36**	**226.12**	**124.77**	**460.39**	**506.82**

APPENDIX 5

ANOVA SHOWING EFFECT OF MATURITY STAGE, HARVESTING METHOD AND STORAGE ON WEIGHT LOSS OF PEPPER FRUIT

3 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.38646944	0.38646944	6.21	0.0200
Ripeness at harvest	1	23.73313611	23.73313611	381.09	<.0001
Storage methods	2	1.57820556	0.78910278	12.67	0.0002
Ripeness at harvest + Harvesting methods	1	0.00513611	0.00513611	0.08	0.7764
Storage method + Harvesting methods	2	1.63803889	0.81901944	13.15	0.0001
Storage + Ripeness at harvest	2	3.46650556	1.73325278	27.83	<.0001
Storage + Ripeness at harvest + Harvest	2	0.07867222	0.03933611	0.63	0.5403
Treatment total	11	30.88616389	2.80783308	45.09	<.0001
Error	24	1.49466667	0.06227778		
Corrected Total	35	32.38083056			

9 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	1.82700278	1.82700278	45.98	<.0001
Ripeness at harvest	1	10.66022500	10.66022500	268.26	<.0001
Storage methods	2	0.67307222	0.33653611	8.47	0.0016
Ripeness at harvest + Harvesting methods	1	0.18062500	0.18062500	4.55	0.0434
Storage method + Harvesting methods	2	0.15787222	0.07893611	1.99	0.1591
Storage + Ripeness at harvest	2	0.10061667	0.05030833	1.27	0.3001
Storage + Ripeness at harvest + Harvest	2	0.14321667	0.07160833	1.80	0.1866
Treatment total	11	13.74263056	1.24933005	31.44	<.0001
Error	24	0.95373333	0.03973889		
Corrected Total	35	14.69636389			

15 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	12.1917361	12.1917361	319.76	<.0001
Ripeness at harvest	1	108.6111361	108.6111361	2848.61	<.0001
Storage methods	2	5.7090889	2.8545444	74.87	<.0001
Ripeness at harvest + Harvesting methods	1	0.6588028	0.6588028	17.28	0.4000
Storage method + Harvesting methods	2	0.2694222	0.1347111	3.53	0.0452
Storage + Ripeness at harvest	2	0.4176889	0.2088444	5.48	0.0110
Storage + Ripeness at harvest + Harvest	2	0.2642889	0.1321444	3.47	0.0476
Treatment total	11	128.1221639	11.6474694	305.49	<.0001
Error	24	0.9150667	0.0381278		
Corrected Total	35	129.0372306			

21 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	14.45266944	14.45266944	166.71	<.0001
Ripeness at harvest	1	75.95122500	75.95122500	876.11	<.0001
Storage methods	2	4.24590556	2.12295278	24.49	<.0001
Ripeness at harvest + Harvesting methods	1	0.73673611	0.73673611	8.50	0.7600
Storage method + Harvesting methods	2	0.87240556	0.43620278	5.03	0.0150
Storage + Ripeness at harvest	2	0.32165000	0.16082500	1.86	0.1782
Storage + Ripeness at harvest + Harvest	2	0.69643889	0.34821944	4.02	0.0313
Treatment total	11	97.27703056	8.84336641	102.01	<.0001
Error	24	2.08060000	0.08669167		
Corrected Total	35	99.35763056			

27 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	14.61787778	14.61787778	227.68	<.0001
Ripeness at harvest	1	44.22250000	44.22250000	688.79	<.0001
Storage methods	2	17.60821667	8.80410833	137.13	<.0001
Ripeness at harvest + Harvesting methods	1	0.00250000	0.00250000	0.04	0.8452
Storage method + Harvesting methods	2	0.81520556	0.40760278	6.35	0.0061
Storage + Ripeness at harvest	2	0.18311667	0.09155833	1.43	0.2599
Storage + Ripeness at harvest + Harvest	2	0.06201667	0.03100833	0.48	0.6228
Treatment total	11	77.51143333	7.04649394	109.75	<.0001
Error	24	1.54086667	0.06420278		
Corrected Total	35	79.05230000			

30 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	54.93280278	54.93280278	639.44	<.0001
Ripeness at harvest	1	12.19173611	12.19173611	141.92	<.0001
Storage methods	2	15.32895000	7.66447500	89.22	<.0001
Ripeness at harvest + Harvesting methods	1	19.14062500	19.14062500	222.80	<1.000
Storage method + Harvesting methods	2	45.17593889	22.58796944	262.93	<.0001
Storage + Ripeness at harvest	2	34.66287222	17.33143611	201.74	<.0001
Storage + Ripeness at harvest + Harvest	2	38.62095000	19.31047500	224.78	<.0001
Treatment total	11	220.0538750	20.0048977	232.86	<.0001
Error	24	2.0618000	0.0859083		
Corrected Total	35	222.1156750			

APPENDIX 6

ANOVA SHOWING THE EFFECT OF RIPENESS AT HARVEST, HARVESTING METHOD AND STORAGE ON FIRMNESS OF PEPPER FRUIT

3 Days in Storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.00002500	0.00002500	0.02	0.8929
Ripeness at harvest	1	0.00780278	0.00780278	5.78	0.0243
Storage methods	2	0.93431667	0.46715833	346.04	<.0001
Ripeness at harvest + Harvesting methods	1	0.00033611	0.00033611	0.25	0.6223
Storage method + Harvesting methods	2	0.00635000	0.00317500	2.35	0.1168
Storage + Ripeness at harvest	2	0.00843889	0.00421944	3.13	0.0622
Storage + Ripeness at harvest + Harvest	2	0.00320556	0.00160278	1.19	0.3223
Treatment total	11	0.96047500	0.08731591	64.68	<.0001
Error	24	0.03240000	0.00135000		
Corrected Total	35	0.99287500			

9 Days in Storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.39271111	0.39271111	321.31	<.0001
Ripeness at harvest	1	0.60321111	0.60321111	493.54	<.0001
Storage methods	2	2.01983889	1.00991944	826.30	<.0001
Ripeness at harvest + Harvesting methods	1	0.08604444	0.08604444	70.40	<.1.000
Storage method + Harvesting methods	2	0.24603889	0.12301944	100.65	<.0001
Storage + Ripeness at harvest	2	0.12487222	0.06243611	51.08	<.0001
Storage + Ripeness at harvest + Harvest	2	0.24553889	0.12276944	100.45	<.0001
Treatment total	11	3.71825556	0.33802323	276.56	<.0001
Error	24	0.02933333	0.00122222		
Corrected Total	35	3.74758889			

15 Day in Storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.10671111	0.10671111	92.79	<.0001
Ripeness at harvest	1	1.41610000	1.41610000	1231.39	<.0001
Storage methods	2	5.55467222	2.77733611	2415.07	<.0001
Ripeness at harvest + Harvesting methods	1	0.00017778	0.00017778	0.15	0.6977
Storage method + Harvesting methods	2	0.01187222	0.00593611	5.16	0.0137
Storage + Ripeness at harvest	2	0.01291667	0.00645833	5.62	0.0100
Storage + Ripeness at harvest + Harvest	2	0.01007222	0.00503611	4.38	0.0239
Treatment total	11	7.11252222	0.64659293	562.25	<.0001
Error	24	0.02760000	0.00115000		
Corrected Total	35	7.14012222			

21 Days in Storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.08027778	0.08027778	41.29	<.0001
Ripeness at harvest	1	1.42404444	1.42404444	732.37	<.0001
Storage methods	2	5.24686667	2.62343333	1349.19	<.0001
Ripeness at harvest + Harvesting methods	1	0.00001111	0.00001111	0.01	0.9404
Storage method + Harvesting methods	2	0.01502222	0.00751111	3.86	0.0351
Storage + Ripeness at harvest	2	0.01308889	0.00654444	3.37	0.0515
Storage + Ripeness at harvest + Harvest	2	0.00962222	0.00481111	2.47	0.1054
Treatment total	11	6.78893333	0.61717576	317.40	<.0001
Error	24	0.04666667	0.00194444		
Corrected Total	35	6.83560000			

27 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.12250000	0.12250000	66.42	<.0001
Ripeness at harvest	1	1.96000000	1.96000000	1062.65	<.0001
Storage methods	2	8.12031667	4.06015833	2201.29	<.0001
Ripeness at harvest + Harvesting methods	1	0.00000000	0.00000000	0.00	1.0000
Storage method + Harvesting methods	2	0.00671667	0.00335833	1.82	0.1836
Storage + Ripeness at harvest	2	0.02015000	0.01007500	5.46	0.0111
Storage + Ripeness at harvest + Harvest	2	0.01235000	0.00617500	3.35	0.0522
Treatment total	11	10.24203333	0.93109394	504.81	<.0001
Error	24	0.04426667	0.00184444		
Corrected Total	35	10.28630000			

30 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Harvesting method	1	0.27040000	0.27040000	91.66	<.0001
Ripeness at harvest	1	1.45604444	1.45604444	493.57	<.0001
Storage methods	2	12.88801667	6.44400833	2184.41	<.0001
Ripeness at harvest + Harvesting methods	1	0.00284444	0.00284444	0.96	0.3359
Storage method + Harvesting methods	2	0.01361667	0.00680833	2.31	0.1211
Storage + Ripeness at harvest	2	0.02570556	0.01285278	4.36	0.0243
Storage + Ripeness at harvest + Harvest	2	0.00597222	0.00298611	1.01	0.3784
Treatment total	11	14.66260000	1.33296364	451.85	<.0001
Error	24	0.07080000	0.00295000		
Corrected Total	35	14.73340000			

APPENDIX 7

ANOVA SHOWING THE EFFECTS OF RIPENESS AT HARVEST, HARVESTING METHODS AND STORAGE ON DECAY LEVEL OF PEPPER FRUITS

3 Days in storage

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Harvesting methods	1	0.60840000	0.60840000	127.86	<0.0001
Ripeness at harvest	1	2.03537778	2.03537778	427.75	<0.0001
Storage methods	2	2.53265000	1.26632500	266.13	<0.0001
Ripeness at harvest + harvesting methods	1	0.02454444	0.02454444	5.16	0.5324
Storage + harvesting methods	2	0.02881667	0.01440833	3.03	0.0672
Storage + Ripeness at harvest	2	0.11327222	0.05663611	11.90	0.0003
Storage + Ripeness at harvest + harvesting methods	2	0.02703889	0.01351944	2.84	0.0781
Treatment total	11	5.37010000	0.48819091	102.60	<0.0001
Error	24	0.11420000	0.00475833		
Corrected Total	35	5.48430000			

9 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Harvesting Methods	1	0.95062500	0.95062500	196.57	<0.0001
Ripeness at harvest	1	2.92980278	2.92980278	605.82	<0.0001
Storage Methods	2	6.87882222	3.43941111	711.19	<0.0001
Ripeness at harvest + Harvesting Methods	1	0.11446944	0.11446944	23.67	<1.000
Storage + Harvesting Methods	2	0.25046667	0.12523333	25.90	<.0001
Storage + Ripeness at harvest	2	0.11508889	0.05754444	11.90	0.0003
Storage + Ripeness at harvest + Harvesting Methods	2	0.03335556	0.01667778	3.45	0.0483
Treatment Total	11	11.27263056	1.02478460	211.90	<0.0001
Error	24	0.11606667	0.00483611		
Corrected Total	35	11.38869722			

15 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Harvesting methods	1	1.05746944	1.05746944	52.56	<0.0001
Ripeness at harvest	1	1.80006944	1.80006944	89.47	<0.0001
Storage methods	2	5.27801667	2.63900833	131.17	<0.0001
Ripeness at harvest + harvesting methods	1	0.13080278	0.13080278	6.50	0.5176
Storage + harvesting methods	2	0.03270556	0.01635278	0.81	0.4555
Storage + Ripeness at harvest	2	0.25203889	0.12601944	6.26	0.0065
Storage + Ripeness at harvest + harvesting methods	2	0.32670556	0.16335278	8.12	0.0020
Treatment Total	11	8.87780833	0.80707348	40.11	<0.0001
Error	24	0.48286667	0.02011944		
Corrected Total	35	9.36067500			

21 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Harvesting Methods	1	0.63733611	0.63733611	91.23	<0.0001
Ripeness at harvest	1	4.68722500	4.68722500	670.93	<0.0001
Storage Methods	2	7.26705000	3.63352500	520.11	<0.0001
Ripeness at harvest + Harvesting Methods	1	0.00966944	0.00966944	1.38	0.5509
Storage + Harvesting Methods	2	0.00917222	0.00458611	0.66	0.5277
Storage + Ripeness at harvest	2	0.57411667	0.28705833	41.09	<0.0001
Storage + Ripeness at harvest + Harvesting Methods	2	0.02703889	0.01351944	1.94	0.1663
Treatment Total	11	13.21160833	1.20105530	171.92	<.0001
Error	24	0.16766667	0.00698611		
Corrected Total	35	13.37927500			

27 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Harvesting Methods	1	0.46013611	0.46013611	92.34	<0.0001
Ripeness at harvest	1	4.55822500	4.55822500	914.69	<0.0001
Storage Methods	2	7.56513889	3.78256944	759.04	<0.0001
Ripeness at harvest + Harvesting Methods	1	0.07200278	0.07200278	14.45	0.6709
Storage + Harvesting Methods	2	0.03483889	0.01741944	3.50	0.0465
Storage + Ripeness at harvest	2	0.04501667	0.02250833	4.52	0.0216
Storage + Ripeness at harvest + Harvesting Methods	2	0.00767222	0.00383611	0.77	0.4742
Treatment Total	11	12.74303056	1.15845732	232.47	<.0001
Error	24	0.11960000	0.00498333		
Corrected Total	35	12.86263056			

30 Days in storage

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Harvesting Methods	1	0.33446944	0.33446944	66.09	<0.0001
Ripeness at harvest	1	2.73902500	2.73902500	541.19	<0.0001
Storage	2	13.26910556	6.63455278	1310.89	<0.0001
Ripeness at harvest + Harvesting Methods	1	0.05840278	0.05840278	11.54	0.5400
Storage + Harvesting Methods	2	0.05557222	0.02778611	5.49	0.0109
Storage + Ripeness at harvest	2	0.16071667	0.08035833	15.88	<0.0001
Storage + Ripeness at harvest + Harvesting Methods	2	0.04273889	0.02136944	4.22	0.0268
Treatment Total	11	16.66003056	1.51454823	299.25	<0.0001
Error	24	0.12146667	0.00506111		
Corrected Total	35	16.78149722			

APPENDIX 8

ANOVA SHOWING THE EFFECT OF PACKAGING METHOD ON WEIGHT LOSS OF PEPPER FRUIT

3 Days in Storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	28.75606667	9.58535556	926.62	<0.0001
Storage condition	2	88.83668889	44.41834444	4293.93	<0.0001
Storage + Packaging	6	5.49400000	0.91566667	88.52	<0.0001
Treatment total	11	123.0867556	11.1897051	1081.71	<0.0001
Error	24	0.2482667	0.0103444		
Corrected Total	35	123.3350222			

9 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	135.0263639	45.0087880	1706.31	<.0001
Storage condition	2	126.1309389	63.0654694	2390.86	1
Storage + Packaging	6	7.9165944	1.3194324	50.02	<.0001
Treatment total	11	269.0738972	24.4612634	927.34	<.0001
Error	24	0.6330667	0.0263778		
Corrected Total	35	269.7069639			

15 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	411.9894306	137.3298102	1798.75	<.0001
Storage condition	2	491.8140500	245.9070250	3220.90	<.0001
Storage + Packaging	6	59.8430611	9.9738435	130.64	<.0001
Treatment total	11	963.6465417	87.6042311	1147.44	<.0001
Error	24	1.8323333	0.0763472		
Corrected Total	35	965.4788750			

21 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	408.9111333	136.3037111	1687.22	<.0001
Storage condition	2	826.7552167	413.3776083	5116.94	<.0001
Storage + Packaging	6	71.6225833	11.9370972	147.76	<.0001
Treatment total	11	1307.288933	118.844448	1471.10	<.0001
Error	24	1.938867	0.080786		
Corrected Total	35	1309.227800			

27 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	564.0480306	188.0160102	2301.85	<.0001
Storage condition	2	911.8552389	455.9276194	5581.84	<.0001
Storage + Packaging	6	69.7648278	11.6274713	142.35	<.0001
Treatment total	11	1545.668097	140.515282	1720.30	<.0001
Error	24	1.960333	0.081681		
Corrected Total	35	1547.628431			

30 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	800.2889222	266.7629741	3690.23	<.0001
Storage condition	2	904.7794667	452.3897333	6258.08	<.0001
Storage + Packaging	6	125.8881778	20.9813630	290.24	<.0001
Treatment total	11	1830.956567	166.450597	2302.58	<.0001
Error	24	1.734933	0.072289		
Corrected Total	35	1832.691500			

APPENDIX 9

ANOVA SHOWING EFFECT OF PACKAGING METHOD ON FIRMNESS OF PEPPER FRUIT

9 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	1.75520833	0.58506944	8425.00	<.0001
Storage condition	2	1.82097222	0.91048611	13111.00	<.0001
Storage + Packaging	6	0.32291667	0.05381944	775.00	<.0001
Treatment total	11	3.89909722	0.35446338	5104.27	<.0001
Error	24	0.00166667	0.00006944		
Corrected Total	35	3.90076389			

15 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	2.33333333	0.77777778	2800.00	<.0001
Storage condition	2	2.49555556	1.24777778	4492.00	<.0001
Storage + Packaging	6	0.0866666	0.01444444	52.00	<.0001
Treatment total	11	4.91555556	0.44686869	1608.73	<.0001
Error	24	0.00666667	0.00027778		
Corrected Total	35	4.92222222			

21 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	1.70527778	0.56842593	1023.17	<.0001
Storage condition	2	1.64055556	0.82027778	1476.50	<.0001
Storage + Packaging	6	0.55055556	0.09175926	165.17	<.0001
Treatment total	11	3.89638889	0.35421717	637.59	<.0001
Error	24	0.01333333	0.00055556		
Corrected Total	35	3.90972222			

27 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	2.84750000	0.94916667	379.67	<.0001
Storage condition	2	1.20500000	0.60250000	241.00	<.0001
Storage + Packaging	6	1.13500000	0.18916667	75.67	<.0001
Treatment total	11	5.18750000	0.47159091	188.64	<.0001
Error	24	0.06000000	0.00250000		
Corrected Total	35	5.24750000			

30 Days in storage

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Packaging Method	3	1.57666667	0.52555556	270.29	<.0001
Storage condition	2	3.20888889	1.60444444	825.14	<.0001
Storage + Packaging	6	2.21333333	0.36888889	189.71	<.0001
Treatment total	11	6.99888889	0.63626263	327.22	<.0001
Error	24	0.04666667	0.00194444		
Corrected Total	35	7.04555556			