EFFECT OF MODIFIED ATMOSPHERE PACKAGING AND STORAGE TEMPERATURE ON THE QUALITY OF GREEN CHILLI PEPPER FRUITS

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL CROP SCIENCE DEGREE

DECEMBER, 2011

DECLARATION

This is to declare that this thesis is the result of research undertaken by EDUSEI, VIDA OPOKU towards the award of Master of Philosophy degree in the Department of Crop Science, University of Ghana.

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ACKNOWLEDGEMENTS

I thank the Almighty God for the successful completion of this work. For kind permission and supervision of this work, I wish to express my deep appreciation and gratitude to Prof. J. Ofosu-Anim and Dr. P-N.T Johnson. I would like to thank Dr. B. K. Dadzie for his guidance and advice. In the same manner, I would also like to appreciate the assistance received from Mr. E.W. Cornelius for his valuable input and provision of personal instruments. I would particularly like to acknowledge the help received from Eden Tree Ltd, Mr. Singh of Polyproducts Ghana Ltd. for complimentary samples of polypropylene films, Trostky Farms as well as Mr. Emmanuel Darkey of E Darkey & Associates Ltd. for providing fresh chilli pepper fruits and Prof. F. K. Kumaga who was also instrumental in obtaining fruits. I also wish to acknowledge the immense assistance offered by Mr. Apollonius Nyarko and Mr. Benjamin Otu in the laboratory work. I am extremely grateful to Dr. M.K. Edusei for his encouragement and steadfast support. Finally, I wish to acknowledge and thank the staff at the Crop Science Department, all my colleagues particularly the Postharvest Students for their enthusiasm to share knowledge and ideas.

DEDICATION

To the Glory of Almighty God and to my late mother,

Madam Comfort Opoku

ABSTRACT

The influence of modified atmosphere packaging (MAP) and storage temperature on the postharvest quality characteristics and biochemical properties of green chilli peppers (*Capsicum* sps. cvs *Legon 18* and KA2) was investigated. Packaging films; Low Density Polyethylene (LDPE) 35µm non-perforated and perforated, Polypropylene(PP) 80µm non-perforated and perforated (twenty perforations were made on each perforated bag using a pin of diameter 0.14 mm) and LDPE micro-perforated 31.75µm were tested at three storage temperatures of 4.3C°, 10°C and 26-34°C (ambient). Fruits were stored for four weeks at low temperatures (4.3°C and 10°C) in a 2 x 5 factorial treatment combinations in completely randomized design with three replications and nine days in ambient temperature (26-34°C) in completely randomized design with three replications. Data on weight loss, firmness, fruit green colour retention and incidences of chilling injury and decay were collected and subjected to statistical analysis. Biochemical analysis of the MAP-stored fruits for changes in titratable acidity, soluble solids, ascorbic acid, total carotenoids and total phenolic contents were also assessed quantitatively before and after storage. Packaging (MAP) resulted in reduced weight loss at all the temperatures (4.3°C, 10°C and 26-34°C) compared to unpackaged pepper fruits stored at the respective temperatures. Fruit weight loss was significantly lower in the film-packed fruits stored at10°C than at 4.3°C. Firmness was fairly maintained in the film-packed fruits at all the storage temperatures than unpacked fruits. Green colour retention of the fruits was significantly higher in packaged fruits held at 4.3°C and 10°C than the control. Chilli peppers stored in the packaging films at 10°C, showed significantly lower chilling injuries compared to those at 4.3°C storage temperature with *KA2* fruits being less susceptible than *Legon 18*. Packaged fruits did not present fruit decay at low

temperature storage (4.3°C and 10°C), however, the combination of film packaging and storage under ambient temperature (26-34°C) had significantly high incidence of fruit decay particularly in the *Legon 18* fruits. Changes in biochemical components were observed in chilli peppers after MAP storage at both low and ambient storage temperatures. This study showed that postharvest treatments involving a combination of MAP and optimum storage temperature (10°C) is beneficial in maintaining the quality and in effect extending the marketable/shelf-life of fresh green chilli pepper fruits.

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CHAPTER ONE

INTRODUCTION

Chilli pepper (*Capsicum* sp*)* is a popular vegetable valued around the world for its colour, flavour, spice and nutritional value (Berke *et al*., 2004). Chilli pepper is also used often in nearly all everyday dishes of Ghanaian cuisine. It is rich in vitamin C and pro-vitamin A (Marin *et al*., 2004). The rich supply of carotenoids contributes to chilli pepper's nutritional value because they serve as pro-vitamin A which after digestion is converted into vitamin A (retinol) and gives the characteristic bright red colour to the ripe fruits (Hornero-Méndezet *et al*., 2002). Chilli peppers are also used medicinally as anti-inflammatory agents, and provide the ingredient for a non-lethal deterrent or repellent to some human and animal behaviour (Krishna, 2003).

The estimated annual demand for vegetables in Ghana is €66.2 million and the demand for chilli pepper is €2.5 million (Ghanaian Living Standard Survey IV, 2000; in Opportunities Industrialization Center (OIC) Ghana, 2004). According to the same study, chilli pepper on the average accounts for about 9.6% of total food expenditure countrywide and consumption is expected to rise even higher due to increasing population and income levels. The production volume of chilli peppers in Ghana increased slightly from 270,000 metric tonnes in year 2000 to 277,000 in 2006 and 279,000 metric tonnes in 2008 (FAOSTAT, 2009). The crop is also gaining importance as a horticultural export commodity in the country. Ghana exported 418 tonnes (€732,980) of chilli peppers in 2001 and 2,947 tonnes (about €5.835 million) in 2007 to the European Union market (Jaeger, 2008).

With the increasing demand of fresh fruits and vegetables, postharvest technology for extending the shelf-life of these perishable commodities has gained significant importance in recent years (Shewfelt and Prussia, 2009). Farmers, exporters, wholesalers, retailers and even consumers have to grapple with quantitative and qualitative postharvest losses during storage which can lead to huge economic losses. Within the handling system, fruits and vegetables can or may have to be placed in storage from a few hours up to several months, depending on the commodity and storage conditions (Shewfelt and Prussia, 2009). Storage of a commodity serves as a means to extend the season, to delay marketing until prices rise, to reduce the frequency of purchase by the consumer or food service establishment and for any unforeseeable circumstances such as delays in export of the produce (Shewfelt and Prussia, 2009). In all these situations, the commodity must have sufficient shelf-life to remain acceptable to the consumer.

Chilli is a highly perishable vegetable with high rates of water loss and decay. The fruit dehydrates, begin to turn colour and deteriorate within a few days after harvest in ambient conditions (Wall and Berghage, 2007). The deterioration leads to huge economic losses for farmers, exporters, wholesalers, retailers and consumers. These limiting factors in the postharvest handling of chilli pepper may be minimized using appropriate storage techniques. After harvest, the commodity is still living as it continues to perform metabolic reactions in order to maintain its physiological system and these cause a reduction of its quality and shelf-life. In order to extend the shelf-life of the commodity, it is necessary to retard certain deteriorative processes. One such method to extend the shelf-life of fresh vegetables is the use of modified atmosphere packaging (MAP)

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Among different techniques, MAP has been reported to be a cost effective and successful technique for extending postharvest longevity of several fresh horticultural produce (Thompson, 1996; Banaras *et al.*, 2002; Zagham, 2003). The packaged produce had also better market acceptability (Gibe, 1999). MAP significantly extended longevity of mid-season field harvested pepper fruits (Lownds and Bosland, 1988). It has also been used to extend the shelf-life of fruits and vegetables, and is considered to be an effective method in preventing microbial and insect contamination (Cliffe-Byrnes and O'Beirne, 2005; Muratore *et al.*, 2005). Thus, the shelf-life of fruits as well as vegetables such as chilli pepper can be extended using MAP. However, the research, promotion and application of MAP in horticultural produce, such as chilli pepper in Ghana are not extensive and information on the use of MAP storage of perishables that can help reduce postharvest losses is also limited.

The main objective of this study was to evaluate the effect of Modified Atmosphere Packaging (MAP) and storage temperature on the quality of fresh green chilli pepper varieties (*Legon 18* and *KA2*).

The specific objectives were to determine the:

1. effectiveness of non-perforated Low Density Polyethylene (LDPE), perforated Low Density Polyethylene (LDPE), non-perforated Polypropylene (PP) and perforated Polypropylene (PP) films as modified atmosphere packaging materials in combination with low temperature in maintaining the quality of fresh green chilli pepper (*Legon 18*).
2. effectiveness of using non-perforated Low Density Polyethylene (LDPE), non-perforated Polypropylene (PP) and micro-perforated LDPE films as modified atmosphere packaging materials in combination with low temperature in maintaining the quality of fresh green chilli pepper fruits (*KA2*).
3. effect of using non-perforated LDPE, perforated LDPE, non-perforated PP, perforated PP and micro-perforated LDPE films as modified atmosphere packaging materials on the quality of fresh green chilli pepper fruits (*Legon 18* and *KA2*) stored under ambient temperature conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Chilli Pepper

Chilli pepper (*Capsicum* sp.), is valued around the world for its colour, flavour, spice and nutritional value (Berke *et al.*, 2004). It is rich in vitamin C (Marin *et al.*, 2004) and provitamin A. It is a good source of most B vitamins, particularly vitamin B6, and also high in potassium, magnesium and iron (Acedo, 2006). Some nutritional facts in cayenne peppers have been presented in Table 2.1. The two chemical groups of greatest interest in chilli are the capsaicinoids and the carotenoids. The capsaicinoids are alkaloids that give hot chilli peppers their characteristic pungency or hot fiery taste. The rich supply of carotenoids contributes to chilli peppers nutritional value because they serve as provitamin A, which after digestion is converted into vitamin A (retinol) and gives the characteristic bright red colour to the dried fruits (Hornero-Méndez *et al.*, 2002). It also has medicinal value as an anti-inflammatory agent and in addition has recently been used in the manufacture of weapons for defence and crowd control (Lindner, 2010).

Chilli peppers are widely produced in Ghana for local consumption and have increasingly been exported to the European market in recent years. The production volume of chilli peppers in Ghana increased slightly from 270,000 metric tonnes in year 2000 to 277,000 in year 2006 and then to 279,000 metric tonnes in year 2008 (FAOSTAT, 2009). Ghana is one of the largest exporters of chilli peppers to the European Union, where the demand for chilli peppers has been growing annually by 17 percent on average since year 2000

(MiDA, 2008). Ghana exported 418 tonnes (€732,980) of chilli peppers in 2001 and 2,947 tonnes (about €5.835 million) in 2007 to the European Union market (Jaeger, 2008).

Table 2.1 Chilli Pepper Nutritional Facts

Principle	Nutrient Value	Principle	Nutrient Value
Energy	318 Kcal	***Electrolytes***	
Carbohydrates	56.63 g	Sodium	30 mg
Protein	12.01 g	Potassium	2014 mg
Total Fat	17.27 g	***Minerals***	
Cholesterol	0 mg	Calcium	148 mg
Dietary Fiber	27.2 g	Copper	0.373 mg
		Iron	7.80 mg
Vitamins		Magnesium	152 mg
Folates	106 mcg	Manganese	2.00 mg
Niacin	8.701 mg	Phosphorus	293 mg
Pyridoxine	2.450 mg	Selenium	8.8 mcg
Riboflavin	0.919	Zinc	2.48 mg
Thiamin	0.328 mg	***Phyto-nutrients***	
Vitamin A	41610 IU	Carotene-ß	21840 mcg
Vitamin C	76.4	Carotene-α	0 mcg
Vitamin E	29.83 mg	Cryptoxanthin-ß	6252 mcg
Vitamin K	80.3 mg	Lutein-zeaxanthin	13157 mcg

Cayenne peppers (*Capsicum annuum* var *annuum*), red, raw, Nutrition value per 100 g (Source: USDA National Nutrient data base)

2.2 Chilli Pepper Production in Ghana

Chilli peppers (*Capsicum* sp) have always been part of Ghana's agricultural produce and forms a major part of the diet of its citizens. They require sunny or tropical conditions and annual rainfall of between 600mm and 1,250mm. Chilli peppers have a relatively quick growing and harvesting period of 3 to 4 months in Ghana and are generally grown by local farmers during the rainy season (MiDA, 2008). Areas of production for the local market include Brong Ahafo, Ashanti, Eastern, Central, Greater Accra and Volta regions while production areas for the international market are located exclusively in the southern regions of Ghana, namely in the Eastern, Central, Greater Accra and Volta regions.

Rainfall has a bimodal distribution pattern in southern Ghana resulting in major and minor seasons. The major rainy season is from March – July and the minor rainy season from mid August–October. November--February is the dry season during which production of chilli pepper is done under irrigation. Yields are therefore low resulting in high prices locally (MiDA, 2008). This period also coincides with the winter months in Europe during which chilli pepper has the highest price.

2.2.1 Varieties

Peppers have grown in popularity in recent years and wide varieties are now available. Native to the Americas, most varieties belong to the *Capsicum annuum* species (Harris, 1998). Almost all peppers turn from green to yellow, orange, red, or purple when they are fully ripe. Mature green peppers are often harvested before they are ripe when they usually withstand handling better and tend to last longer. Varieties commonly grown in Ghana include *Legon 18*, *Bird's eye* (MiDA, 2008), *Kpakpo shito*, *Scotch bonnet* and *KA2.*

2.2.2 Harvest Maturity Indices and Harvesting of Chilli Pepper

Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during postharvest handling (Florkowski *et al.*, 2009). Maturity of a crop is an assessment of physiological development. Physiological maturity is described as the stage of development when a plant or plant part will continue ontogeny even if detached, whereas commercial maturity is defined as the stage of development when the plant or plant part possesses the prerequisite for utilization by consumers for a particular purpose (Wadata *et al*., 1984). Maturity of a crop at harvest directly affects the colour and size and thus its grade. Usually the first peppers are ready for harvest about 2 months after transplanting, depending on the cultivar and season of the year (Acedo, 2006). Several different indices are commonly used in determining harvest maturity. Size of the fruit is the most widely used index of maturity. The fruit should be fully developed and at full size for the particular cultivar, with a firm thick wall and waxy (shiny) skin. The calyx and stem should be fresh and green. External colour is another widely used index of harvest maturity. Chilli is generally harvested when ripe, but it also can be harvested at a green, mature or immature stage (Berke *et al*., 2004). Specific colour demanded in the market will dictate when to harvest the fruit. Chili peppers are usually pale green when immature and turn deep green with maturity and red when ripe. Chilli peppers for processing are usually harvested when red. For the fresh market, particularly for export, they are usually harvested green because of better quality maintenance during shipping. However, some hot pepper cultivars can be marketed with a mixed skin colour, so harvest time depends on product usage and market destination (Ministry of Agriculture of Guyana, 2010).

Chilli is picked by hand. The fruit is harvested by removing it from the branch and ensuring that the stem remains intact and attached to the fruit. Care should be taken not to sever or damage the fruiting branches while attempting to remove the fruit. Pepper plants have brittle branches that may break during harvest. Most sweet bell pepper cultivars lack a defined abscission zone in the stem, while pungent cultivars do possess a clearly defined abscission layer, allowing for a cleaner separation of the fruit from the mother plant (Ministry of Agriculture of Guyana, 2010). Peppers are typically harvested once per week. They are picked in the cool hours of the day and placed directly into a field basket, plastic container, a field crate or directly into paper cartons for export. Peppers are not to be harvested when wet because surface moisture increases decay. Fruit which have injuries that penetrate the skin are likely to rot and are eliminated during packaging (Ministry of Agriculture of Guyana, 2010).

2.3 Chilli Pepper Postharvest Operations

2.3.1 Cleaning

Chilli is cleaned in the field by gently rubbing the fruit with a clean cloth to remove debris and soil particles. If washing has to be employed, the wash water must be clean or sanitized with chlorine. After washing, the fruit must be dried properly before packaging to prevent decay (Acedo, 2006).

2.3.2 Sorting/Grading.

Good quality fruit should be of uniform shape, size and colour typical of the variety. Fruit with defects such as cracks, decay, mechanical damage and sunburn are sorted out and rejected. Undersized, shriveled, dull-looking, pitted or softening fruit should also be rejected (Acedo, 2006).

2.3.3 Packaging for the National and International Markets

A basic function of packaging in fresh produce is to protect and preserve the contents during transit from the farm to the ultimate consumer. It is the protection of food products during transport and distribution from climatic effects (heat, cold, moisture, vapour and drying atmospheres), contaminants and infestation (Rapusas and Rolle, 2009). Packaging should preserve the contents in 'Farm Fresh' condition during the period of storage and transportation, ensuring good quality and safety.

Different kinds of packaging containers are used for chilli in Ghana. Chilli peppers are packed in nylon sacks, cane baskets and wooden crates for the Ghanaian local market. At all traditional markets, fresh chilli is wholesaled in three different measures: a maxi bag, a mini bag or a bucket. A bucket weighs about 5.0 to 5.5kg and roughly 3.5 buckets fit in one mini bag. A maxi bag is twice as big as a mini bag and thus has a capacity of about seven buckets, weighing on average approximately 37kg (Schipmann, 2006). Large canvas or nylon sacks are not suitable for packaging because they are usually stuffed with too many fruits and provide little protection against mechanical pressure. The fruit may also heat up and deteriorate more rapidly due to restricted ventilation. For exports, chillies are generally harvested early in the morning and packed in 5kg shallow paper cartons ventilated with holes and transported to the Kotoka International Airport for overnight transportation. Chilli peppers from Ghana are on the shelf in Europe the day after harvest (MiDA, 2008).

2.4 Postharvest Losses in Chilli Pepper

Traditional packages and containers used for fresh produce in Ghana are large and much less protective. Wooden crates and nylon sacks are filled with 50kg to 60kg or more produce in weight, making them very difficult to fill, handle, lift, transport and stack without causing severe damage to the contents. Postharvest losses (physical losses) of peppers at the farm level in Ghana have been recorded to be 13% from decay and 14% from mechanical damage, while at the wholesale the losses are 15% and 7.5% from decay and mechanical damage respectively and 9% and 17.5% at the retail levels (World Food Logistics Organization Grant Final Report, 2010).

2.5 Impact of Postharvest Losses in Chilli Pepper

One of the sources of food insecurity in Africa is post-harvest crop loss. Pre- and post-harvest losses in Africa are higher than the global average and impact more severely on livelihoods, especially, the rural poor. Postharvest losses affect income growth, food security, poverty alleviation and sustainable agriculture particularly in developing countries. Postharvest losses during handling and storage result in food and income losses for farmers. In addition, postharvest losses decrease the amount of food available to people for consumption and food losses in itself retrogress sustainability. Reducing the loss of already produced food is more sustainable than increasing production to compensate for postharvest losses. Increasing production leads to more intensive farming or to an expansion of the area under cultivation, both of which may have negative effects on the environment especially when poor rural households tend to farm in fragile ecosystems or marginal land (Goletti and Wolff, 1999).

2.6 Postharvest Physiological Processes Affecting Quality of Chilli Pepper

Postharvest physiology is commonly defined as the study of living, respiring plant tissue that has been separated from the parent plant (Shewfelt, 1986). While the commodity is attached to the parent plant, it obtains all the energy it needs from the balance between utilization of carbon compounds (respiration) and acquisition (photosynthesis). However, once the commodity is harvested this balance is changed and the source of organic compounds comes from the reserves of the commodity, which are depleted by the respiration process causing a decrease in the quality of the commodity (Kays, 1991; Maguire *et al.,* 2004). Respiration and transpiration are important metabolic processes which occur before and after harvest. Postharvest improvements aim to slow down these physiological processes. A reduction in the rate of transpiration or respiration extends market life and maintains overall fruit quality.

2.6.1 Transpiration.

Fresh produce continues to lose water after harvest, but unlike the growing plant it can no longer replace lost water from the soil and so must use up its water content remaining at harvest. This loss of water from fresh produce after harvest is a serious problem, causing shrinkage and loss of weight. When the harvested produce loses 5% or 10% of its fresh weight, it begins to wilt and soon becomes unusable (Mahajan *et al*., 2008). To extend the usable life of produce, its rate of water loss must be as low as possible. Transpiration accounts for most of the mass loss in the majority of horticultural produce (Burton, 1982). Plants lose water by transpiration through the stomata. Transpiration is related to cooling and photosynthesis. As temperature increases, the rate of transpiration also increases. Fruits lose water through the peel. Different fruits lose water at different rates, because of varying peel thickness. An orange, for example, has a thick waxy peel which holds in water, whereas a grape has a very thin peel which increases water loss.

2.6.2 Respiration

After harvest, many physiological changes occur. The respiration rate can give an overall perspective of commodity metabolism (Kader and Salveit, 2003; Maguire *et al.*, 2004). Aerobic respiration is the central process in living cells that release energy through the utilization of organic compounds. This energy is trapped in the biological form of adenosine triphosphate (ATP), which is used to drive energy through catabolic and anabolic reactions inside the cell (Wills *et al.*, 1982; Kays, 1991). While the fruit is attached to the parent plant, its energy requirements are provided by the parent plant through the balance between utilization of carbon compounds (respiration) and acquisition (photosynthesis). Once the fruit is harvested this balance changes and the source of organic compounds for its energy comes from its own reserves. These reserves are depleted by the respiration process causing a decrease in the quality of the commodity (Kays, 1991; Maguire *et al.*, 2004). Respiration involves the uptake of oxygen, the release of carbon dioxide and the breakdown of stored reserves and provides energy for metabolism, growth and maturation. All cells respire, continuously oxidizing starch and sugars to produce carbon dioxide, water and energy. The respiration process under aerobic conditions involves a series of oxidation-reduction reactions, where glucose is the main metabolite used to maintain an adequate supply of ATP. However, other substrates like proteins and organic acids are used when glucose is exhausted (Wills *et al.*, 1982; Kays, 1991).

In the absence of oxygen, the commodities can initiate anaerobic respiration, where glycolysis is the only source of ATP production. Here, the pyruvate is decarboxylated to form lactic acid and acetaldehyde with the release of a molecule of CO_2. Subsequently, acetaldehyde form alcohol by the action of the enzyme alcohol dehydrogenase. The final equation can be written as follows:

$$C_6H_{12}O_6 + 2ATP + 2ADP + 2Pi \rightarrow 2CO_2 + 2Ethanol + 4ATP$$

(Wills *et al.*, 1982; Kader and Salveit, 2003).

Anaerobic respiration is detrimental to the quality of the commodity due to the fact that more glucose must be oxidized to maintain the requirements of the cell, resulting in the production of off-odours and off-flavours. The release of CO_2 and the consumption of O_2 in the respiration process makes it possible to measure the respiration rate as a function of one of these metabolites during maturation, ripening and senescent periods to obtain a respiratory pattern (Wills *et al.*, 1982).

Commodities can be divided into two respiratory patterns: climacteric and non-climacteric. Non-climacteric commodities show a steady decline in respiration after harvest, in contrast, climacteric commodities increase the respiration rate during ripening until a peak is attained after which there is a subsequent decline in respiration (Wills *et al.*, 1982; Kader and Salveit, 2003; Maguire *et al.*, 2004). Tomatoes, mangoes and chilli peppers, among others, present climacteric ripening. The respiration rate can be affected by several intrinsic and environmental factors. Church and Parsons (1995) indicated that the respiration rate depends on product type (fruit or vegetable), variety and stage of maturity. Environmental factors, such as temperature also influence the metabolic rate of

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2.7 Fresh Produce Quality

Quality of fruits and vegetables is a combination of attributes or properties that give them value in terms of food. Fresh produce quality is usually evaluated against grades and standards. Such grades and standards tend to be based on attributes that can be readily determined. Quality attribute can be divided into purchase quality and consumption quality (Florkowski *et al.*, 2009). Purchase quality is composed of those characteristics that are important to the consumer when deciding whether to buy a particular commodity and which item(s) to select. Purchase quality attributes may include colour, size, shape, absence of defects, firmness to touch and aroma. Consumption quality consists of those characteristics assessed by the consumer to determine how much that item is liked during eating. Consumption attributes include flavour (taste and aroma) and mouth feel. In addition to purchase and consumption quality there are other hidden (cannot be readily determined by visual inspection or consumption, but by sophisticated analysis) attributes such as wholesomeness, nutritional value and safety (Florkowski *et al.*, 2009). Perception of these hidden attributes plays an important role in the consumer purchase decision.

2.7.1 Quality attributes in fresh Chilli Pepper

Good quality chilli fruits should be of uniform shape, size, colour flavour and pungency typical of the variety. It should be firm and have a bright, glossy surface appearance free from bruises, blemishes and insect damage (Acedo, 2006).

The genus *Capsicum* (Family: Solanaceae) contains five commonly cultivated species (*C. annuum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L. and *C. pubescens* Ruiz & Pav.). Varieties of these *Capsicum* spp. exhibit varying degrees of pungency that reflect the relative concentrations of capsaicin [N-vanillyl-8-methyl-6-nonenamide], dihydrocapsaicin, and other analogs that are known collectively as capsaicinoids (Karjewska and Powers, 1988). Capsaicin is the most pungent member in this group. All capsaicinoids exhibit antioxidant activity and anti-mutagenic and anti-carcinogenic properties (Surh and Seoul, 2002). Capsaicin and dihydrocapsaicin typically account for an estimated 80-95% of the naturally occurring capsaicinoids in peppers (Bennett and Kirby, 1968).

Pungency is a key characteristic associated with chilli peppers and is also an important fruit quality attribute. Pungent chilli varieties are grown for their food value, health-promoting properties and also as a source of capsaicinoids that have a variety of medicinal uses (Sicuteri *et al.*, 1990). There is a growing interest in the enhancement of compounds in foods having health-promoting attributes such as capsaicinoids and their antioxidant properties. Pungency associated with many forms makes the fresh or dried fruit a desirable spice and a valuable international commodity (DeWitt and Bosland, 1996). In the early 1900s, Wilbur L. Scoville devised a test to determine the relative hotness of different peppers. Capsaicin from a known weight of pepper was extracted with alcohol and mixed to various concentrations with sweetened water. Human tasters were asked to determine the point at which the water neutralized the hotness. A rating (in Scoville units) was assigned based on the volume of water required to neutralize the hotness. In the early 1980s this technique was replaced by a high-pressure liquid chromatography test that measures the amount of capsaicin more accurately (Harris, 1998).

Depending on the level of ripeness, whether as immature (green) or mature (red) pepper fruits, their aromas are different due to differences in volatile compounds. Volatiles have been identified in fresh, homogenized, cooked and stir-fried bell peppers and the effects of ripening and tissue disruption on the composition of volatiles have been determined (Cremer and Eichner, 2000). There are common aroma compounds amongst the different species of the different fresh pepper, namely, 2,3-butanedione (caramel), 1-penten-3-one (pungent/spicy), hexanal (grassy, herbal), 3-carene (red bell pepper, rubbery), b-ocimen (rancid), octanal (fruity), trans-2-hexenal (sweet) and 2-isobutyl-3-methoxypyrazine (green bell pepper) (Mazidaa *et al.*, 2005). Keller *et al.* (1981) reported that volatiles of fresh red Jalapeno pepper extracts had a pleasant floral aroma (3-carene). Likewise, trans-2-hexenal and trans-2-hexenol, which have an almond, fruity and spicy odour, were found to increase during maturation.

2.8 Changes affecting the quality of fresh produce

Many compositional changes can occur during the ripening of vegetables that influence their appearance, texture and flavour. Some changes can be desirable, while others can be detrimental to the quality of the commodity (Kader, 1986; Maguire *et al.*, 2004). Appearance comprises external appeal of the commodity.

Colour is the most visible change that occurs during storage of many vegetables and it can serve as an indicator of ripeness and absence of disease or insect injury to the consumer (Wills *et al.*, 1982; Shewfelt, 1994; Maguire *et al.*, 2004) The green colour of fresh vegetables is due to chlorophylls, which are tetrapyrrole pigments in which the porphyrin ring is in the dihydro form and the central metal atom is magnesium. Shewfelt (2003) indicated that spinach, broccoli and green beans have a chlorophyll content of >200, 50-100 and 1-10 mg/g fresh weight, respectively. Yellowing and browning are the most common defects in appearance in commodities (Shewfelt, 1994). During advanced senescence, chlorophylls located in the chloroplast, are oxidized enzymatically unmasking the yellow xanthophylls that coexist with chlorophyll, causing appearance of yellowing (Abott, 2004). Gnanasekharan *et al.* (1992), indicated that tomato storage above 30°C developed yellowing due to disappearance of chlorophyll and the inhibition of lycopene synthesis caused by ethylene production. In addition, browning can occur by degradation of chlorophyll to brown pheophytin, or by mechanical damage that unites polyphenoloxidase and phenolic compounds to form brown pigment (Wills *et al.*, 1982). Yellowing and browning can be inhibited using low temperature storage, atmospheric modification, chemicals and careful handling (Shewfelt, 1994).

Another defect in appearance is the shriveling caused by the transpiration process, which is the evaporation of water on the produce surface by the heat of respiration (Wills *et al.*, 1982; Maguire *et al.*, 2004). Besides shriveling, transpiration can cause loss of colour and saleable weight (Maguire *et al.*, 2004). Moisture loss can also contribute to changes in texture. Bourne (1978) defined texture as the group of physical characteristics that result from the structural elements of the food, are sensed by sensation of touch in the hand or in the mouth, are related to the deformation, disintegration and flow of food under force, and is measured as a function of force, distance and time. The texture can be quantified by sensory evaluation or instrumental analysis. Usually the texture in commodities is expressed as hardness, defined as the peak force during the first compression cycle. The puncture test is usually used to measure hardness and consists of measuring the force required to push the probe or punch into a food to a depth that causes irreversible deformation (Bourne, 1980). In addition, hardness of commodities is a function of structure, physiology and biochemical characteristics of the tissue and needs to be considered when measuring texture (Abott, 2004). Abott (2004) also mentioned that toughening in asparagus, broccoli and pineapple is a result of cell wall lignifications during maturation. However, during fruit ripening, cell wall changes from starch to non-starch polysaccharides cause a softening in fleshy fruits (Yashoda *et al.*, 2006).

The flavour of vegetables is composed of aroma and taste. Aroma, due to volatile compounds is detected before and during mastication (Shewfelt, 1994; Sims and Golaszeweski, 2003). Major volatiles include esters, terpenes, aldehydes and alcohols (Shewfelt, 1994). Non-climacteric vegetables do not synthesize compounds that are as aromatic as climacteric ones, but these compounds are still important in purchasing decisions (Wills *et al.*, 1982). Otherwise, taste of vegetables is a result of combination of sweet, sour, salty and bitter sensations. Sugars, primarily glucose, sucrose and fructose contribute to sweetness (Shewfelt, 1994). The perceptions of sourness and saltiness are due to the presence of organic acids (such as citric, malic and acetic), and sodium and potassium, respectively. The bitterness in vegetables is related to phenolic compounds (Sims and Golaszeweski, 2003).

2.9 Methods used to extend marketable life of fresh produce

The shelf-life of a fruit or vegetable during storage is dependent on its production history, initial quality, its storage stability, the external conditions and the handling methods (Florkowski *et al.*, 2009). Local produce often characterized by seasonal production, its small volume and short transport distances, could require less storage facilities and technology. In this case, the lead time between harvesting and customer sale could be limited to less than a day. It is important to note that the effective distribution of the produce is more important than its preservation in storage. However, storage is a strategy for achieving higher economic returns. Shelf-life can be extended by maintaining a commodity at its optimal temperature, relative humidity (RH) and environmental conditions as well as the use of chemical preservatives or gamma irradiation treatment (Shewfelt, 1986; Lee and Kader, 2000).

2.9.1 Ambient storage

Before the advent of refrigeration, ventilated storage was the only means available for storage of fresh produce; and today it's still widely used all over the world for a variety of crops. Ventilated storage is ambient air storage for relatively short storage periods. Most chilli peppers retain best quality for 2 to 3 days if stored at room temperature (Wall and Berghage, 2007). The fruits are stored under shade in a cool airy room to reduce weight loss and wilting.

2.9.2 Low Temperature Storage

Lower storage temperatures offer the additional advantage of greatly reduced water loss from the produce with reduced transpiration. High relative humidity slows down water loss and enhances storage life of the produce. Temperatures below 7 degrees Celsius (7°C) are known as cold storage for certain commodities such as carrots, peas etc. whereas potatoes, bananas and peppers require slightly warmer temperatures between 10-18°C (Florkowski *et al.*, 2009). If cold storage facilities are available, peppers can be stored at 10°C with 85-90% RH (Kitinoja and Kader, 2004). The fruit can last for 2-3 weeks.

Temperature and relative humidity (RH) are the most important environmental factors affecting the sensory quality of fruits and vegetables (Nunes, 2008), and therefore, the consumer acceptability for the fruits and vegetables displayed in a store or fresh produce market. Temperature and relative humidity (RH) are therefore two major criteria used to define critical limits in monitoring programs. During the movement of fresh products to market, wholesalers and retailers frequently do not have enough facilities set to the optimum conditions for each commodity and fresh fruits and vegetables probably receive the greatest temperature abuse at the retail level. Good temperature management is the simplest and easiest way of delaying produce deterioration. Low storage temperatures depress physiological activity of tissues and activity of spoilage microorganisms, and, in general, the lower the storage temperature, the longer the produce postharvest life (Nunes and Emond, 2002). However, some fruits and vegetables of tropical and subtropical origin such as papaya, mango, tomato, cucumber and bell pepper are chilling-sensitive, and may develop symptoms of chilling injury (CI) at temperatures below a certain threshold (i.e., usually below10^{0}C) (Lurie, 2009).

2.9.3 Use of Ethylene Inhibitor

Ethylene is one of several plant growth regulators that affect growth and developmental processes including ripening and senescence (Abeles *et al.*, 1992). It is a simple hydrocarbon that can diffuse into and out of plant tissues from both endogenous and exogenous (non-biological and biological) sources (Saltveit, 1999, Watkins, 2002; Adams-Phillips *et al.*, 2004). Ethylene can profoundly affect quality of harvested products. These effects can be beneficial or deleterious depending on the product, its ripening stage, and its desired use (Saltveit, 1999). Endogenous ethylene production is an essential part of ripening of climacteric fruits and probably acts as rheostat for ethylene-dependent processes (Theologis, 1992). Exogenous ethylene application is routinely used to initiate uniform ripening for fruits such as banana. Most commonly, however, commercial strategies for horticultural products are based on avoiding exposure to ethylene and/or attempting to minimize ethylene production and action during ripening, harvest, storage, transport and handling by temperature and atmosphere control (Watkins, 2002). A new strategy for controlling ethylene production and thus ripening and senescence of fruits, especially climacteric ones, as well as senescence of vegetative tissues, has emerged with the discovery and commercialization of the inhibitor of ethylene, 1-methylcyclopropane (1-MCP). 1-MCP is thought to interact with ethylene receptors and thereby prevent ethylene-dependent responses (Sisler and Serek, 1997, 2003). The application of 1-methylcyclopropane (1-MCP) has been shown to delay ripening by slowing respiration and volatile compound generation (Golding *et al*, 1999). 1-MCP dramatically inhibits ripening of apple fruit. The increases in ethylene production and internal ethylene concentrations (IECs) associated with the climacteric ripening stage are prevented or delayed by 1-MCP treatment, the extent of inhibition being related to cultivar, storage type and length of storage (Watkins *et al*., 2000; Saftner *et al*., 2004; Mattheis *et al*., 2005; Watkins and Nock, 2005).

Respiration rates in treated fruit have been less commonly reported, but are also inhibited by 1-MCP (Defilippi *et al*., 2004; Toivonen and Lu, 2005). Softening is prevented or delayed by 1-MCP, the effects of treatment often closely associated with ethylene production (Watkins *et al*., 2000; Mir *et al*., 2001). Loss of greenness usually considered as a negative attribute in some commodities in commercial conditions, is inhibited (Zanella, 2003), although no effect of 1-MCP on colour was detected by Dauny and Joyce (2002).

2.9.4 Application of Calcium

Calcium is involved in maintaining the textural quality of produce since calcium ions form cross-links or bridges between free carboxyl groups of the pectin chains, resulting in strengthening of the cell wall (Garcia *et al*., 1996). Manganaris *et al*. (2007) suggested 62.5 mM calcium chloride immersion treatment as a potential postharvest treatment for whole peaches, since increased tissue firmness reduced the susceptibility to physiological disorders and reduced the risk of salt-related injuries. Calcium can also help to keep longer the fresh-like appearance of minimally processed fruits and vegetables by controlling the development of browning. Control of the flesh browning has been observed in fruits in different studies, e.g. in peaches (Manganaris *et al.*, 2007) and pineapple (Hewajulige *et al.*, 2003). Another benefit derived from the use of calcium treatments is the incorporation of significant quantities of calcium to the fruit or vegetable matrix. Thus calcium treatment is applied to maintain the quality of the produce and for calcium enrichment purposes (Cerklewski, 2005).

2.9.5 Waxing

Wax coatings have been used since the 1930s to protect and extend shelf-life of various fruits and vegetables (Hardenburg, 1967; Kester and Fennema, 1986). Edible films and waxes have been used for decades on fresh produce to create a semi permeable membrane on the surface to suppress respiration, control moisture loss, add gloss, and more recently, to provide a delivery mechanism for additional functional components (Min and Krochta, 2005). Wax coating applications to fruits and vegetables such as apples, cucumbers, citrus and tomatoes are being used (Kays, 1997). A light supplementary wax coating applied to the surface of pepper fruit can increase market life, reduce fruit shriveling and diminish the amount of vibration damage incurred during transit. Fruit appearance may also be enhanced by making the fruit more glossy. Pepper waxes are food grade and are often made from plant extracts. (Min and Krochta, 2005).

2.9.6 Irradiation

Alternative methods suitable for the control of human pathogens in fruits and vegetables have been explored, and ionizing radiation could be one such alternative. Most studies conducted on irradiation of vegetables (also on fruits) have been targeted to alter ripening and to control postharvest pathogens and disinfectants. Low-dose gamma irradiation is very effective in reducing bacterial, parasitic and protozoan pathogens in raw foods (Rico *et al.*, 2007). Microbiological studies carried out in Cantaloupes (Boynton *et al.*, 2006) showed that samples irradiated had a lower and more stable rate of respiration than non-irradiated samples over about 20 days and total plate counts were significantly higher in non-irradiated control samples through storage.

2.9.7 Controlled Atmosphere storage

Controlled-atmosphere (CA) storage is a technique for maintaining the quality of fresh fruits and vegetables in an atmosphere that differs from normal air (about 78% N_2, 21% O_2 and 0.03% CO_2). Generally, oxygen (O_2) below 8% and carbon dioxide (CO_2) above 1% are used (Kader, 1986). The desired compositions of the atmosphere for storing commodities are usually obtained by initially increasing CO_2 or decreasing O_2 levels in a gas-tight storage room or container. Sometimes, the addition of carbon monoxide (CO) or removal of ethylene (C_2H_4) may also be beneficial (Olsen and Couey, 1975).

CA benefits include reduced respiration rate, reduced scald, decay, discolouration and internal breakdown, inhibition of ethylene production and ripening, and retention of firmness, flavour and nutritional quality. The rate of respiration of fresh fruits and vegetables has been shown to be reduced by low O_2 or high CO_2 levels (Biale, 1960). The lower respiration rate indicates that CA has an inhibitory effect on the overall metabolic activities of stored commodities. A slower rate of utilization of carbohydrates, organic acids and other reserves usually leads to prolonging the life of the produce. CA storage also results in retardation of senescence (including ripening) and associated biochemical and physiological changes, i.e. slowing down rates of respiration, ethylene production, softening and compositional changes. It also results in the alleviation of certain physiological disorders such as chilling injury of avocado and some storage disorders, including scald, of apples (Kader, 1986). CA can have a direct or indirect effect on postharvest pathogens (bacteria and fungi) and consequently decay incidence and severity. For example, CO_2 at 10 to 15% significantly inhibit development of botrytis rot on strawberries, cherries and other perishables. CA storage is also beneficial in the retention of ascorbic acid and amino acids in several fresh fruits and vegetables (McGill *et al*., 1966).

Detrimental effects of CA storage on fruits and vegetables may include the following features. Initiation and/or aggravation of certain physiological disorders such as internal browning in apples and pears, brown stain of lettuce and chilling injury of some commodities. Irregular ripening of fruits, such as banana, mango, pear and tomato can result from exposure to O_2 levels below 2% and/or CO_2 levels above 5% for more than one month. Other adverse effects include the development of off-flavours and off-odours at very low O_2 concentrations (as a result of anaerobic respiration) and very high CO_2 levels (as a result of fermentative metabolism). There is also increased susceptibility to decay when the fruit is physiologically injured by too-low O_2 or too-high CO_2 concentrations (Olsen and Couey, 1975).

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2.9.8 Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) system is defined as the enclosure of food products in materials that create a gas barrier so that the gaseous environment changes from ambient conditions (78% N_2, 21% O_2, 0.03% CO_2 and traces of noble gases) (Church and Parsons, 1995). Figure 2.1 illustrates a MAP system.

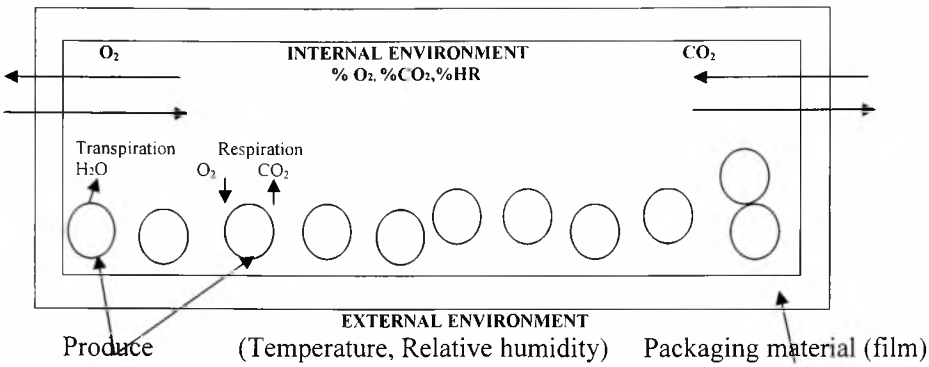

Fig.2 1 Modified Atmosphere Packaging (MAP) System (Durand, 2006).

The goal of MAP in fresh commodities is to create an atmosphere in the package with enough low O_2 and high CO_2 concentrations (relative to air) to maintain the quality of produce at a specific cold temperature (Zagory, 1998; Sanz *et al.*, 1999). MAP utilizes polymeric films with selective permeability for O_2, CO_2 and H_2O vapour to create a modified atmosphere (MA) around the packaged produce due to the respiration of the product and the selective permeability of the packaging material (Guevara *et al.*, 2003).

MAP can be active or passive. In active MAP, the desirable atmosphere can be achieved by flushing out the air with a mixture of O_2, CO_2 and N_2 of known desirable concentrations inside the package. A steady state is reached immediately in the package atmosphere. Usually nitrogen is used as the balance or filler gas to provide a precise concentration of other gases in the package, or to prevent package collapse caused by absorption of CO_2 (Church and Parsons, 1995; Al-Ati and Hotchkiss, 2002). However, in a passive MAP, the optimal atmosphere is developed by the respiration process of the commodity working together with the permeability of the packaging, which causes a reduction in O_2, while increasing the CO_2 concentration. After a period of adjustment, the steady state is established inside the package (Al-Ati and Hotchkiss, 2002; Jayathunge and Illeperuma, 2005). Since O_2 and CO_2 permeate through plastic, permeability of the film package is important in designing a MAP system (Talasila *et al.*, 1995; Jayathunge and Illeperuma, 2005). If the respiration rates of the commodity and film permeability characteristics are properly matched, the selected film allows O_2 to enter at a rate that matches the consumption by the commodity. Similarly, CO_2 must be vented out of the package at a rate that will offset its evolution (Rakotonirainy *et al.*, 2001). However, if a film of excessive gas permeability is used there will be no atmospheric modification. Conversely, if a film of insufficient permeability is used, an atmosphere of O_2 content of less than 2% v/v will cause quality losses due to anaerobiosis (Church and Parsons, 1995).

The principal characteristic for a film in MAP are, required permeability for the different gases, non-reactive with produce, good transparency and gloss, thermal and ozone resistance, light weight commercial suitability, resistance to puncture, ease of handling, low temperature heat seal ability, ease of printing for labeling purposes and nontoxic (Kader *et al.*, 1992). In order to choose the correct plastic film for MAP, the permeability ratio (PCO_2/ PO_2) or β is very useful because it helps to choose the most appropriate film for a recommended modified atmosphere (Mannapperuma and Singh, 1994; Zagory, 2000). The permeability ratio required by the product is calculated using the desired partial pressure of O_2 and CO_2 inside the package and the respiratory quotient. This ratio can be matched with the permeability ratio of the film (β) at a specific temperature of storage. Exama *et al.* (1993) indicated that at 4 °C most commercial films have the desired O_2 and CO_2 permeability for produce with low or medium respiration rates. However, for produce with high respiration rates, the combination of polymeric and perforated films must obtain an adequate flux of O_2 and CO_2.

Different films are used for MAP systems. Low density polyethylene (LDPE) films are the most common in the industry (Zagory, 2000), due to the wide range of β values (2~5) that make them suitable for commodities which require low levels of O_2 and CO_2, such as celery, carrots and cabbage (Exama *et al.*, 1993; Mannapperuma and Singh, 1994). Other films that are available in the market include ethyl cellulose, polyethylene terephalate (PET), polyamide (PA), high density polyethylene (HDPE), polyvinyl chloride (PVC) and Saran, which have a β value of 2.4, 3.4, 4.7, 4.8, 6.1 and 10.2 respectively at 4°C (Exama *et al.*, 1993). Micro-perforated (Aharoni et al., 2007) also known as breatherable films as well as environmentally friendly biodegradable films (Tharanathan, 2003) are also available.

2.10 Packaging Materials for Modified Atmosphere Packaging

Packages are convenient units for marketing and distribution of horticultural products and they have many special requirements. Packages must protect the contents against damage during distribution and must maintain their shape, often for long periods at a relative humidity near saturation and sometimes after water drenching (Hussein *et al.*, 1997).

MAP, a practical way to modify the gas environment surrounding the fruit, uses polymeric films with different permeabilities to oxygen and carbon dioxide to prolong the shelf-life of fruits and vegetables. Atmospheric modification evolves within the package as a result of the respiration rate of the fruit, temperature and the gas diffusion characteristics of the film. In a modified atmosphere pack, changes start to take place immediately after packing the fresh produce as a result of the respiration of the packaged produce. The gases of the contained atmosphere and the external ambient atmosphere try to equilibrate by permeation through the package walls at a rate dependent upon the differential pressures between the gases of the headspace and those of the ambient atmosphere. It is in this context that the barrier to gases and water vapour provided by the packaging material must be considered. Thus, the success of the modified atmosphere pack depends upon the barrier material used. Obviously, film selection is important to the system of MAP, because proper matching of the commodity characteristics with the film results in the passive evolution of an appropriate atmosphere within the sealed package (Zanderighi, 2001). A wide range of packaging materials is used for MAP. The most suitable packaging materials for extending the shelf-life of fresh commodity are polyolefin (co-extruded) polyethylene and polypropylene with an antifogging additive [AF] (Rizzo and Muratore, 2009).

2.10.1 Polyolefins

Polyolefins include low density polyethylene (LDPE) and polypropylene (PP). Low density polyethylene is an extremely versatile material and accounts for the biggest proportion of plastic materials used for packaging. It is an inert film with low permeability for water vapour but high gas permeability. Low-density polyethylene can be laminated, extrusion-coated or co-extruded. Polypropylene is chemically similar to polyethylene and can be extruded or co-extruded to provide as the sealant layer. Oriented polypropylene (OPP) provides high moisture vapour barrier and gas barrier, seven-to ten-times that of polyethylene. It also has excellent grease resistance (PDF file, 2010).

2.10.2 Vinyl Polymers

Vinyl polymers are a group of polymers used in MAP and they include the following; Ethylene Vinyl Acetate Co-polymer (EVA) is a polymer with high flexibility in sheet form and has higher permeability to water vapour and gases (in comparison to LDPE). In both, lidding and base films, it is mainly used as a component of the sealant layer. Poly Vinyl Chloride (PVC) is most widely used as the thermoformable base for modified atmosphere (MA) packs. PVC provides good gas barrier and a moderate barrier to moisture vapour. It has excellent oil and grease resistance. Both the barrier properties and strength characteristics vary with thickness. PVC film is manufactured in a different way than the 'blown' or 'stentered' techniques used for other MAP films; it is milled and calendered (PDF file, 2010).

2.10.3 Microperforated and Microporous Films.

Alternative approaches to providing high oxygen transmission rates (OTRs), especially in applications where there is limited package surface area for gas exchange, have included films with holes or pores. Most cut fruit is packaged in rigid, gas impermeable trays with a permeable film overwrap sealed to the tray. Because the tray is impermeable to gases, there is reduced surface area for gas exchange. All the gas exchange must occur through the film overwrap. Microporous and microperforated films allow much more rapid gas exchange than would normally be possible through plastic films (Rodov *et al.*, 2000).

2.10.4 Films with Anti-fog Properties.

Potential buyers like to see fresh produce before they buy it. Therefore plastic packages need to be clear and the product visible. Condensation of water inside the bag can often occlude the view of the product. Anti-fog compounds have been developed that, when included in co-extruded films, migrate to the inner surface of the film and prevent large water drops from forming. This results in a more attractive package and a better view of the product (Rizzo and Muratore, 2009).

2.10.5 Biodegradable films

There is growing pressure in the fresh fruits and vegetables packaging sector to replace the petrochemical based packaging films with more environmentally friendly biodegradable materials (Tharanathan, 2003). Although biodegradable films are more expensive than the petrochemical materials, they will biodegrade into CO_2, water and biomass under aerobic conditions, or methane and biomass under anaerobic conditions (Avella *et al.*, 2005). Based on these characteristics, biodegradable films can contribute towards effectively reducing environmental pollution.

2.11 Biochemical and Physiological effect of MAP on fresh produce

MAP has been successful in the marketing of fresh produce by working together with low temperatures in order to maintain freshness, ensure safety and extend shelf-life. Changes in the composition of the gaseous atmosphere of the commodity can result in significant changes in the respiratory process. Low oxygen and high carbon dioxide concentrations have an effect on respiratory pathways (Kays, 1991). A decreasing O_2 content around fresh vegetables reduces the respiration rate in proportion to the O_2 concentration, which is important in postharvest handling in order to delay senescence in comparison with storage in air (Wills *et al.*, 1982; Kader, 1986; Kays, 1991). The respiration rate is decreased by low O_2 due to a reduction in the activity of polyphenol oxidase, ascorbic acid oxidase and glycolic acid oxidase (Kader, 1986; Kays, 1991). Kader (1986) and Wills *et al.* (1982) observed that respiration rate had a significant reduction below 10% O_2, with an optimal value between 2-5% of O_2. However, this range depends on gas diffusion characteristics of the tissues of the specific commodity and the storage temperature. As the temperature is reduced the required concentration of O_2 by the respiration process is also decreased (Wills *et al.*, 1982). Lebermann (1968) mentioned that the respiration rate of broccoli decreased 50% when O_2 content was reduced from 21% to 1% at 23.8°C. Also Kader (1986) mentioned that the respiration rate of fresh vegetables in an atmosphere with 3% O_2 was proportionally reduced between 10-46% at 0°C and 20-60% at 10 or 20°C.

Chilli Pepper packages using 25μm low-density polyethylene and 30μm cast polypropylene could attain modified atmosphere close to the optimal gas concentrations

(3% O_2 and 5% CO_2), and therefore provided better quality retention compared with unpackaged controls (Lee *et al*, 2006). Extremely low O_2 levels (<2%), however, can cause anaerobic respiration. At this point the tricarboxylic acid cycle (TCA) is blocked. Pyruvic acid is no longer oxidized, but it is accumulated and is decarboxylated to form CO_2 and acetaldehyde, which is then reduced to ethanol, resulting in the production of off-odour, off-flavour and tissue breakdown (Kays, 1991; Kader, 1986). Under aerobic conditions, CO_2 has a significant effect in decreasing the respiratory rate when the storage substrate of the commodity is not depleted (Kader, 1986). However, a high level of CO_2 (about 15%) results in toxic levels of succinate in apples (Kays, 1991) and ethanol and acetaldehyde production in black currants (Kader, 1986). The combined effects of reduced O_2 and elevated CO_2 levels on the respiration rate are greater than either component alone (Kader, 1986).

Loss of chlorophyll is slowed down in vegetables kept in modified atmospheres. Chlorophyll in betel leaf (*Piper betel* L.) was maintained during the entire storage period, and the final retention levels were highly influenced by package headspace atmosphere dynamics (Rai *et al*, 2010). The texture of vegetables can also be influenced by modified atmospheres. Modified atmospheres can improve the retention of flavour, but it depends on the commodity (Wills *et al.*, 1982). Elevated CO_2 can reduce the rate of conversion of sugar to starch, which is undesirable in peas and sweet corn, and also improves the retention of organic acids in tomato but accelerates loss of acids in asparagus (Kader, 1986; Wills *et al.*, 1982).

2.11.1 Effects of modified atmospheres on microorganisms

Post-harvest diseases destroy 10-30% of the total yield of crops; and in some perishable crops especially in developing countries, they destroy more than 30% of the crop yield (Kader, 2002; Agrios, 2005). Fruits and vegetables are highly perishable products and the quality is affected by post-harvest handling, transportation, storage and marketing. The improper handling, packaging, storage and transportation may result in decay and production of microorganisms, which become activated because of the changing physiological state of the fruits and vegetables (Wilson *et al.*, 1991).

Fungi are the most important and prevalent pathogens, infecting a wide range of host plants and causing destructive and economically important losses of most fresh fruits and vegetables during storage and transportation (Sommer, 1985). The common microflora of vegetables such as Bacterial soft rot -*Erwinia carotovora*, Anthracnose- *Colletotrichum capsici*, Gray Mould- *Botrytis* sp., Alternaria rot - *Alternaria alternate*, *Flavobactrium*, *Xanthomonas*, *Enterobacter agglomerans*, *Pseudomonas spp.*, *Lactobacillus spp.*, yeasts and molds contribute to the decline of commodity quality (Jay, 1996; FDA/CFSAN, 2001). However, MAP in combination with low storage temperature is an effective way to reduce the growth of spoilage microflora and food borne pathogens, due to increasing the solubility of CO_2 in the liquid phase surrounding the food. CO_2 is a bacterial and fungal growth inhibitor. Although it is unknown how CO_2 affects the microorganism, Faber (1991) summarized several theories in four main effects as follows: alteration of cell membrane function, direct inhibition of enzymes or decreased rate of reactions, changes in pH caused by penetration of the bacterial membrane and direct changes of physico-chemical properties of protein. However, CO_2 has an overall effect on microorganisms by increasing the duration of the lag phase of growth; but as soon as bacteria move from the lag to log phase of growth, the inhibitory effect is reduced (Church and Parsons, 1995; Jay, 1996). In addition, the effect of CO_2 is influenced by the type of microorganism. Gram negative bacteria are more sensitive than gram positives. For instance whereas pseudomonas bacteria are inhibited with 10-20% CO_2, the growth of lactic acid bacteria can be enhanced by the same CO_2 content (Jay, 1996; FDA/CFSAN, 2001). Conversely, molds are strictly aerobic microorganisms and their growth is inhibited by CO_2 concentrations as low as 10%. Yeast growth, however, is more resistant to CO_2 concentration (FDA/CFSAN, 2001; Al-Ati and Hotchkiss, 2002). An appropriate level of O_2 content can also reduce the growth of spoilage microorganisms (aerobic bacteria) (Church and Parsons, 1995) and inhibit the growth of strictly anaerobic bacteria such as *Clostridium botulinum* (Faber, 1991).

2.12 Physiological and Pathological Disorders in Chilli Pepper

Physiological disorders are tissue damage or breakdown and undesirable compositional changes not related to pathogens, insects or mechanical damage. Causes include high or low temperature which can result in sunscald and chilling injury respectively, altered atmospheric gas composition (very low O_2 and very high CO_2 levels) can also lead to development of off-flavours and off-odours (as a result of anaerobic respiration and fermentative metabolism), nutrition (e.g. calcium deficiency [stem-end rot] and boron toxicity). However, chilling injury is a major problem during low temperature storage of most tropical crops (Hardenburg *et al.*, 1986; Paull, 1990).

2.12.1 Chilling Injury

Not all the effects of reducing temperature to slow down respiration rate are beneficial. Chilling injury is a common physiological disorder that arises during storage between 0 and 10°C in tropical and subtropical crops (Serrano *et al.*, 1997). The chilling mechanism is explained as the changes in the membrane lipids of the cell, from flexible liquid crystalline into a solid gel structure at critical low temperatures (Wang, 1982; Wills *et al.*, 1982). This change affects the enzymatic activity of the membrane as well as synthesis and degradation of proteins causing a metabolic disruption of the cell.

Chilling injury is developed under low temperature and usually observed once the sensitive commodity is returned to non-chilling temperature (Wills *et al.*, 1982; Kays, 1991). The physical change of the membrane causes secondary responses or symptoms that are irreversible and results in quality loss and death of the commodity (Wills *et al.*, 1982; Kays and Paull, 2004). The symptoms depend on the temperature, the duration of exposure, plant part, cultivar, maturity at harvest, and also appear to increase after transferring to non-chilling temperatures (Wang, 1982; Kays and Paull, 2004). As the time of exposure increases, the sensitivity of the commodity to the chilling temperature increases. Secondary effects are frequently observed, such as loss of membrane integrity, leakage of solutes, like sugars, amino acids and minerals salt, which can also promote bacterial and fungal growth (Kays and Paull, 2004; Wills *et al.*, 1982). Other symptoms include uneven and abnormal senescence, an increase in water loss, increasing CO_2 and ethylene production, surface pitting and internal browning (Wills *et al.*, 1982; Serrano *et al.*, 1997). Pitting of the skin is often due to collapse of the cell and takes a form of surface discolouration. A crucial point of low temperature storage studies is that, for climacteric tropical and temperate commodities showing low temperature injury, there is interplay of reasons for the termination of shelf-life (Paull, 1993). For papaya, at storage temperatures above 10–12°C, shelf-life is terminated because of fruit ripening, while at lower temperatures ripening is not the concern, the limitation to storage being imposed by chilling injury. Chilling injury is seen in a commercial setting as greater susceptibility to disease, as well as skin scald, failure to ripen and flesh breakdown (Paull and McDonald, 1994). However, if fruits are removed from chilling temperature storage to a higher temperature before chilling symptom development occurs, fruits ripen normally; hence they have an overall longer shelf life and some retailing time (Morris, 1982).

Maximum useable shelf-life is obtained when storage time at chilling temperatures does not exceed the threshold for injury. However, other quality attributes such as texture, flavours and aromas may be lost before obvious changes occur in external criteria used to judge storage life. Storage recommendations for vegetables are generally the minimum temperature that provides the maximum shelf-life (Morris, 1982).

Some techniques have been proposed to reduce chilling injury in different fruits and vegetables. These techniques include conditioning at near chilling temperatures before chilling, intermittent warming during storage, pre-treatments with calcium, chemical treatments and controlled or modified atmosphere (Morris, 1982; Wang, 1982). Still, the best way to avoid chilling injury is storing the sensitive commodity above the threshold of chilling temperature (Morris, 1982). Temperature conditioning consists of exposing the sensitive commodity to temperatures slightly above the critical chilling temperature before transfer to this temperature. Sweet peppers stored at 10°C for 5-to-10 days had reduced chilling injury at 0°C (McColloch, 1962). In addition, the interruption of chilling temperature storage in sensitive commodities with one or more short periods of warm temperature is defined as the technique of intermittent warming. This allows the tissues to metabolize the toxic substance accumulated during chilling storage (Wang, 1982). Controlled and modified atmospheres can be used to reduce chilling injury symptoms and also extend the shelf-life of the commodity. Serrano *et al.* (1997) mentioned that chilling injury symptoms in mature green peppers were reduced considerably and increased their shelf-life using a modified atmosphere packaging with 16.1% O_2 and 4.5% CO_2 at 2°C. On the other hand, many chemical treatments are used to reduce chilling injury. Growth regulators such as jasmonic acid, methyl jasmonate and methyl salicylic acid, which are found in a wide range of plants, induce a mechanism to protect the commodity from chilling injury (Gonzales *et al.*, 2001). Tasneem (2004) indicated that methyl jasmonate at 1 and 7°C and diphenylamine at 4 and 7°C were successful in reducing chilling injury in mangoes cv. Kent.

2.12.2 Postharvest decays

Postharvest decays of fruits and vegetables account for significant levels of postharvest losses. It is estimated that about 20–25% of the harvested fruits and vegetables are decayed by pathogens during postharvest handling even in developed countries. In developing countries, postharvest losses are often more severe due to inadequate storage and transportation facilities (Singh and Sharma, 2007).

The major postharvest diseases of peppers are *Alternaria*, *Botrytis* rots and Anthracnose. *Phytophthora* rots can also occur if the pepper fruit are exposed to prolonged periods of heavy rainfall. Fruit infected by *Phytophthora capsici* have water-soaked lesions (Agblor and Waterer, 2001). Anthracnose (caused by *Collectotrichum* spp.) may occur in the field or develop as a postharvest decay of pepper fruits. Typically, symptoms first appear on mature fruits as small, water-soaked, sunken lesions that rapidly expand. The lesions may increase to 3-4 cm in diameter on large fruits. Fully expanded lesions are sunken and range from dark-red to light tan. The disease may occur wherever pepper is grown under overhead irrigation or rain fed conditions (Berke *et al.*, 2005). The pathogens can be seed-borne in pepper and persist in crop debris. They have a wide host range. To control anthracnose, the use of pathogen-free seed and crop rotation is encouraged. Fungicides can also reduce losses. Since symptoms usually occur on mature fruits, harvesting and utilization of fruit in the immature green stage instead of the mature fruit stage should be frequently practiced (Agblor and Waterer, 2001).

2.13 Measurement of Quality in fresh produce

2.13.1 Visual Evaluation

The visual appearance of fresh fruits and vegetables is one of the first quality determinants made by the buyer whether wholesaler, retailer or consumer. Often the appearance of the commodity is the most critical factor in the initial purchase (in addition to price) while subsequent purchases may be more related to texture and flavour (Mitcham *et al.*, 1996). Visual evaluation of quality characteristics by an expert judge, despite limitations, is a widely used and accepted technique (Florkowski *et al.*, 2009). Numerical scales for specific attributes are also available.

2.13.2 Colour

Measurement of colour is an important means of quality assessment of food products. Although colour of fruits and vegetables is an external manifestation of composition and form of plant pigments, a sample compositional analysis of extracted pigments does not necessarily predict visual impact (Florkowski *et al.*, 2009). Fruit ripening and vegetable yellowing frequently involve the unmasking of yellow-to-orange xanthophylls and carotenes by the disappearance of chlorophyll (Chan and Ramaswamy, 2002). Evaluating colour can be subjective or objective. Colour perception depends on the type and intensity of light, chemical and physical characteristics of the commodity, and the person's ability to characterize colour (Mitcham *et al.*, 1996). Colour charts or guides can be used as references for matching and describing colours as in bananas and tomatoes. The predominant colour scale used for fruits and vegetables is the Hunter "Lab" or its variant *Commission Internationale de l'Eclairage* (CIE) L*a*b (Florkowski *et al.*, 2009).

2.13.3 Gloss

Gloss is a visual aspect of quality that depends on the ability of a surface to reflect light. Products that are freshly harvested often have a bright, glossy surface and this appearance factor can be greatly reduced with weight loss and other postharvest handling conditions. There are small portable instruments from Minolta and BKY Gardner for measurement of gloss (Mitcham *et al.*, 1996).

2.13.4 Shape & Size

Uniform and characteristic shapes are important quality characteristics. Misshapen products may be more susceptible to mechanical injury and are generally avoided by consumers. Consumers tend to associate large size with higher quality and view larger fruits as more mature. A subjective evaluation of size and shape can be conducted on incoming product once the desirable and undesirable characteristics are determined. Size and shape charts are available for various commodities and weight is a fairly accurate measure of product size (Mitcham *et al.*, 1996).

2.13.5 Absence of Defects

The product should be evaluated for the presence of defects. The level of tolerance for each type of defect such as cuts, bruises, disease, chilling injury and physiological disorders should be determined. During quality evaluation, the percentage of fruit with each class of defect can be determined as a guide to overall product quality. A scoring system (such as 1 = none, 2 = slight, 3 = moderate, 4 = severe and 5 = extreme) can be used to describe the incidence and severity of defects (Mitcham *et al.*, 1996).

2.13.6 Texture/Firmness

Firmness is a primary textural attribute measured in fruits and vegetables. Firmness is usually measured using objective instruments by destructive puncture tests, including handheld Effegi (Voltz *et al.*, 2003) and mechanized Instron tests (White *et al.*, 2004). An indication of firmness is obtained by the force necessary to cause penetration of a standard probe a specified distance into the product. These tests are being replaced by more non-destructive tests (Macnish *et al.*, 1997; Gomez *et al.*, 2005). Non-destructive tests are particularly effective in sorting fruits by firmness, but may not be as effective in measurement as in quality monitoring during handling and storage (Abbott, 2004). Firmness can be measured in Newtons (N) and the probe diameter should be reported (Bourne, 2002).

2.13.7 Flavour

Flavour quality of fruits and vegetables is influenced by genetic, preharvest, harvesting and postharvest factors (Kader, 2008). The longer the time between harvest and eating, the greater the losses of characteristic flavour (taste and aroma) and the development of off-flavours in most fruits and vegetables. Chemical analysis of fruit and vegetable composition is used primarily to estimate consumption quality and hidden attributes. Sweetness is a function of sugar concentration and sourness a function of acidity. Consumer perception of sweetness or sourness is related to the ratio of sugars and acids, but the relationship is complex (Malundo *et al*., 1995; Crisosto *et al*., 2007). Sugar composition is usually estimated by measuring the percentage of soluble solids (°Brix) using refractometer (Esti *et al*., 2002). Acidity is determined by titration with a standard base (Abegaz *et al*., 2004). More detailed analysis and separation of individual sugars and acids can be determined using HPLC (Sturm *et al*., 2003).

2.13.8 Total Soluble Solids Content (TSS)

Sugars are the major soluble solids in fruit juice and therefore soluble solids can be used as an estimate of sugar content. Organic acids, amino acids, phenolic compounds and soluble pectins also contribute to soluble solids. Soluble solids content (SSC) can be determined in a small sample of fruit juice using a refractometer. The refractometer measures the refractive index, which indicates how much a light beam will be slowed down when it passes through the fruit juice. The refractometer has a scale for refractive index and another for equivalent °Brix or SSC percent which can be read directly. Digital refractometer removes potential operator error in reading values. The temperature of the juice is a critical factor for accuracy because all materials expand when heated and become less dense. For a sugar solution, the change is about 0.5% sugar for every 5.6°C (10°F) temperature variation. A good quality refractometer has a temperature compensation capability or at least a thermometer attached to them so that the operator can make the necessary corrections. It is essential to clean the refractometer between each reading and to standardize it with distilled water [should read a refractive index of 1.3330 at 20°C (68°F) or 0% SSC] (Mitcham *et al.*, 1996).

2.13.9 Titratable Acidity

Titratable acidity (TA) is directly related to the concentration of organic acids in fruits and vegetables (Kays, 1991). Sourness is determined by the concentrations of the predominant organic acids. Fruits and vegetables with very low levels of organic acids may therefore lack characteristic flavour [taste] (Kader, 2008).

Titratable acidity (TA) can be determined by titrating a known volume of fruit juice with 0.1 N NaOH (sodium hydroxide) to an end point of pH = 8.2 as indicated by phenolphthalein indicator or by using a pH meter. NaOH is added to the juice until the pH changes to 8.2. The milliliters of NaOH needed is used to calculate the TA. The TA, expressed as percent malic, citric or tartaric acid can be calculated as follows:

TA= ml NaOH x N (NaOH) x ***acid meq.factor*** x 100 (Mitcham *et al.*, 1996).

2.13.10 Nutrients

Nutrient composition varies widely in raw commodities because of genetic and preharvest factors, maturity at harvest and postharvest handling conditions. The two most commonly measured nutrients in fruits and vegetables are ascorbic acid (Vit C) and β-carotene (provitamin A) and are currently measured by HPLC (Asami *et al.*, 2003) though chemical methods are available.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General Outline of Study

The effect of type of Modified Atmospheric Packaging (MAP) material and storage temperature on the quality of fresh green chilli pepper fruits (*Capsicum* sps. cvs *Legon 18* and *KA2*) was determined using three experiments. In Experiment 1, fresh green chilli pepper fruits (*Legon 18*) were packed in different types of modified atmosphere packaging materials with different permeabilities and stored at an average temperature of 4.3°C in a refrigerator and 10°C in a Climatic Chamber for four weeks. Another variety of chilli pepper fruits (*KA2*) were packed using modified atmosphere packaging materials with different permeabilities and stored at the same temperatures (4.3°C and 10°C) for four weeks in Experiment 2. In Experiment 3, fruits of both varieties (*Legon 18 and KA2*) were packed in different types of modified atmosphere packaging materials with different permeabilities and stored at ambient temperature. *Legon 18* chilli pepper fruit is long and tapered, has glossy exocarp (skin), tough mesocarp and ripen from green to red. Comparatively *KA2* chilli pepper fruit is intermediate in length, slightly tapered, less glossy, has a tougher mesocarp and calyx and ripen from deep green to red.

Fresh green chilli pepper fruits used in experiments 1, 2 and 3, were obtained at their commercial maturity stage (firm and mature green) from a farm at Amasaman in the

Greater Accra Region, the Department of Crop Science Farm, University of Ghana, and from commercial farmers in the Greater Accra Region, respectively. The fruits were transported to the Food Processing and Engineering laboratory of the Food Research Institute, CSIR, Accra. They were selected for absence of defects and washed with tap water and then with sodium hypochlorite solution (150ppm) for 2 minutes to reduce the microbial load. They were then carefully mopped with tissue paper to dry. The fruits were weighed and packed in different types of plastic bags as treatments consisting of the following: (i) Low Density Polyethylene (LDPE) non-perforated and perforated bags, (ii) Polypropylene (PP) non-perforated and perforated bags and (iii) Low Density Polyethylene (LDPE) microperforated bags. Unpacked fruits were used as control. The packed and unpacked fruits were stored at low and ambient storage temperatures. Details of the experiments in the study are described below.

3.2 Experiment 1: Determination of the effect of different types of modified atmosphere packaging materials on the quality of fresh green chilli pepper fruits (Legon 18) stored under low temperature.

Chilli pepper fruits (*Legon 18*) weighing 70g were placed and sealed in each of plastic packages consisting of Low Density Polyethylene (LDPE) bag, (18 cm x 20 cm x 35 μm) non-perforated, Low Density Polyethylene (LDPE) bag, (18 cm x 20 cm x 35 μm) perforated, Polypropylene (PP) bag (17.5 cm x 24 x 80 μm) non-perforated and Polypropylene (PP) bag, (17.5 cm x 24 cm x 80 μm) perforated (Table 3.1). Twenty perforations were made on each perforated bag using a pin of diameter 0.14 mm. Control samples consisted of unpackaged fruits. The packed and unpacked fruits were stored for four weeks under two different temperatures: in a refrigerator(AKAI-RF-

ED14SR2G,China) at an average temperature of 4.3°C for four weeks and in a Climatic Chamber (BINDER KBF-GmbH, Germany) at 10°C. The experiment was performed using 2 x 5 factorial treatment combinations in completely randomized design with three replications.

Table 3.1 Description of treatment for Experiment 1 (*Legon 18* chilli pepper fruits)

Packaging film		Storage condition	
		Refrigerator	Climatic Chamber
LDPE non-perforated bag	(18 cm x 20 cm x 35 μm)		
LDPE perforated bag	(18 cm x 20 cm x 35 μm)		
PP non-perforated	(17.5 cm x 24cm x 80 μm)	4.3(°C)	10(°C)
PP non-perforated	(17.5 cm x 24cm x 80 μm)	(Average)	
Control (unpacked)			

LDPE = Low Density Polyethylene, PP = Polypropylene

3.3 Experiment 2: Determination of the effect of different types of modified atmosphere packaging materials on the quality of fresh green chilli pepper fruits (*KA2*) stored under low temperature.

The chilli pepper fruits (*KA2*) weighing 70g were sealed in each of plastic packages consisting of LDPE bag (18 cm x 20 cm x 35 μm) non-perforated, PP bag (17.5 cm x 24 cm x 80 μm) non-perforated, LDPE bag microperforated (17.5 cm x 24 cm x 31.75 μm) and LDPE bag non-perforated (18 cm x 20 cm x 35 μm, containing fruits with pedicel removed) (Table 3.2). Fruits with pedicel removed were included as fourth treatment to determine its effect on water loss from the fruits. Control samples consisted of unpackaged fruits. The packed and unpacked fruits were stored for four weeks under two different temperatures: in a refrigerator (AKAI-RF-ED14SR2G,China)at an average temperature of 4.3°C for four weeks and in a Climatic Chamber (BINDER KBF-GmbH, Germany) at 10°C. The experiment was performed using 2 x 5 factorial treatment combinations in completely randomized design with three replications.

Table 3.2 Description of treatment for Experiment 2 (*KA2* chilli pepper fruits)

	Storage condition	
Packaging film	**Refrigerator**	**Climatic Chamber**
LDPE non-perforated bag (18 cm x 20 cm x 35 μm)		
PP non-perforated bag (17.5 cm x 24cm x 80μm)		
LDPE microperforated (17.5 cm x 24 x 31.75μm)	4.3(°C)	10(°C)
LDPE non-perforated bag (18 cm x 20 cm x 35 μm) containing fruits with pedicel removed	(Average)	
Control (unpacked)		

LDPE = Low Density Polyethylene, PP = Polypropylene

3.4. Experiment 3: Determination of the effect of different types of modified atmosphere packaging materials on the quality of fresh green *KA2* and *Legon 18 chilli* pepper fruits under ambient temperature.

Chilli pepper fruits, *KA2* and *Legon 18*, weighing 70g each were placed and sealed in each of plastic bags. The bags consisted of LDPE (18 cm x 20 cm x 35 μm) non-perforated, LDPE (18 cm x 20 cm x 35 μm) perforated, PP (17.5 cm x 24 x 80 μm) non-perforated, PP (17.5 cm x 24 cm x 80 μm) perforated and LDPE (17.5 cm x 24 cm x 31.75 μm) microperforated. (Table 3.3). Twenty perforations were made on each perforated bag using a pin of diameter 0.14 mm. Control samples consisted of unpackaged fruits. The packed and unpacked fruits were placed on a bench under a shed and stored at ambient temperature (26-34°C) for 9 days (because of relatively short storage life of chillies under high temperatures). The experiment was performed using a completely randomized design with three replications.

Table 3.3 Description of treatment for Experiment 3 (*Legon 18* and *KA2* chilli pepper fruits)

Packaging film		Storage Temperature (°C)
LDPE non-perforated bag	(18 cm x 20 cm x 35 μm)	
LDPE perforated bag	(18 cm x 20 cm x 35 μm)	Ambient(26-34)
PP non-perforated bag	(17.5 cm x 24 x 80 μm)	
PP perforated bag	(17.5 cm x 24 x 80 μm)	
LDPE microperforated bag	(17.5 cm x 24 x 31.75μm)	
Control (unpacked)		

LDPE = Low Density Polyethylene, PP = Polypropylene

3.5 Data collection and analysis

The collected data were as follows: weight loss, firmness, changes in fruit colour and chilling injury. The biochemical changes in the MAP-stored chilli pepper fruits were determined by chemical analysis for titratable acidity (TA), total soluble solids (TSS), ascorbic acid content, total carotenoids and total phenolic compounds. The data were subjected to analysis of variance (ANOVA) using Genstat Release 9.2, and means were compared using least significant difference (LSD) at 5%.

Procedure for the data collection on each quality attribute is described as follows:

3.5.1 Weight loss

Fruit weight in each sample was determined using Kern-510 electronic balance (Gottle KERN & Solution GmbH-Germany) and weight loss (%) was calculated as a percentage of the original fresh weight of each replicate sample. The weight of the fruits per packaging types were recorded at the beginning of storage (Day 0), and on the 7th, 14^{th}, 21st and 28th day of the experiment for the 4.3°C and 10°C storage temperatures, and on daily basis for the ambient temperature for 9 days.

$$\text{Weight loss (WL)(\%)} = \left(\frac{W1-W2}{W1}\right) X100$$

W_1= Original weight of sample
W_2= Weight of sample on sampling day

3.5.2 Firmness

Firmness was measured non-destructively using an Intertest Benelux Penetrometer (Netherlands). The firmness measurement was carried out using a cylindrical stainless steel screw head of 7mm diameter taken from two locations on the same fruit of each of ten (10) fruits randomly selected from each package at each sampling period and the average value determined. Measurement of the firmness was carried out at the beginning of the experiment (Day 0) and on the 7th, 14th, 21st and 28th day of the experiment for the 4.3°C and the 10°C storage temperatures. Firmness at ambient room temperature was recorded at the beginning of the experiment (Day 0) and then daily for 9 days.

3.5.3 Colour measurement

Colour was measured using a Minolta CR-310 Chromameter (Minolta Corp. Japan) on CIE L*a*b* chromatic space. The instrument was initially calibrated using a white standard tile (Y 93.7, X 0.3138, y 0.3194). Colour measurements were taken five (5) times on each tested sample. The L variable ranges from 0 (black) to 100 (white) and is a useful indicator of darkening or lightening during storage either from oxidative browning or changes taking place in the type of pigments or pigment concentration. The a* scale measures the degree of red (+a*) and green (-a*) colour while b* scale measures the degree of yellow (+b*) and blue (-b*) colour. The values of the brightness (L) and a* values (− green to + red) were used to evaluate the colour in the study. Colour measurements were carried out at the beginning of the experiment (Day 0) and on the 7th, 14th, 21st and 28th day of the experiment for the 4.3°C and the 10°C storage temperatures. For the ambient temperature, colour changes were recorded at the beginning of the experiment (Day 0) and then daily for 9 days.

3.5.4 Chilling injury (CI)/decay incidence

Chilli pepper fruits having symptoms of chilling injury were counted on the 7th, 14th, 21st and the 28th day of storage for the 4.3°C and 10°C storage temperatures. A fruit was counted as affected by CI if skin darkening, sheet pitting and water-soaked areas appeared on the exocarp (skin). Appearance of mycelia on the peel was scored as decay. CI and decay incidence were expressed as a percentage of the total amount of fruits observed.

3.5.5 Ascorbic acid content

Ascorbic acid content was quantitatively determined at the beginning and end of storage using the 2,6-dichloroindophenol-dye method (AOAC, 1990). A 0.05g 2,6-dichloroindophenol dye was dissolved in 100ml of distilled water. Standard solution of ascorbic acid was prepared by dissolving 0.2g of pure ascorbic acid in 1000ml of distilled water. The indophenol solution was placed in a burette and titrated against 10mls of the standard ascorbic acid solution in a conical flask until the indophenol dye changed from violet to rose pink and the average titre value recorded. Chilli pepper, 10g fruit sample. was then macerated in 100ml distilled water using a commercial blender and filtered. Then 25ml of 20% metaphosphoric acid was added to the juice for stability and titrated with the standard 2, 6-dichloroindophenol solution until the colour changed from violet to rose pink and the average titre value recorded.

Ascorbic acid content of the juice was determined on equivalent basis as follows:

$$\frac{\text{Average Titre value of pure Ascorbic Acid}}{\text{Weight of pure Ascorbic Acid}} = \frac{\text{Average Titre value of Pepper juice}}{\text{Weight of Ascorbic Acid in Fresh Pepper}}$$

Sample calculation. If:

Average Titre value of pure Ascorbic Acid = 8.8ml

Weight of pure Ascorbic Acid in 10ml standard solution = 2.0mg

Average Titre value of Pepper juice = 3.0ml

Weight of Ascorbic Acid in Fresh Pepper = x mg

Weight of Ascorbic Acid in Fresh Pepper (x) = $\frac{3.0\text{ml} \times 2.0\text{mg}}{8.8\text{ml}}$ = 0.6818mg

But 0.6818mg of Ascorbic Acid is contained in 10g of fresh pepper which is then expressed in mg/100g fresh weight as follows:

100g/10g X 0.6818mg = 6.818mg/100g fresh weight.

Thus Ascorbic acid concentration in the fresh pepper = 6.8 mg/100g fresh weight.

3.5.6 Titratable Acidity

Fifty (50) grams of the pepper fruits were macerated in 50ml of distilled water and filtered. Ten (10) milliliters of the juice were diluted with 100ml of distilled water and titrated against 0.1MNaOH using phenolphthalein as indicator. The volume (in milliliters) of NaOH required was used to calculate the Titratable acidity (TA). The TA was expressed as percent citric acid and was calculated as follows:

TA= ml NaOH x M (NaOH) x *acid meq. factor* x 100

[Acid milliequivalent (meq) factor for the predominant organic acid (citric) in pepper fruit]. (Mitcham *et al*, 1996).

3.5.7 Total Soluble Solids

Total Soluble solids were determined before and after storage by taking representative juice of each sample onto the glass of a handheld refractometer (RB 32 Hanna Instruments). The refractometer was closed and held up to the light for viewing through the eyepiece. The readings were taken on the internal scale directly at room temperature. (Mitcham *et al*, 1996).

3.5.8 Total Carotenoids and Total Phenolic Compounds

The total carotenoids and total phenolic compounds were determined by the Chlorophyll II Determination (US10200H) method (PerkinElmer, Inc. USA) using PerkinElmer Lamda 850 UV Spectrophotometer. A 1g sub-sample pepper fruit was ground using a mortar and pestle and the pigments extracted using 50ml of 96% methanol. The filtrate was sieved into a beaker using a cheese cloth and the volume recorded. The filtrate was poured into a 50ml falcon tube and centrifuged at a spin of 2500rpm for 10 minutes. Total carotenoids and total phenols were estimated by taking the absorbance at 480nm, 630nm, 647nm, 664nm, 665nm and 700nm and expressed as g/100g fresh weight equivalent of total carotenoid and total phenol content as follows:

If results displayed by Spectrophotometer = a ppb (parts per billion)

Then gram per 100g of sample = $a \times 10^{-9}/10^{-7}$

$= a \times 10^{-2}$ g/100g fresh weight

Polyethylene film (PE)

Polypropylene film (PP)

Microperforated polyethylene film (MP)

Fig. 3.1 Plastic packaging types used for packaging (MAP) chilli pepper fruits

CHAPTER FOUR

RESULTS

4.1 Experiment 1: Effect of Modified Atmosphere Packaging (MAP) and Low Temperature Storage on the quality of Green *Legon 18* Chilli Pepper

4.1.1 Effect of low Temperature or Packaging (MAP) on Weight Loss

In general, progressive increase in weight loss was observed in all treatments with prolonged storage period. Generally, the use of packaging film and low temperature reduced weight loss significantly as shown in Tables 4.1 and 4.2.

Temperature effect alone on weight loss was significantly lower at 10°C than at 4.3°C on the 28th day of storage. However, there were no significant differences in weight loss between the two temperatures on days 7, 14 and 21 (Table 4.1).

Packaging alone affected weight loss. Weight loss was significantly reduced in packaged fruits than in the control at any particular storage period. Significant reduction in weight loss among the packaged fruits occurred on days 7 and 28. On day 7, PP perforated was significantly higher than PE perforated and PE non-perforated and on day 28, PP perforated was significantly higher than the rest of the packaging types; however, on days 14 and 21, there were no significant differences among the packaging types (Table 4.1). Weight loss in the unpacked fruits was approximately 4 times higher than in the film-packed fruits at the end of the 28 days storage period.

Table 4.1 Effect of low Temperature or Packaging (MAP) on Weight Loss in Chilli Pepper fruits

Treatment	% Weight Loss			
	Day 7	Day 14	Day 21	Day 28
Temperature				
4.3°C	5.68	11.94	19.88	27.01
10°C	5.94	11.97	17.80	23.22
LSD 5%	0.91	1.69	2.90	1.38
Packaging				
PE non-perforated	2.38	5.63	12.02	15.53
PE perforated	2.4 2	5.74	9.93	14.60
PP non-perforated	3.10	7.14	12.01	16.15
PP perforated	3.92	7.80	11.98	16.90
Control(unpacked)	17.23	33.45	48.26	62.40
LSD 5%	1.45	2.68	4.59	2.19

PE and PP represent Polyethylene and Polypropylene films, respectively.

4.1.2 Effect of Packaging (MAP) and low Temperature Interaction on Weight Loss

Significant interaction effect of packaging and low temperature on weight loss was observed. The combined interaction effect of packaging and low temperature significantly reduced weight loss in the packed fruits more than the control at both 10°C and 4.3°C in all the storage periods (Table 4.2). On days 7 and 28 at 4.3°C, there were no significant differences among packaging types. However, on the 14th day, weight losses were significantly lower in non-perforated PE and perforated PE than in non-perforated PP perforated PP; and on the 21st day, non-perforated PE than in perforated PE. At 10°C on day 7, weight losses were significantly lower in non-perforated PE than in non-perforated PP and perforated PP. On the 14th day, weight loss was significantly lower in perforated PE and non-perforated PP than in perforated PP. However, there were no significant differences among the packaging types on days 21 and 28. At the end of the low temperature storage period (day 28) at 10°C, the average loss of weight in the packaged pepper fruits was 10.64% whereas the control (C) lost 73.55% of its weight. At the same storage time (28th day) at 4.3°C the average weight loss in the packed fruits was 20.94%, while the control (C) lost 51.25% (Table 4.2).

Visual inspections of the final produce revealed very slight sign of shriveling in the packaged samples stored at 4.3°C or 10 °C at the end of the 28 day storage period. In addition, weight loss in fruits packaged at 10°C was approximately two times lower (10%) than the fruits packaged at 4.3°C (20%) (Fig. 4.1). In the unpacked (Control) fruits, weight loss was lower at 4.3°C (51.25%) than at 10°C (73.55%) (Fig. 4.1)

Table 4.2 Interaction effect of packaging (MAP) and low temperature on weight loss

Treatment	**Percentage Weight Loss**			
	Day 7	Day 14	Day 21	Day 28
4.3°C				
PE non-perforated	2.18	7.10	16.97	21.15
PE perforated	0.83	7.78	13.50	18.67
PP non-perforated	1.52	10.68	15.52	22.09
PP perforated	2.87	9.80	16.02	21.87
Control(unpacked)	22.28	24.32	37.42	51.25
10°C				
PE non-perforated	2.57	4.16	7.08	9.91
PE perforated	4.01	3.70	6.37	10.53
PP non-perforated	4.69	3.60	8.50	10.20
PP perforated	4.96	5.80	7.94	11.93
Control(unpacked)	12.18	42.58	59.11	73.55
LSD 5%	2.05	1.81	3.11	6.46

PE and PP represent Polyethylene and Polypropylene films respectively.

4.1.3 Effect of low temperature or packaging (MAP) on Fruit Firmness

Generally, there was slight progressive decrease in firmness of the film-packed chilli pepper fruits at both 4.3°C and 10°C which was fairly maintained throughout the storage period, however, the firmness of the unpacked (C) fruits decreased sharply to unacceptable levels at the end of the storage period. Firmness at the beginning of storage was 1.45kg-force.

Low temperature alone maintained fruit firmness. Firmness was significantly higher in fruits stored at 10°C than 4.3°C on days 7, 21 and 28. (Table 4.3). Firmness was significantly higher in fruits packed in film compared to those unpacked at all the storage periods. (Table 4.3). The unpacked fruits became desiccated (dehydrated), shriveled, tough and less firm at the end of the storage period. The packed chilli peppers exhibited similar firmness among the different packaging films at any particular storage time.

Table 4.3 Effect of low temperature or packaging (MAP) on fruit firmness in chilli pepper.

Treatment	Firmness (kg-force)			
	Day 7	**Day 14**	**Day 21**	**Day 28**
Temperature				
4.3°C	1.3353	1.2947	1.2653	1.1960
10°C	1.3792	1.3147	1.2840	1.2307
LSD 5%	0.0257	0.0201	0.0159	0.0231
Packaging				
PE non-perforated	1.4300	1.4183	1.4000	1.3500
PE perforated	1.4333	1.4133	1.3933	1.3617
PP non-perforated	1.4300	1.4117	1.3950	1.3717
PP perforated	1.4383	1.4150	1.3883	1.3617
Control(unpacked)	1.0547	0.8650	0.7967	0.6217
LSD 5%	0.0407	0.0317	0.0251	0.0365

PE and PP represent Polyethylene and Polypropylene films respectively.

4.1.4 Interaction effect of packaging (MAP) and low temperature on fruit firmness.

Packaging type and the storage temperature interaction effect on firmness was observed.

Packaging type and the storage temperature interaction significantly maintained firmness of fruits during storage in all the packaging types than the control at both 4.3°C and 10°C. (Table. 4.4). There were no significant differences among the packaging types at both temperatures at any given storage period. Firmness in film-packed fruits at 10°C was slightly higher, though not significant, than those packed at 4.3°C. The initial firmness of the pepper fruits was 1.45kg-force. At the end of the storage period (28th day), the average firmness of fruits stored in packaging at 4.3°C was 1.35kg-force (6.89% reduction) and that of the control was 0.56kg-force (61.37% reduction). Similarly, at 10°C, firmness was reduced to 1.37kg-force (5.51% reduction) for packaged fruits and 0.68kg-force (53.10% reduction) for the control.

Table 4.4 Interaction effect of packaging (MAP) and low temperature on fruit firmness.

Treatment	Firmness (kg-force)			
	Day 7	Day 14	Day 21	Day 28
4.3°C				
PE non-perforated	1.4333	1.4200	1.4000	1.3500
PE perforated	1.4300	1.4033	1.3833	1.3433
PP non-perforated	1.4333	1.4200	1.4000	1.3667
PP perforated	1.4367	1.4167	1.3867	1.3567
Control	0.9433	0.8133	0.7567	0.5633
10°C				
PE non-perforated	1.4267	1.4167	1.4000	1.3500
PE perforated	1.4367	1.4233	1.4033	1.3800
PP non-perforated	1.4267	1.4033	1.3900	1.3767
PP non-perforated	1.4400	1.4133	1.3900	1.3667
Control	1.1660	0.9167	0.8367	0.6800
LSD 5%	0.0576	0.0449	0.0355	0.0516

PE and PP represent Polyethylene and Polypropylene films respectively.

4.1.5 Effect of low temperature or packaging (MAP) on Fruit Colour

Fruit colour was affected by the treatments during storage. Generally the reflectance value (lightness or brightness, L) was maintained in the packaged fruits than in the control. Green colour or greenness (-a*) in the fruits was also retained. L and a* values before storage was 39.31 and -3.01 respectively. Storage temperature affected fruit colour. L values at 4.3°C were significantly lower (less bright) than at 10°C in all the storage periods. On the other hand, greenness (–a*) values were significantly maintained (retained) at 10°C than at 4.3°C in all the storage periods. (Table 4.5). L values were significantly maintained in the film-packed fruits (PE non-perforated, PE perforated, PP non-perforated and PP perforated) than the control in all the storage periods and the packaging types did not present significant difference(s) among them. Greenness (-a*) was significantly better in fruits packed in all film types than the control on days 7, 14 and 21. (Table 4.5).

Table 4.5 Effect of low temperature or packaging (MAP) on fruit colour.

	Colour of Fruits							
Treatment	Day 7		Day14		Day 21		Day 28	
Temperature	L	a *	L	a *	L	a *	L	a *
4.3°C	40.07	-5.13	40.30	-4.86	40.21	-5.16	39.40	-7.69
10°C	40.93	-3.30	41.27	-3.54	41.85	-3.49	42.48	-3.42
LSD5%	0.64	0.77	0.73	0.35	0.79	0.21	0.58	0.90
Packaging								
PE non-perforated	40.22	-3.82	39.92	-3.76	40.40	-3.92	40.45	-5.12
PE perforated	39.68	-4.14	39.98	-3.95	39.95	-4.35	40.18	-5.73
PP non-perforated	39.82	-3.87	39.75	-4.03	39.96	-3.81	40.65	-5.52
PP perforated	40.06	-3.87	39.89	-3.83	40.88	-3.89	40.83	-5.18
Control	42.74	-5.38	44.39	-5.44	43.95	-5.67	42.58	-6.22
LSD5%	1.02	1.22	1.15	0.55	1.25	0.34	0.92	1.42

PE and PP represent Polyethylene and Polypropylene films respectively.

4.1.6 Interaction effect of packaging (MAP) and low temperature on Fruit Colour

As shown in Table 4.6, significant interaction effect of packaging and temperature on fruit colour was observed. The lightness (L) of fruits in all the packaging types, were significantly lower than in the control on the 7^{th} and 14^{th} day of storage at 4.3°C. The lightness (L) values were again significantly lower in PE non-perforated, PP non-perforated and PP perforated than the control on day 21. However, the L values of the control was significantly lower than those of fruits in the packaging type PE perforated at the end of 28 days of storage. For greenness (-a*), values for packaged chilli peppers were significantly retained than those in the control. (Table 4.6). At 10°C the lightness

(L) of fruits in all the packaging types were significantly lower than fruits in the control at all the various storage periods. (Table 4.6). Greenness (-a*) values in packaged chilli peppers were significantly retained than in the control at the end of the storage period. (Table 4.6).

Table 4.6 Interaction effect of Packaging (MAP) and low Temperature on Fruit Colour.

Treatment	Colour of Fruits							
	Day 7		Day14		Day 21		Day 28	
4.3°C	L	a *	L	a *	L	a *	L	a *
PE non-perforated	39.36	-4.36	39.50	-4.10	39.65	-4.05	39.35	-6.28
PE perforated	39.62	-4.74	39.61	-4.03	40.20	-4.79	40.03	-7.46
PP non-perforated	39.37	-4.49	39.57	-4.20	39.65	-4.07	39.40	-7.24
PP perforated	39.52	-4.43	39.61	-4.06	39.78	-4.06	39.87	-6.41
Control	42.50	-7.65	43.23	-7.92	41.76	-8.83	38.33	-11.09
10°C								
PE non-perforated	41.07	-3.28	40.35	-3.43	41.15	-3.79	41.54	- 3.97
PE perforated	39.74	-3.53	40.34	-3.87	39.70	-3.91	40.33	-4.01
PP non-perforated	40.27	-3.25	39.92	-3.86	40.26	-3.55	41.90	-3.81
PP perforated	40.61	-3.32	40.18	-3.77	41.98	-3.72	41.79	-3.94
Control	42.97	-3.11	45.55	-2.96	46.14	-2.52	46.82	-1.36
LSD5%	1.45	1.73	1.63	0.78	1.77	0.49	1.30	2.01

Fig.4.1 Colour changes in *Legon 18* chilli pepper fruits 28 days after storage under MAP in refrigerator (4.3°C) and at 10°C

a and b = chilli pepper 28 days after storage at 4.3°C and 10°C respectively in PE films

c and d = chilli pepper 28 days after storage at 4.3°C and 10°C respectively in PP films

e and f = chilli pepper 28 days after storage at 4.3°C and 10°C respectively . Unpacked (control)

4.1.7 Effect of low Temperature or Packaging (MAP) on fruit Chilling Injury (CI)

Chilling injury (CI) increased with prolonged storage and was more pronounced at 4.3°C storage temperature. CI was significantly lower in the fruits stored at 10°C than at 4.3°C at all storage periods. (Table 4.7). At the end of the 28 days of storage, chilling injury recorded was 1.6% and 33.5% for 10°C and 4.3°C storage temperatures respectively (about 20 times higher at 4.3°C). Chilling injury was significantly lower in the packaged fruits than the control at all storage periods. There were no significant differences among packaging types. Packaging effect on chilling injury was highest among the packages on day 28; but, the highest chilling injury was recorded in the control at the end of the 28 days of storage. (Table 4.7).

Table 4.7 Effect of low temperature or packaging (MAP) on chilling injury in chilli pepper fruits

Treatment	Chilling injury (%)			
	Day 7	Day 14	Day 21	Day 28
Temperature				
4.3°C	3.09	7.90	11.00	33.50
10°C	0.00	0.00	0.00	1.60
LSD5%	0.62	4.61	4.60	9.16
Packaging				
PE non-perforated	0.53	5.60	5.60	16.60
PE perforated	0.50	0.50	2.20	13.60
PP non-perforated	0.00	5.20	5.20	14.30
PP perforated	0.00	1.80	1.80	15.90
Control	6.68	6.70	12.70	27.40
LSD5%	0.98	7.29	7.27	5.79

PE and PP represent Polyethylene and Polypropylene films respectively.

4.1.8 Interaction effect of packaging (MAP) and low temperature on Chilling injury

No symptoms of CI were found in fruits stored at 10°C until day 28. (Table 4.8). On the contrary, CI symptoms of fruits were observed during storage at 4.3°C after 7 days of storage. Packaging and temperature interaction significantly reduced chilling injury at 10°C more than at 4.3°C after 28 days of storage. There were no significant differences among the packaging types at both storage temperatures. No chilling injury was observed in the control. The lowest chilling injury in packed fruit was observed in PP perforated at 10°C. CI in packed fruits was on the average 14 times higher at 4.3°C than at10°C after 28 days of storage.

Table 4.8 Interaction effect of packaging (MAP) and low temperature on Chilling injury

Treatment	**Chilling injury (%)**			
	Day 7	Day 14	Day 21	Day 28
4.3°C				
PE non-perforated	1.07	11.30	11.30	29.70
PE perforated	1.03	1.00	4.40	25.90
PP non-perforated	0.00	10.40	10.40	26.70
PP perforated	0.00	3.60	3.60	30.60
Control	13.37	13.40	25.30	54.80
10°C				
PE non-perforated	0.00	0.00	0.00	3.50
PE perforated	0.00	0.00	0.00	1.30
PP non-perforated	0.00	0.00	0.00	2.00
PP perforated	0.00	0.00	0.00	1.20
Control	0.00	0.00	0.00	0.00
LSD 5%	1.39	10.32	10.29	12.95

PE and PP represent Polyethylene and Polypropylene films respectively.

Figure 4.2 Chilling injury in *Legon 18* chilli pepper fruits stored at 4.3°C

4.1.9 Titratable Acidity

Generally, there was increase in titratable acidity (TA) of fruits at the end of the storage period with storage at 4.3°C resulting in lower TA than at 10°C. (Table 4.9). TA was lower for fruits stored in PE non-perforated and PE perforated than in PP non-perforated and PP perforated at 4.3°C. At 10°C there were differences among the packaging types with PP non-perforated and PP perforated having highest and lowest, respectively. The initial TA of the pepper fruits was 1.15%. At the end of the storage period (28th day), the average TA of fruits stored in packaging at 4.3°C was 1.24% (9.22% increase), similarly at 10°C, TA had increased to 1.5% (30.4% increase).

4.1.10 Total Soluble Solids

Total soluble solids (TSS) of fruits decreased over time during storage as shown in (Table 4.9). Total soluble solids content were higher at 4.3°C storage than at 10°C. TSS was higher in PE perforated than in PE non-perforated, PP non-perforated and PP perforated at 4.3°C. At 10°C, fruit TSS was higher in PE perforated than in PP non-perforated and PP perforated. Comparing TSS before storage (3%), fruits held in PP non-perforated at 10°C showed the lowest content of total soluble solids of 2% (33.3% reduction), while the highest of 2.9% (3.3% reduction) was recorded in fruits held in PE perforated at 10°C during the storage period.

4.1.11 Ascorbic Acid

Ascorbic acid content generally decreased in all treatments after the storage period. (Table 4.9). On the average, there was about 29% decrease in Ascorbic acid content after storage. The decrease was lower in fruits packed in PE non-perforated and PE perforated at 4.3°C. However, there were no differences among the rest of the packaging types at both temperatures.

4.1.12 Total Carotenoids

Carotenoids generally increased during the storage period. The initial carotenoids content of fruits was 0.085g/100gFW. (Table 4.9). Total carotenoids of fruits in PP non-perforated and PP perforated were higher than in PE non-perforated and PE perforated at 4.3°C. Also, carotenoids content of fruits in PP non-perforated and PP perforated were higher than those in PE non-perforated and PE perforated at 10°C. Regarding the packaging type on fruit total carotenoids content, it was observed that fruits stored in PP non-perforated and PP perforated at 10°C had the highest total carotenoids of 1.1693g/100gFW, while PE non-perforated at 4.3°C had the lowest carotenoid content of 1.1042g/100gFW.

4.1.13 Total Phenols

The total phenolic (TP) content of fruits in the different packaging types and storage temperature before and after 28 days of storage are shown in Table 4.9. The results show that, after storage there were increases in the TP at 10°C in all the packaging types while at 4.3°C, TP increases were observed in PP non-perforated and PP perforated. TP in PP non-perforated and PP perforated were higher than PE non-perforated and PE perforated at 4.3°C. Also, TP in PP non-perforated was higher than PE perforated at 10°C. The highest level of TP in the pepper fruits was found in PP non-perforated at 10°C (0.0678mg/100gFW) and the lowest in PE non-perforated and PE perforated (0.0417mg/100gFW) at 4.3°C.

Table 4.9 Changes in Ascorbic Acid (AsA), Titratable acidity (TA), Total soluble solids (TSS), Total Carotenoids and Total Phenols in MAP-stored *Legon 18* chilli pepper after 28 days of storage at 4.3°C and 10°C.

	TA (%)	TSS (% Brix)	AsA	Total Carotenoids	Total Phenols
			mg/100gFW	g/100gFW	g/100gFW
Initial	1.15	3.0	3.4	0.0850	0.0450
Treatment					
4.3°C					
PE non-perforated	1.24	2.8	2.8	0.1045	0.0417
PE perforated	1.26	2.9	2.8	0.1042	0.0417
PP non-perforated	1.15	2.6	2.3	0.1351	0.0538
PP perforated	1.35	2.6	2.3	0.1352	0.0536
10°C					
PE non-perforated	1.45	2.4	2.3	0.1423	0.0566
PE perforated	1.52	2.5	2.3	0.1422	0.0565
PP non-perforated	1.67	2.0	2.3	0.1691	0.0678
PP perforated	1.35	2.2	2.3	0.1693	0.0677

PE and PP represent Polyethylene and Polypropylene films, respectively.

4.2 Experiment 2: Effect of Modified Atmosphere Packaging (MAP) and Low Temperature Storage on the quality of green KA2 Chilli Pepper fruits.

4.2.1 Effect of low temperature or packaging (MAP) on weight loss

In general, weight loss was observed in all treatments with prolonged storage period. Generally, the use of packaging film and low temperature on the whole, reduced weight loss significantly. (Table 4.10). Temperature effect alone on weight loss at 4.3°C was not significantly different from that at 10°C throughout the storage period at any particular sampling period.

Packaging alone affected weight loss (Table 4.10). Weight loss was significantly reduced in packaged fruits than in the control at any particular storage period. Weight loss was significantly lower in PE non-perforated than in microperforated PE. However, there were no significant differences among the rest of the packaging types at any sampling period. (Table 4.10). Average weight loss in the unpacked fruits was approximately 4 times higher than that of the film packed fruits at the end of the 28 days storage period.

Table 4.10 Effect of low Temperature or packaging (MAP) on weight loss

Treatment	Percentage Weight Loss			
	Day 7	Day 14	Day 21	Day 28
Temperature				
4.3°C	5.64	10.83	15.85	20.04
10°C	6.38	11.59	16.74	19.18
LSD 5%	1.19	1.65	2.14	2.81
Packaging				
PE non-perforated	2.46	6.14	9.55	9.69
PP non-perforated	3.64	7.27	10.11	12.46
PE microperforated	3.64	7.64	11.58	14.96
PE (no pedicel)	3.23	5.46	8.35	10.75
Control	17.09	29.55	41.88	50.17
LSD 5%	1.88	2.61	3.38	4.45

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.2 Effect of Packaging (MAP) and low Temperature Interaction on weight loss

Significant interaction effect of packaging and low temperature on weight loss was observed. Interaction effect of packaging and low temperature significantly reduced weight loss in the packed fruits than the control at both 10°C and 4.3°C in all the storage periods. (Table 4.11). On the 28th day, weight loss was significantly lower in PE non-perforated than in microperforated PE at 4.3°C, however, there were no significant differences in weight loss among the packaging types. At 10°C there were no significant differences among the packaging types at any particular sampling period. At the end of the low temperature storage period (day 28) at 10°C, the average loss in weight in packaged pepper fruits was 9.15%, whereas the control sample lost 59.28%. At the same storage time at 4.3°C the average weight loss in the packed fruits was 14.78% while the control sample lost 41.06% (Table 4.11). The interaction effect of packaging and low temperature on weight loss in fruits packaged at 10°C was approximately 1.6 times (9.15%) lower than the packaged fruits at 4.3°C (14.78%). However, in the unpacked fruits (control), weight loss was lower (41.06 %) at 4.3°C than (59.28 %) at 10°C. (Fig. 4.11).

Table 4.11 Interaction effect of packaging (MAP) and low temperature on weight loss in chilli pepper fruits.

Treatment	Percentage Weight Loss			
	Day 7	Day 14	Day 21	Day 28
4.3°C				
PE non-perforated	3.33	8.37	11.81	10.88
PP non-perforated	4.22	8.70	12.11	15.82
PE microperforated	4.32	9.60	13.73	18.72
PE (no pedicel)	3.73	6.23	9.93	13.71
Control	12.60	21.24	31.69	41.06
10°C				
PE non-perforated	1.59	3.90	7.30	8.51
PP non-perforated	3.06	5.85	8.11	9.10
PE microperforated	2.96	5.67	9.43	11.21
PE (no pedicel)	2.72	4.68	6.78	7.80
Control	21.59	37.86	52.08	59.28
LSD 5%	2.67	3.70	4.78	6.29

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.3 Effect of low temperature or packaging (MAP) on Fruit Firmness

There was generally a decrease in firmness of the film-packed chilli pepper fruits at both 4.3°C and 10°C which was fairly maintained throughout the storage period. However, firmness in the unpacked (C) fruits decreased sharply over the storage period. Low temperature alone maintained fruit firmness. Firmness was significantly higher in fruits stored at10°C than at 4.3°C on days 21 and 28. (Table 4.12). Firmness was significantly higher in fruits packed in film compared to those unpacked at any particular storage period. There were no significant differences in fruit firmness among the packaging types at any particular sampling time.

Table 4.12 Effect of low temperature or packaging (MAP) on fruit firmness

Treatment	Firmness (kg-force)			
	Day7	Day 14	Day21	Day28
Temperature				
4.3°C	1.4893	1.4047	1.2960	1.2253
10°C	1.4853	1.4207	1.3373	1.2847
L SD 5%	0.0192	0.0242	0.0243	0.0270
Packaging				
PE non-perforated	1.5533	1.5333	1.5083	1.4850
PP non-perforated	1.5517	1.5417	1.5233	1.4967
PE microperforated	1.5517	1.5300	1.5167	1.4800
PE(no pedicel)	1.5450	1.5350	1.5083	1.4850
Control	1.2350	0.9233	0.5267	0.3283
LSD 5%	0.0303	0.0382	0.0384	0.0426

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.4 Interaction effect of packaging (MAP) and low temperature on fruit firmness.

Packaging type and the storage temperature interaction effect on firmness was observed. Packaging type and the storage temperature interaction significantly maintained firmness of fruits during storage in all the packaging types than the control at both 4.3°C and 10°C. (Table 4.13). Firmness in packed fruits at 10°C was slightly higher, though not significant, than those packed at 4.3°C. There were no significant differences among the packaging types at both temperatures at any given storage period. Initial firmness was 1.56kg-force and the average firmness in the packed fruits at 4.3°C after the 28 days storage period was 1.48kg-force (5.1% decrease) and that for the control was 0.20kg-force(87.1% decrease). Also, at 10°C, firmness was reduced to 1.49kg-force (4.4% decrease) for packaged fruits while the control was 0.45kg-force (71.1% decrease).

Table 4.13 Interaction effect of packaging (MAP) and low temperature on fruit firmness.

Treatment	Firmness (kg-force)			
	Day7	Day14	Day21	Day 28
4.3°C				
PE non-perforated	1.5500	1.5333	1.5067	1.4800
PP non-perforated	1.5467	1.5333	1.5133	1.4867
PE microperforated	1.5533	1.5400	1.5200	1.4733
PE (no pedicel)	1.5433	1.5367	1.5100	1.4800
Control	1.2533	0.8800	0.4300	0.2067
10°C				
PE non-perforated	1.5567	1.5333	1.5100	1.4900
PP non-perforated	1.5567	1.5500	1.5333	1.5067
PE microperforated	1.5500	1.5200	1.5133	1.4867
PE (no pedicel)	1.5467	1.5333	1.5067	1.4900
Control	1.2167	0.9667	0.6233	0.4500
LSD 5%	0.0429	0.0541	0.0544	0.0603

4.2.5 Effect of low temperature or packaging (MAP) on fruit colour

Generally the reflectance value (lightness, L) was maintained in the packaged fruits than in the control. Green colour or greenness (-a*) in the packed fruits was also retained. Storage temperature alone affected fruit colour. L values at 4.3°C were significantly lower than at 10°C at all the sampling periods. On the other hand, greenness (–a*) values were significantly maintained (retained) at 4.3°C than at 10°C on day 21. (Table 4.14). For packaging alone, L values were significantly lower in PE non-perforated than in PE (no pedicel) and the unpacked fruits (control) on day 21; while on day 28, lightness (L) was significantly lower in the film-packed fruits PP non-perforated than in the unpacked fruits (control). (Table 4.14). Packaging alone did not significantly present differences in greenness (-a*) in the chilli fruits among all the packaging types at all the sampling periods. (Table 4.14).

Table 4.14 Effect of low temperature or packaging (MAP) on fruit colour.

Treatment	Fruit Colour							
	Day 7		Day14		Day 21		Day 28	
Temperature	L	*a	L	*a	L	*a	L	*a
4.3°C	38.92	-3.03	38.38	-2.51	39.13	-2.27	37.79	-2.09
10°C	40.03	-3.24	39.89	-1.51	40.15	-0.37	40.59	-0.98
LSD 5%	0.44	0.47	1.37	1.56	0.57	1.55	1.01	1.26
Packaging								
PE non-perforated	39.05	-2.50	38.62	-1.57	38.99	-0.78	39.23	-0.12
PP non-perforated	39.67	-3.31	38.92	-2.83	39.19	-2.60	38.30	-2.72
PE microperforated	39.28	-3.29	39.04	-0.74	39.19	-0.83	38.88	-1.27
PE (no pedicel)	39.86	-3.21	40.37	-1.99	40.45	-0.98	39.05	-3.82
Control	39.53	-3.36	38.72	-2.93	40.39	-1.42	40.50	-0.25
LSD 5%	0.71	0.74	2.17	2.47	0.91	2.46	1.60	1.99

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.6 Interaction effect of packaging (MAP) and low temperature on fruit colour.

Packaging and temperature interaction retained fruit colour. In general lightness L, was lower at 4.3°C while it slightly increased at 10°C storage temperature. The lightness (L) of the fruits at 4.3°C was significantly lower than that at 10°C. (Table 4.15). On average, there was no significant difference in greenness (-a*) at 4.3°C and 10°C after 28 days of storage. The packed fruits in PE (no pedicel) at 10°C were significantly greener than those in PE microperforated and the control after 28 days of storage. Fruits without stem and calyx in PE non-perforated packages recorded the highest lightness and highest greenness values at 10°C after 28 days of storage.

Table 4.15 Interaction effect of packaging (MAP) and low temperature on fruit colour.

Treatment	Colour of Fruits							
	Day 7		Day14		Day 21		Day 28	
4.3°C	L	*a	L	*a	L	*a	L	*a
PE non-perforated	38.36	-2.25	37.77	-1.50	38.75	-0.34	38.81	-1.26
PP non-perforated	39.06	-3.58	38.13	-2.55	39.09	-3.27	37.40	-3.93
PE microperforated	38.67	-3.14	37.85	-1.50	38.51	-1.48	37.06	-1.54
PE (no pedicel)	39.85	-3.29	39.71	-3.84	40.14	-3.55	38.01	-3.51
Control	38.69	-2.86	38.43	-3.17	39.15	-2.72	37.68	-2.71
10°C								
PE non-perforated	39.73	-2.75	39.46	-1.64	39.24	-1.23	39.65	-1.50
PP non-perforated	40.29	-3.03	39.71	-3.11	39.28	-1.92	39.19	-1.50
PE microperforated	39.90	-3.43	40.22	-0.02	39.87	-0.17	40.71	-1.00
PE (no pedicel)	39.87	-3.13	41.02	-0.15	40.76	-1.59	40.09	-4.12
Control	40.37	-3.86	39.02	-2.69	41.62	-0.12	43.32	-0.78
LSD 5%	1.00	1.05	3.07	3.49	1.29	3.47	2.27	2.82

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

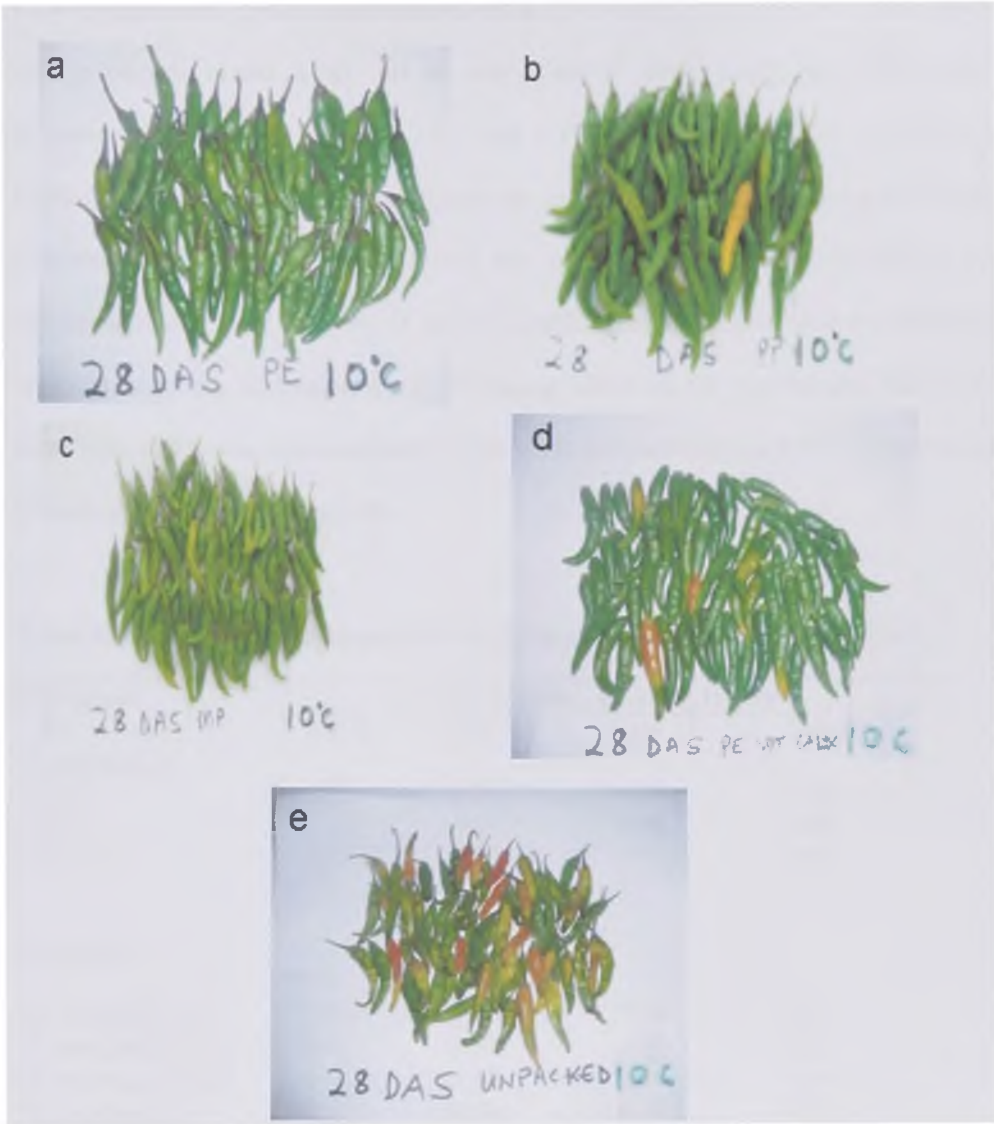

Fig. 4.3 Colour changes in *KA2* chilli pepper fruits 28 days after storage under MAP at 10°C

a, b, c, d and e = chilli pepper 28 days after storage at 10°C in PE, PP, PE Microperforated, PE (containing fruits without pedicel) and unpackaged (control) fruits, respectively.

4.2.7 Effect of low Temperature or Packaging (MAP) on Chilling Injury (CI)

CI was significantly lower in the fruits stored at 10°C than at 4.3°C on days 14, 21 and 28 storage periods. (Table 4.16). At the end of the 28 days of storage, chilling injury recorded was 0.0% and 1.6% for 10°C and 4.3°C storage temperatures, respectively. Chilling injury of fruits was lower, though not significant, in PP non-perforated, PE non-perforated without stem and calyx and the control than in PE non-perforated and microperforated PE on days 14, 21 and 28 sampling periods. There were no significant differences among packaging types. Packaging effect on CI was highest though not significant in PE non-perforated and lowest in PP non-perforated and PE non-perforated without stem and calyx on day 28.

Table 4.16 Effect of low Temperature or Packaging (MAP) on Chilling Injury

Treatment	Percentage Chilling Injury			
	Day 7	Day 14	Day 21	Day 28
Temperature				
4.3°C	0.35	1.37	0.00	1.60
10°C	0.00	0.00	0.00	0.00
LSD 5%	0.73	2.15	-	2.49
Packaging				
PE non-perforated	0.88	2.34	0.00	2.67
PP non-perforated	0.00	0.00	0.00	0.00
PE microperforated	0.00	1.09	0.00	1.33
PE (no pedicel)	0.00	0.00	0.00	0.00
Control	0.00	0.00	0.00	0.00
LSD 5%	1.15	3.40	-	3.94

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.8 Interaction effect of Packaging (MAP) and low Temperature on Chilling Injury

Packaging and temperature interaction prevented chilling injury in all the packaging types at 4.3°C except PE non-perforated on days 7, 14, 28 and in addition PE microperforated on days 14 and 28 of storage. (Table 4.17). No symptoms of CI were found in fruits stored at 10°C. There were no significant differences among the packaging types at both storage temperatures on days 14, 21 and 28. No chilling injury was observed in the control at both temperatures.

Table 4.17 Interaction effect of Packaging (MAP) and storage Temperature on Chilling Injury

Treatment	**Percentage Chilling Injury**			
	Day 7	Day 14	Day 21	Day 28
4.3°C				
PE non-perforated	1.75	4.68	0.00	5.35
PP non-perforated	0.00	0.00	0.00	0.00
PE microperforated	0.00	2.19	0.00	2.66
PE (no pedicel)	0.00	0.00	0.00	0.00
Control	0.00	0.00	0.00	0.00
10°C				
PE non-perforated	0.00	0.00	0.00	0.00
PP non-perforated	0.00	0.00	0.00	0.00
PE microperforated	0.00	0.00	0.00	0.00
PE (no pedicel)	0.00	0.00	0.00	0.00
Control	0.00	0.00	0.00	0.00
LSD 5%	1.63	4.81	-	5.57

PE and PP represent Polyethylene and Polypropylene films respectively (no pedicel = fruits without stem and calyx).

4.2.9 Titratable Acidity (TA)

Generally, there was an increase in titratable acidity at the end of the storage period. There were differences among the packaging types at both temperatures except between PE non-perforated without stem and calyx at 4.3°C and PP non-perforated at 10°C. (Table 4.18). Microperforated PE at 4.3°C had the highest TA while microperforated PE at 10°C had the lowest TA.

4.2.10 Total soluble solids (TSS)

Generally, total soluble solids increased over time during the storage period. (Table 4.18). There were differences among all the packaging types at both temperatures. Total soluble solids content was highest in PP non-perforated at 10°C than all the other packaging types at both temperatures. Fruits in microperforated PE at 10°C had the lowest TSS at both 4.3°C and 10°C storage temperatures. Comparing TSS before storage (2%), fruits held in PE microperforated without stem and calyx at 10°C showed the lowest content 1.9% (5% decrease) of total soluble solids during the storage period, while the highest 3.2% (60% increase) was in fruits held in PP non-perforated at 10°C.

4.2.11 Ascorbic Acid (AsA)

Ascorbic acid content of fruits generally decreased in all treatments after the storage period. (Table 4.18). The decrease was lowest in fruits packed in PE non-perforated at 4.3°C and PP non-perforated at 10°C. There were also differences in AsA content of fruits among all the packaging types at 4.3°C. However, there were no differences in AsA content of fruits among microperforated PE and PE non-perforated without stem and calyx at 10°C. Comparing AsA content before storage (5 mg/100gFW), fruits held in PE non-perforated at 4.3°C and PP non-perforated at 10°C showed the lowest decrease of

4.8mg/100gFW (4% decrease), in AsA after the storage period, while the highest decrease of 2.2 mg/100gFW (56% decrease) was in fruits held in PE non-perforated at 10°C.

4.2.12 Total Carotenoids

Carotenoids content of fruits generally increased during the storage period. The initial carotenoids content was 0.06mg/100gFW. Total carotenoids of fruits in PE non-perforated was significantly higher (41.6% increase) among all the other packaging types at 4.3°C, while those in microperforated PE was highest (53.3% increase) among all the other packaging types at 10°C.

4.2.13 Total Phenols (TP)

The total phenolic content in the chilli peppers varied in the different packaging types and storage temperatures. (Table 4.18). There were significant differences in TP of fruits among all the packaging types at 4.3°C. Higher total phenolic content was recorded for fruits in PE non-perforated without stem and calyx at 4.3°C. Fruits in PP non-perforated and PE non-perforated without stem and calyx had higher total phenolic content at 10°C, compared to PE non-perforated and microperforated PE, though there was no significant differences in the TP of fruits in the two packaging materials.

Table 4.18 Changes in ascorbic acid (AsA), titratable acidity (TA), total soluble solids (TSS), total Carotenoids and total phenols in MAP-stored *KA2* chilli pepper after 28 days of storage at low temperature.

Treatment	TA (%)	TSS (% Brix)	Ascorbic Acid	Total Carotenoids	Total Phenols
			mg/100gFW	g/100gFW	g/100gFW
Initial	0.73	2.0	5.0	0.060	0.036
4.3°C					
PE non-perforated	1.21	2.80	4.80	0.085	0.034
PP non-perforated	1.08	2.40	3.60	0.073	0.031
PEmicroperforated	1.45	3.00	3.20	0.051	0.022
PE (no pedicel)	1.12	2.80	4.60	0.072	0.041
10°C					
PE non-perforated	1.15	2.20	2.20	0.055	0.022
PP non-perforated	1.12	3.20	4.80	0.072	0.042
PEmicroperforated	0.89	1.90	4.10	0.092	0.035
PE (no pedicel)	1.04	2.20	4.00	0.072	0.042

PE and PP represent Polyethylene and Polypropylene films, respectively (no pedicel = fruits without stem and calyx).

4.3 Experiment 3: Effect of Modified Atmosphere Packaging (MAP) on the quality of Green *KA2* and *Legon 18* Chilli Pepper under Ambient Temperature

4.3.1 Effect of Packaging (MAP) on Weight Loss in green *KA2* Chilli Pepper

Generally, there was progressive loss in fruit weight in all treatments during storage. Weight loss was significantly lower in the film-packed fruits than the control (unpacked) at all the storage periods. (Table 4.19). PE non-perforated packed fruits had significantly lower loss in weight than PE microperforated on days 1 and 2 while for the rest of the sampling periods no significant differences in fruit weight were observed among the packaging. For chilli pepper fruits without packaging, the weight loss after twenty four hours (1 day) was as high as 10.54% while the packed fruits on average lost 0.93%. At the end of the storage period (9 days) the weight loss in unpacked (control) fruits reached 51.92% while the packed fruits averaged 8.14%. Weight loss in the packed fruits was approximately 6 times lower than in the unpacked (control) fruits at the end of the 9 days storage period.

Table 4.19 Effect of Packaging (MAP) on Weight Loss of *KA2* Chilli Pepper stored at ambient temperature

Treatment	Percentage Weight Loss								
	Days after Storage								
Packaging	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
PE non-perforated	0.77	1.78	2.68	3.90	5.70	6.71	5.45	6.23	7.70
PE perforated	0.94	2.16	3.23	4.06	6.10	6.74	6.74	7.61	8.30
PP non-perforated	0.97	2.19	4.13	4.71	5.77	5.80	6.78	7.77	8.37
PP perforated	0.92	2.05	3.03	4.12	4.53	5.11	6.09	7.05	8.34
PE microperforated	1.06	2.20	3.26	4.09	4.71	5.45	6.10	7.05	8.03
Control (unpacked)	10.54	17.21	22.97	27.87	33.72	37.42	41.22	46.78	51.92
LSD5%	0.24	0.37	2.42	1.62	1.56	2.70	2.57	2.44	2.61

4.3.2 Effect of Packaging (MAP) on Fruit Firmness in *KA2* chilli pepper

Generally, there was a decrease in firmness of the chilli pepper in all treatments during storage. Film-packed fruits were significantly firmer than the unpacked fruits at all sampling periods. (Table 4.20). At the beginning of storage, firmness was recorded as 1.52kg-force. Among the packaging types, firmness was fairly maintained throughout the storage period with no significant difference among treatments. On the other hand, the firmness of the unpacked (control) fruits decreased sharply and remained the same from the 7th day to the end of the storage period.

Table 4.20 Effect of Packaging (MAP) on Fruit Firmness

Treatment	Fruit Firmness (kg-force)								
				Days	after	Storage			
	1	2	3	4	5	6	7	8	9
Packaging									
PE non-perforated	1.5167	1.5100	1.5067	1.5067	1.5033	1.5000	1.5000	1.4867	1.4867
PE perforated	1.5167	1.5100	1.5100	1.5067	1.5067	1.5067	1.5000	1.4967	1.4900
PP non-perforated	1.5100	1.5067	1.5067	1.5033	1.4967	1.4967	1.4967	1.4900	1.4900
PP perforated	1.5133	1.5067	1.5033	1.5033	1.5033	1.5000	1.4967	1.4933	1.4933
PEmicroperforated	1.5100	1.5067	1.5067	1.5033	1.5033	1.5033	1.5000	1.5000	1.4900
Control (unpacked)	1.4333	1.4067	1.1533	0.9133	0.6567	0.4333	0.4000	0.4000	0.4000
LSD5%	0.0167	0.0110	0.0415	0.0251	0.0410	0.0431	0.0059	0.0102	0.0139

4.3.3 Effect of Packaging (MAP) on Fruit Colour (brightness L) in *KA2* chilli pepper.

The reflectance value (lightness or brightness, L) in all treatments increased during storage. The lightness value was significantly higher (lighter/brighter) in the control than the film-packed fruits from the 6^{th} to the 9^{th} day of storage. (Fig.4.4a). Greenness (–a*) values were significantly maintained (retained) in the packed fruits than the unpacked (control) from days 5 to 9. (Fig.4.4b). While the film-packed fruits retained greenness throughout the storage period, the unpacked fruits decreased sharply in greenness from the 5^{th} day and were recorded as red on the 8^{th} and 9^{th} day. (Fig.4.3b). However, among the packaging types there were no significant differences in the greenness.

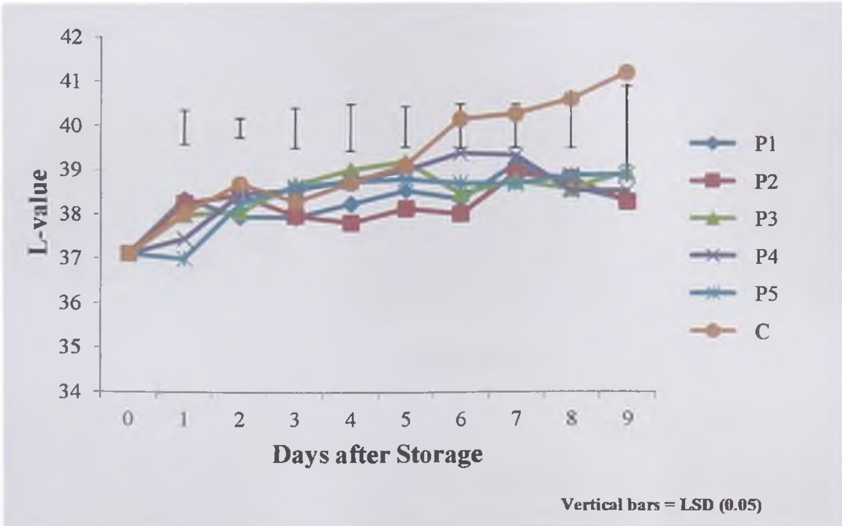

Fig. 4.4a Effect of Packaging (MAP) on Fruit Colour (brightness) in *KA2*

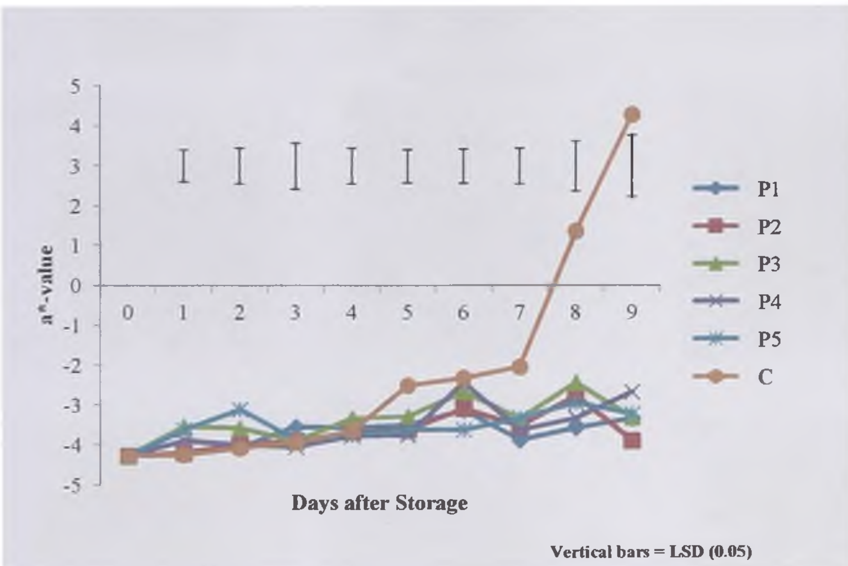

Fig. 4.4b Effect of Packaging (MAP) on Fruit Colour (a*) in KA2

Chilli pepper

P1= PE (nonperforated), P2= PE (perforated), P3= PP (nonperforated) P4= PP (perforated) P5=PE (microperforated) C=Control (unpacked)

Control

Fig. 4.5 Colour changes in *KA2* chilli pepper fruits during 9 days ambient storage

PE=polyethylene, PP=polypropylene, MP=Microperforated films and unpackaged (control-CR2) fruits

4.3.4 Effect of Packaging (MAP) on Fruit Decay in *KA2* chilli pepper

Fruit decay occurred in the film-packed fruits but not the unpacked during storage. Decay of fruits in PE non-perforated and PP non-perforated were recorded on the 4th and 5th day of storage, respectively (Fig.4.6), while PE perforated and PP perforated recorded fruit decay on the 6th day with no significant differences among them. The percentage incidence of decay was 0% for the unpacked (control) and on average 1.38% for the film-packed fruits during the 9 days of storage.

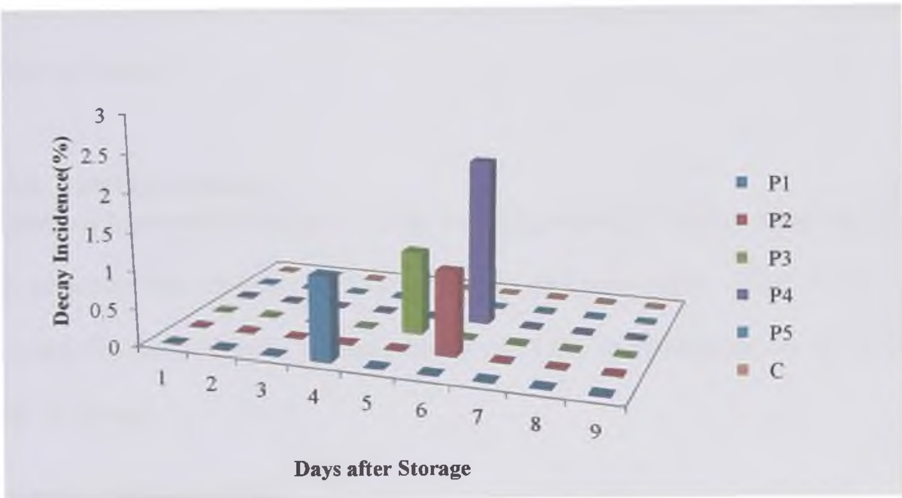

Fig 4.6 Effect of Packaging (MAP) on Fruit Decay in *KA2* chilli pepper fruits under ambient storage

P1= PE (nonperforated), P2= PE (perforated), P3= PP (nonperforated) P4= PP (perforated) P5=PE (microperforated) films and C=Control (unpacked)

4.3.5 Titratable Acidity (TA)

Generally, there was an increase in titratable acidity of fruits at the end of the storage period. TA of fruits in PE non-perforated and PE perforated were higher. On the average, TA in the film-packed fruits increased by 46.1%. (Table 4.21).

4.3.6 Total Soluble Solids Content (TSS)

Generally, total soluble solids in the PE film-packed fruits remained the same after the 9 days storage period. (Table 4.21).

4.3.7 Ascorbic Acid (AsA)

Ascorbic acid content generally decreased in all treatments after the storage period (Table 4.20). The decrease was lowest in fruits packed in PE microperforated. It was observed that the AsA content of fruits held in the films on average was reduced by 25.2% after the 9 days of storage.

4.3.8 Total Carotenoids

Carotenoids generally increased during the storage period. Total carotenoids content in PP perforated was highest among all the other packaging types. (Table 4.21). On the average, film-packed fruits had an increase of 14.6% in carotenoids content after the 9 days of storage.

4.3.9 Total Phenols (TP)

The total phenolic content in the chilli peppers increased after storage. (Table 4.21). Higher total phenolic content was recorded in PP perforated than in all the other film-packed fruits. On the average, film packed fruits had an increase of 15.8% in total phenols after the 9 days of storage.

Table 4.21 Changes in ascorbic acid (AsA), titratable acidity (TA), total soluble solids (TSS), total carotenoids and total phenols in MAP-stored *KA2* chilli pepper under ambient temperature after 9 days.

	TA (%)	TSS (% Brix)	Ascorbic Acid	Total Carotenoids	Total Phenols
			mg/100gFW	g/100gFW	g/100gFW
Initial	0.78	2.0	6.9	0.0740	0.0296
Packaging					
PE non-perforated	1.19	2.0	5.20	0.0778	0.0312
PE perforated	1.21	2.0	5.20	0.0781	0.0313
PP non-perforated	1.07	2.0	4.80	0.0940	0.0380
PP perforated	1.15	2.0	4.80	0.0960	0.0390
PEmicroperforated	1.12	2.0	5.80	0.0797	0.0321

4.3.10 Effect of Packaging (MAP) on Weight Loss in Green *Legon 18* Chilli Pepper Fruits

Generally, loss in fruit weight was observed in all treatments during storage. Weight loss was significantly lower in the film-packed fruits than the control (unpacked) at all the storage periods. (Table 4.22). PE non-perforated packed fruits had significantly lower loss in weight than PE microperforated after the nine day storage period. For chilli pepper fruits that were not packed, weight loss after 24 hours (day1) was as high as 15.53 % while the packed fruits on the average lost 1.32%. At the end of the storage period (day 9) the weight loss in unpacked (control) fruits was 68.53 % while that in the packed fruits was 9.52% on the average. Weight loss in the packed fruits was approximately 7 times lower than those in the unpacked (control) fruits at the end of the 9 days storage period.

Table 4.22 Effect of packaging on weight loss of chilli pepper fruits stored at ambient temperature

Treatment	**Percentage Weight Loss**								
			Days after Storage						
Packaging	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
PE non-perforated	0.88	2.07	3.30	3.82	4.21	5.04	5.54	7.19	7.81
PE perforated	1.40	2.77	3.88	4.76	5.06	6.05	7.44	8.77	9.83
PP non-perforated	1.22	2.65	3.86	4.37	4.91	5.61	7.00	8.42	9.32
PP perforated	1.21	2.75	4.18	4.52	4.93	5.58	6.90	8.86	9.84
PE microperforated	1.91	3.16	4.46	4.78	5.47	6.12	7.97	10.15	10.84
Control(unpacked)	15.53	26.13	33.67	39.45	47.02	54.48	59.96	65.09	68.53
LSD5%	0.59	0.86	1.24	0.71	0.92	1.02	2.10	2.13	2.28

4.3.11 Effect of Packaging (MAP) on Fruit Firmness in Green *Legon 18* Chilli Pepper Fruits

Fruit firmness generally decreased in all treatments. However, film-packed fruits were significantly firmer than the unpacked fruits at all sampling periods. (Table 4.23). At the beginning of storage, firmness was recorded as 1.42kg-force. Among the packaging materials, fruit firmness was fairly maintained throughout the storage period with no significant differences. On the other hand, the firmness of the unpacked (control) fruits decreased sharply and remained constant towards the end of the storage period.

Table 4.23 Effect of Packaging on Fruit Firmness

Treatment	Fruit Firmness(kg-force)								
				Days	after	Storage			
Packaging	1	2	3	4	5	6	7	8	9
PE non-perforated	1.4033	1.4033	1.3967	1.3900	1.3833	1.3533	1.2670	1.1170	0.9030
PE perforated	1.4066	1.4033	1.4000	1.3833	1.3600	1.2967	1.2570	1.1400	1.0070
PP non-perforated	1.4100	1.4100	1.4100	1.4000	1.4000	1.3667	1.3200	1.2930	1.2030
PP perforated	1.4100	1.4100	1.4000	1.3833	1.3767	1.3400	1.2100	1.0970	0.9700
PEmicroperforated	1.4100	1.4033	1.3833	1.3767	1.3033	1.2067	1.1330	1.0370	0.9770
Control(unpacked)	1.3966	1.2233	1.1133	1.0100	0.9367	0.6500	0.3070	0.3070	0.3070
LSD5%	0.0072	0.0233	0.0162	0.0192	0.0209	0.0650	0.0934	0.1251	0.0952

4.3.12 Effect of Packaging (MAP) on Fruit Colour in Green *Legon 18* Chilli Pepper

The reflectance value (lightness or brightness, L) in all treatments increased during storage. The lightness value was significantly higher (lighter/brighter) in the control than the film-packed fruits from the 2nd day of storage. (Fig.4.7a). Greenness (–a*) values were significantly maintained (retained) in the packed fruits than the unpacked (control). (Fig.4.7b). While the unpacked fruits lost greenness and were red ripe at the end of 9 days, the film-packed fruits considerably retained greenness with few fruits turning red during the storage period.

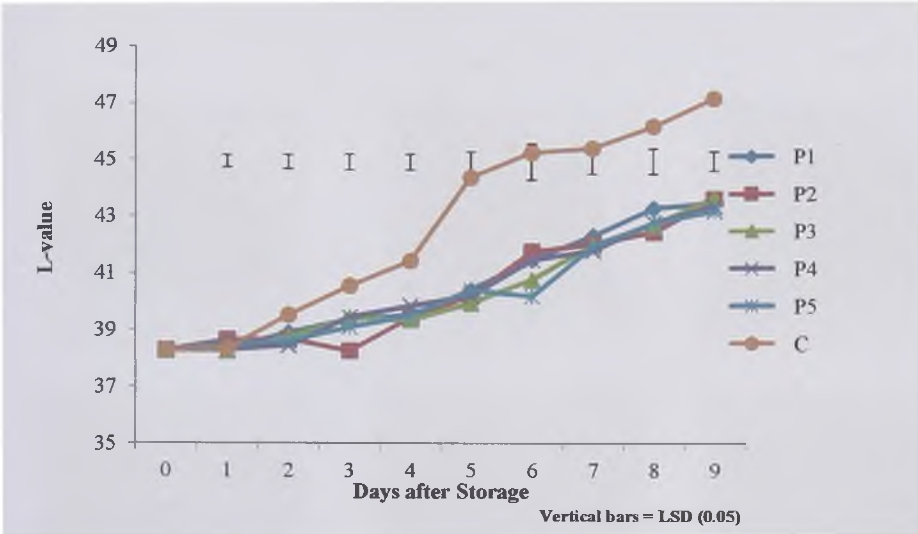

Fig 4.7a Effect of Packaging on Fruit Colour (brightness) in *Legon 18* chilli pepper fruits

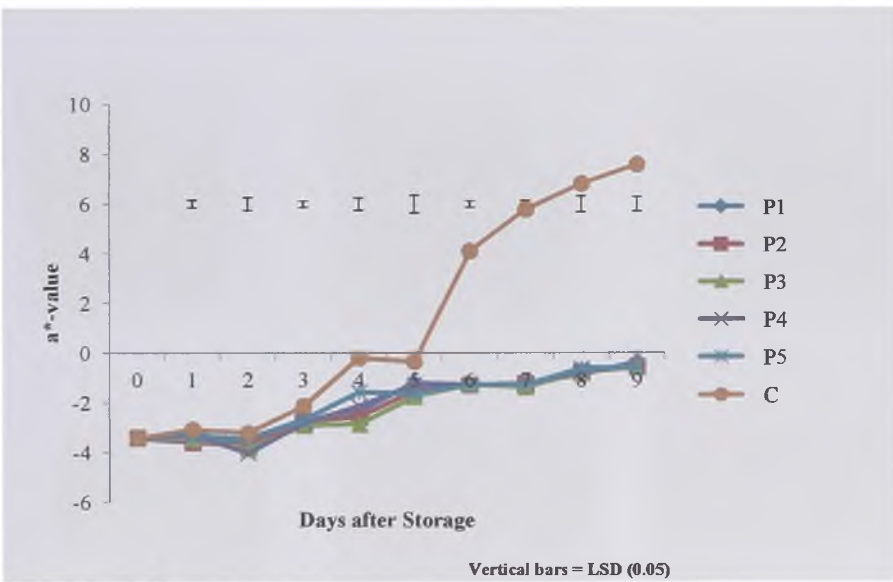

Fig 4.7b Effect of Packaging on Fruit Colour (greenness) in *Legon 18* chilli pepper fruits

P1= PE (nonperforated), P2= PE (perforated), P3= PP (nonperforated) P4= PP (perforated) P5=PE (microperforated) C=Control (unpacked)

Fig. 4.8 Colour changes in *Legon 18* chilli pepper fruits during 9 days ambient storage

PE=polyethylene, PP=polypropylene, MP= Microperforated films and unpackaged (control CTR) fruits

4.3.13 Effect of Packaging on Fruit Decay

Fruit decay occurred in the film-packed fruits but not in the unpacked during storage. Fruit decay was recorded in PE microperforated, PE non-perforated and PP non-perforated packages. PE microperforated package recorded significantly highest fruit decay on the 9th day of storage (Fig.4.9), while no significant differences in fruit decay were observed among the other packages. The percentage incidence of decay was 0% for the unpacked (control) fruits and on the average 4.74% for the film-packed fruits during the 9 days of storage.

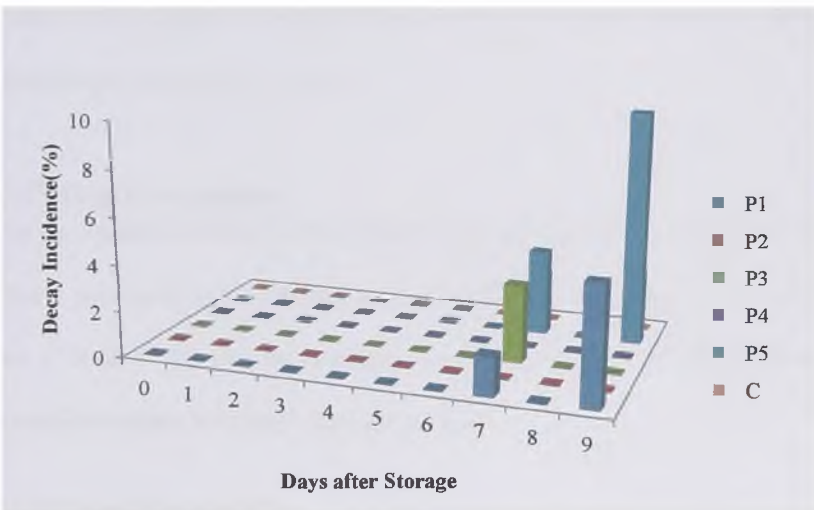

Fig4.9 Effect of Packaging (MAP) on Fruit Decay in *Legon 18* chilli pepper fruits after ambient storage

P1= PE (nonperforated), P2= PE (perforated), P3= PP (nonperforated), P4= PP (perforated), P5=PE (microperforated) and C=Control (unpacked)

4.3.14 Titratable Acidity (TA)

There was increase in titratable acidity at the end of the storage period. TA of fruits in the PE microperforated was highest. On the average, TA in the film-packed fruits increased by 40%. (Table 4.24).

4.3.15 Total Soluble Solids Content (TSS)

Total soluble solids of fruits in the PE perforated PE non-perforated and PE microperforated film-packed fruits increased. The TSS of fruits in PP non-perforated remained unchanged while that in the PP perforated decreased. (Table 4.24).

4.3.16 Ascorbic Acid (AsA)

Ascorbic acid content generally decreased in all treatment fruits after the storage period. (Table 4.24). The decrease was low in fruits packed in PE microperforated. Comparing the AsA of fruits before storage with those held in the films showed an average of 49.4% decrease after the 9 days of storage.

4.3.17 Total Carotenoids

Total carotenoids in fruits increased during the storage period. Total carotenoids content of fruits packaged in PE microperforated was highest among all the other packaging types. (Table 4.24). On the average, film-packed fruits had an increase of 45% in carotenoids content after the 9 days of storage.

4.3.18 Total Phenols (TP)

The total phenolic content in the chilli peppers increased after the 9-day storage. (Table 4.24). On the average film packed fruits had an increase of 88.2% in total phenols after the 9 days of storage.

Table 4.24 Changes in Ascorbic Acid (AsA), titratable acidity (TA), total soluble solids (TSS), total carotenoids and total phenols in MAP-stored *Legon 18* chilli pepper under ambient temperature after 9 days.

Treatment	TA (%)	TSS (% Brix)	Ascorbic Acid mg/100gFW	Total Carotenoids g/100gFW	Total Phenols g/100gFW
Initial	0.65	2.0	3.4	0.0595	0.0239
Packaging					
PE non-perforated	0.96	2.5	1.7	0.0878	0.0443
PE perforated	0.94	2.3	1.7	0.0788	0.0541
PP non-perforated	0.83	2.0	2.1	0.0886	0.0356
PP perforated	0.78	1.9	2.1	0.0784	0.0462
PEmicroperforated	1.08	2.3	1.0	0.0983	0.0451

CHAPTER FIVE

DISCUSSION

5.1 Effect of Modified Atmosphere Packaging (MAP) and Low Temperature Storage on the quality of *Legon 18* and *KA2* chilli pepper.

5.1.1 Effect of packaging (MAP) and low temperature interaction on weight loss in *Legon 18* and *KA2* chilli pepper.

Packaging and low temperature interactions reduced weight loss in the chilli pepper fruits due possibly to better water retention and reduced temperature. There were low percentage weight losses in *Legon 18* and *KA2* in film-packed fruits at both 4.3°C (refrigerator storage) and 10°C (Climatic Chamber) compared to the control. However, percentage weight losses at 4.3°C storage temperature for both varieties were higher than at 10°C storage temperature. The high weight loss at 4.3°C storage might be due to the fluctuating temperature in the refrigerator which was evident as heavy water condensation in the packaging. The temperature fluctuation encouraged accelerated water loss from the fruits in the packaging (Burton *et al.*, 1987; Kader *et al.*, 1989). The relative humidity (RH) in most sealed packaging is close to saturation. Therefore, even very small fluctuations in temperature during storage and/or shipment may result in water condensation on the surface of both film and produce (Aharoni *et al.*, 2007).

Fluctuating temperatures usually result in accelerated loss of moisture. Broccoli florets exposed to fluctuating temperatures encountered weight loss, decreased firmness and yellowing (Nunes *et al.*, 1999). Strawberries exposed to fluctuating temperatures during storage had higher weight loss and lower firmness and glucose content than fruits held at a constant temperature (Nunes and Emond, 1999). However, temperature (10°C) in the Climatic Chamber was comparatively more stable and therefore caused less water loss from the fruits. Secondly, another possible cause of the higher percentage weight losses of fruits stored in the refrigerator (4.3°C) is higher incidences of chilling injury recorded at 4.3°C (Wills *et al.*, 1982). Electrolyte leakage as a result of chilling injury has been shown to cause an increase in water loss (Wills *et al.*, 1982; Serrano *et al.*, 1997).

Among the packaging types within each variety, percentage weight loss differences were similar and not statistically significant and this might be due to the very close oxygen transmission rate (OTR) and water vapour transmission rate across the different films or packaging materials used in the study. This probably allows the different packaging materials to be easily substituted for one another in commercial application. However, comparing weight losses in the packed *Legon 18* and *KA2* fruits at both temperatures, lower weight losses were observed in KA2 than in *Legon 18* and this might be due to varietal differences in fruit morphology, degree of waxy cuticle and skin toughness. Control (unpacked) fruits of both varieties at the end of the 28 day storage period at both temperatures lost weight severely, became desiccated (dehydrated), wilted and shriveled and therefore became unsuitable for the fresh market for chillies (Mahajan *et al.*, 2008).

Low weight losses in the film-packed fruits observed were also probably due to the passive MAP, developed by the respiration process of the commodity which together with the permeability of the packaging film, might have caused a reduction in the O_2 content, while increasing the CO_2 concentration (Guevara *et al.*, 2003). After a period of adjustment, a steady state was established inside the package creating a modified atmosphere with higher concentration of carbon dioxide and reduced oxygen around the produce that slowed down fruit metabolic processes and transpiration (Day, 1993). In addition, confinement of moisture around the produce by the polyethylene, polypropylene and microperforated bags increased the relative humidity inside the packaging (90-95%) and reduced vapour pressure deficit and transpiration. Wall and Berghage (2007) reported 0% weight loss in chilli pepper packed in polyethylene bags and stored for one week at 8°C while the control fruits lost 3.8% of weight at 8°C. Manolopoulou *et al.* (2010) showed that storage of bell pepper in packaging films for 14 days resulted in limited weight loss (<2% of the initial weight) at both 5°C and 10°C storage temperatures.

Lower weight loss that was observed with a decrease in storage temperature could be attributed to the reduced rate of physiological processes such as respiration and transpiration that occurred at low temperatures as indicated by Kays (1991). Furthermore, Ben-Yehosua and Rodov (2003) reported that carbon loss caused by the respiration process can be an important source of weight loss when moisture loss is low. Therefore, slowing down the respiration rate through the MAP storage and low temperature, enhanced the reduction in weight loss in the packed fruits. Also, the packaging of (fruits without stem and calyx) of the *KA2* variety resulted in lower loss in weight (though not significant) and that postharvest treatments intended to reduce water loss from the calyx may be beneficial in extending shelf life in chilli pepper. Diaze-Perez (1998) observed high rate of water loss in eggplant through the calyx.

Cantwell and Thangaiah (2001) reported 2-4% as being the lowest limit for shriveling appearance in bell pepper and eggplant. It is interesting to note that though the percentage weight losses in the packaged fruits after 28 days at 4.3°C and 10°C for both varieties were high and inappropriate for quality storage, from visual inspections of the final produce, there were no appreciable wilting and shriveling in the packaged samples. Wadata *et al.*, (1987) reported that wilting condition did not always correlate with weight loss in bell pepper.

From a marketing perspective, one critical feature of fresh green chilli pepper quality is weight, as losses are translated into economic losses because weight loss greater than 5% would cause a reduction in retail value of vegetables and fruits (Ohta *et al.*, 2002).

5.1.2 Effect of low temperature and packaging (MAP) on Fruit Firmness

Generally, fruit firmness decreased with prolonged storage. However, the combination of packaging with low temperature maintained firmness of the fruit as compared to non-packed fruits. Thus, firmness was fairly maintained (had higher firmness) in the packed fruits at both 4.3°C and 10°C storage temperatures for the *Legon 18* and *KA2* throughout the storage period. This result is in agreement with that reported by Manolopoulou *et al.* (2010), in which packaging and temperature interactions reduced firmness loss in bell peppers packed in films. The film-packed fruits exhibited limited firmness at 5°C and 10°C while control samples were unable to preserve their firmness and suffered from significant firmness loss.

Fruit softening (firmness decline) has been found to be associated with pectin degradation in the middle lamella of the cell wall though Tijskens and Schouten (2009) suggests that firmness can originate from different sources, and that though moisture loss is a major cause of changes in firmness of horticultural products (particularly vegetables), it cannot be solely responsible for firmness loss. Van Dijk and Tijskens (2000) and Tijskens and Luyten (2004) indicated that most common sources of firmness are pectins, cellulosic structuring material, cell turgor, granule inside cells, shape and size of cells. Tijskens and Schouten (2009) suggested that not all of the sources of firmness have to change under the same conditions.

5.1.3 Effect of packaging (MAP) and low temperature on Fruit Colour

Fruit colour was measured and expressed with the CIE L*a*b*-system. The L-value describes the reflectivity (lightness or brightness). The parameters a* and b* are opponent colour scales. A negative value of a*(-a*) refers to green colour and a positive value (+a*) to red colour. Negative and positive values of b* refer to blue and yellow colours, respectively. Brightness (L values) in packed fruits was higher than unpacked (control) fruits at 4.3° C in both *Legon 18* and *KA2*. However, at 10°C fruits were brighter in the control (unpacked) than in the film-packed fruits of both varieties. Greenness (-a*) values in both varieties did not change remarkably in the film-packed fruits at the two temperatures which remained comparatively green throughout the storage period while the control fruit was less green.

The reduction in brightness at 4.3°C might be due to darkening of the fruit which is a symptom of chilling injury in some of the fruits which were even more pronounced in the unpacked fruits (control). Loss in green colour in the control fruits may be caused by increased breakdown of chlorophyll and synthesis of β-carotene and lycopene pigments, which occur during ripening (Grierson and Kader, 1986; Nyalala and Wainwright, 1998). Atmosphere modification and lowering of the temperature of non-climacteric fruits like chilli pepper lower their rate of ripening and deterioration (Kays, 1991) and hence the retention of green colour observed on film-packed fruits stored at 4.3°C and 10°C. Wang (1982) reported that peppers stored in modified atmosphere of 3% O_2 and 5% CO_2 showed reduced chlorophyll degradation compared with air control. Since there was no considerable development of a yellow or red colour in the film-packaged fruits, it appeared that the chlorophyll content was stable throughout the storage period indicating that such chilli pepper would still be marketable after 28 days of storage if colour was the primary quality indicator.

5.1.4 Effect of packaging and temperature on chilling injury

Packaging and temperature interactions affected the level of chilling injury. The chilling injury (CI) symptoms in the chilli pepper fruits were expressed as surface fruit darkening, water soaked areas and sheet pitting. In general, CI was more pronounced at 4.3°C in both varieties though *Legon 18* was more susceptible. However, CI was lower in the film-packed fruits than the control at 4.3°C. Fallik *et al.* (1995) observed that storing disinfected eggplant fruits inside polyethylene (PE) bag enabled them to be stored at 8°C for more than three weeks without sustaining any chilling injury. On the other hand, no CI was observed in film-packaged *KA2* and the control fruits for both varieties at 10°C while the film-packed *Legon 18* fruits recorded CI on the 28th day of storage. This finding is in agreement with the report by Smith *et al.* (2003), that chilling damage often depends on temperature and storage time. The high chilling injury recorded and more so at 4.3°C might be as a result of the changes in the membrane lipids of the cell, from flexible liquid crystalline into a solid gel structure at critical low temperatures. This change affects the enzymatic activity of the membrane as well as the synthesis and degradation of proteins causing a metabolic disruption of the cell (Wang, 1982; and Wills *et al.,* 1982). Membrane alterations and protein/enzyme diffusion and physiological changes lead to losses of structural integrity and overall fruit quality (Morris, 1982).

It is worth mentioning that no chilling injury was observed in *KA2* fruits stored at 10°C indicating varietal responses to low temperature storage. Brecht *et al.*, (1984) reported that genetic diversity of chilling sensitivity within a species can influence chilling injury.

5.1.5 Titratable Acidity

Generally, there was increase in titratable acidity (TA) at the end of storage period in both *Legon 18* and *KA2* at both temperatures. At 4.3°C, TA in *Legon 18* increased by 8.6% while that in *KA2* increased by 65.7%. Also at 10°C, the *Legon 18* increase was 30.4% and that of the *KA2* was 43.8%. Poubol *et al.* (2000), reported acidity increase in okra during storage in PE bags at 10°C. TA is directly related to the concentration of organic acids in fruits and vegetables (Kays, 1991). Organic acids exist as free acids, anions (malate) or combined as salt (potassium bitartarte) and esters such as isopentyle acetate (Kays, 1991). Sourness is determined by the concentrations of the predominant organic acids. Fruits and vegetables with very low levels of organic acids may therefore lack characteristic flavour (taste) (Kader, 2008).

5.1.6 Total soluble solids

Total soluble solids (TSS) generally decreased in *Legon 18* but increased in *KA2* film-packed chillies. The average decreases of TSS in the film-packed fruits after the 28 day storage period were 10% at 4.3°C and 26.6% at 10°C in *Legon 18* while increases of 35% at 4.3°C and 15% at 10°C in *KA2* were recorded compared to the initial value at the beginning of storage. The overall decrease in soluble solids in the *Legon 18* packages might be due to the respiration of the chilli fruits which consumed the soluble solids as reported by Wills *et al.* (1981). The higher decrease at 10°C is probably due to a higher respiration rate (Ayala-Zavala *et al.*, 2004). The increase in TSS of the *KA2* variety may be attributed to the hydrolysis of carbohydrates to soluble sugars (Waskar *et al.*, 1999).

5.1.7 Ascorbic Acid

There was a decrease in ascorbic acid (AsA) content in the packed fruits after 28 days of storage and the losses were lower at 4.3°C than at 10°C. *KA2* had a lower decrease in AsA content than *Legon 18* on the average and this might be due to pre-harvest conditions and varietal differences. At 4.3°C AsA in *KA2* decreased by 19% while *Legon 18* lost 49%. Also at 10°C *KA2* lost 24% while *Legon 18* lost 54% of the AsA content. Generally, fruits and vegetables show a gradual decrease in AsA content as the storage temperature or duration increases (Adisa, 1986). Wang (1977), also reported that storage for 6 days in CO_2-enriched atmospheres resulted in a reduction in AsA content of sweet pepper kept at 13°C. Therefore, the reduced O_2 level coupled with the elevated CO_2 level as a result of passive MAP in the packaging films might have caused the reduction in AsA content. Lee and Kader (2000), suggested that temperature management after harvest is the most important factor to maintain the vitamin C (ascorbic acid) content of fruits and vegetables and that ascorbic acid losses are accelerated at higher temperatures and with longer storage durations. Losses have also been reported by Lee and Kader (2000), to be enhanced by extended storage, higher temperatures and sometimes chilling injury. This might explain why the losses in ascorbic acid were higher at 10°C than at 4.3°C in both varieties after 28 days of storage. Gonzalez-Aguilar *et al.* (2004), reported that fresh-cut peppers under MAP and vacuum packages showed the highest values of ascorbic acid during storage at 5°C. Nevertheless water loss may enhance loss of ascorbic acid because of increased oxidation. (Nunes *et al.*, 1998).

5.1.8 Total Carotenoids

Generally, there was increase in total carotenoids at the end of the storage period in both *Legon 18* and *KA2* at both temperatures. The average total carotenoids in the film-packed *Legon 18* increased by 40% at 4.3°C and 82.3% at 10°C while *KA2* recorded 16% and 20% increase at 4.3°C and 10°C respectively. Carotenoid biosynthesis or chlorophyll degradation can cause the disappearance of chlorophylls and the appearance of carotenoids leading to increased accumulation or increased appearance of carotenoids. Carrillo-Lopez and Yahia (2009), reported that content of some carotenoids can increase from zero to high levels in a few days as a consequence of maturation and ripening. Lee *et al.* (2005) also reported that immature pepper fruits (*Capsicum* spp.) generally contained lower levels of lutein and xeaxanthin than mature and coloured fruits.

Adequate modified atmospheres (MA) and controlled atmospheres (CA), especially atmospheres with low concentrations of oxygen, are known to maintain carotenoids and reduce their losses (Yahia, 2009). Carotene content of tomatoes increased during storage when fruit were still in the ripening process, and this increase was more pronounced at higher temperatures of up to 25°C (Watada *et al*., 1987). These reported findings might explain the increase in the total carotenoid content during storage in the study.

5.1.9 Total Phenols

The average total phenols in the film-packed fruits increased slightly. An increase of 4.4% was recorded at 4.3°C and a much higher level (37.7%) at 10°C in *Legon 18*. On the other hand, *KA2* recorded 11.1% at 4.3°C and 2.7% at 10°C. Rai *et al*. (2010), reported a higher increase in the phenol content in betel leaves (*Piper betel L*) under MAP. The effect of storage temperatures on total phenol compounds on strawberry fruit has also been reported (Ayala-Zavala *et al.*, 2004). Total phenol compounds increased in berries stored at 5°C and 10°C.

5.2 Effect of Modified Atmosphere Packaging (MAP) on the quality of *Legon 18* and *KA2* chilli pepper under Ambient Storage Temperature.

5.2.1. Effect of packaging (MAP) on weight loss in *Legon 18* and *KA2* chilli pepper

The lower weight loss in film-packed fruits at ambient storage temperature for both *Legon 18* and *KA2* chilli pepper varieties is in agreement with the findings of Vanndy *et al.* (2007), that MAP films remarkably reduced weight loss of chilli pepper fruits; weight loss was only about 1.5% or less after three days of storage whereas fruits held in the open lost more than 10% of their initial weight. Packaging (MAP) might have created a passive MAP (higher concentration of carbon dioxide and reduced oxygen around the produce) resulting in reduction or slow down of the metabolic processes and transpiration (Thompson, 1996).

Secondly, increased relative humidity (90-95%) inside the packaging as a result of confinement of moisture around the produce by the packaging films might have reduced vapour pressure deficit and transpiration. Weight losses in the *KA2* for both film-packed fruits and control were comparatively lower than that in the *Legon 18* fruits which might be due to varietal or morphological differences as *KA2* has a tougher exocarp (skin).

5.2.2 Effect of packaging on fruit firmness

Fruit firmness generally decreased in all treatments over the storage period. However, film-packed fruits had reduced firmness compared to non-packed fruits (control) in both varieties. Control fruit reached lowest measured firmness by day 7 for both *KA2* and *Legon 18*. One of the main factors used to determine fruit quality and postharvest shelf-life is hardness (firmness) during storage (Tanada-Palmu and Grosso, 2005). The texture (firmness), in particular the crispness of the pepper is an important quality attribute to consumers. The softening (firmness decline) that occurs in fruits has primarily been reported to be due to a change in cell-wall carbohydrate metabolism, resulting in a net decrease in certain structural components (Labavitch, 1981). The changes in cell-wall composition result from the action of hydrolytic enzymes produced by the fruit. Prominent among the enzymes implicated are polygalacturonase (PG) and pectin methyl esterase (PME), because striking changes in cell wall pectin content are observed in ripening fruits, and activities of these two enzymes often increase as ripening continues (Fischer,1991). This might explain the gradual decrease in firmness over time though at a reduced rate in the film-packed fruits. Thus, it appears that the PE and PP films can adequately be used to preserve the firmness of green chilli pepper under ambient conditions particularly during short storage.

5.2.3 Effect of packaging (MAP) on fruit colour

The brightness (L values) generally in packed and unpacked fruits for both *KA2* and *Legon 18* increased over time. The unpacked fruits presented highest brightness (lightness) which might be due to ripening of the fruits which was more pronounced in *Legon 18* than *KA2*. However, ripening in film-packed fruits appeared to have slowed down or inhibited. Greenness (-a*) was maintained in the film-packed fruits than in the control. Control samples in both *KA2* and *Legon 18* varieties recorded +a* values (red) on days 8 and 6, respectively. Higher loss in green colour at ambient temperatures may be caused by increased breakdown of chlorophyll and synthesis of β-carotene and lycopene pigments, which occur during ripening (Grierson and Kader, 1986; Nyalala and Wainwright, 1998).

5.2.4 Effect of packaging (MAP) on fruit decay in KA2 and Legon 18

Incidence of fruit decay was recorded in the film-packed fruits, but not in the control. The high disease incidence observed with film packaging may be due to high relative humidity and water condensation around the produce, which promote the development of post-harvest decay (Coates *et. al.* 1995). Fruit decay was comparatively lower in the *KA2* than in *Legon 18* which might be due to varietal differences in susceptibility. *Fusarium* sp. was identified on the *KA2*.

5.2.5 Biochemical changes in *Legon 18* and *KA2* chilli pepper stored under MAP and ambient temperature.

Generally, there were increases in TA at the end of storage period in both *KA2* and *Legon 18*. Total soluble solids (TSS) in *KA2* remained the same while that in *Legon 18* generally increased. Sakaldas and Kaynas (2010) reported increase in TSS in bell peppers after 45 days of storage under MAP. The increased and the maintained TSS in *Legon 18* and *KA2* varieties respectively could be due to increased rate of ripening as a result of the high ambient temperature.

There was a decrease in ascorbic acid (AsA) content in the packed *KA2* and *Legon 18* fruits after 9 days of storage. On the average *Legon 18* had a higher decrease (49.4%) in AsA than *KA2* (25.2%) and this might be due to varietal differences. A gradual decrease in AsA content as the storage temperature or duration increases has been reported by Adisa (1986). Lee and Kader (2000), suggested that temperature management after harvest is the most important factor to maintain the vitamin C (ascorbic acid) content of fruits and vegetables and that losses are accelerated at higher temperatures and with longer storage durations.

Generally, there was an increase in total carotenoids at the end of the storage period in both *KA2* and *Legon 18*. Adequate modified atmospheres (MA) and controlled atmospheres (CA), especially atmospheres with low concentrations of oxygen, are known to maintain carotenoids and reduce their losses (Yahia, 2009). Carotene content of tomatoes increased during storage when fruits were still in the ripening process, and this increase was more pronounced at higher temperatures of up to 25°C (Watada *et al.*, 1987). These might explain the increase in the total carotenoid content during storage. The average total phenols in the film-packed fruits increased slightly. Rai *et al.* (2010), reported a higher increase in the phenol content in betel leaves (*Piper betel L*) under MAP storage.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

It can be concluded from the study that:

1. The use of non-perforated/perforated LDPE, non-perforated/perforated PP and microperforated films as packaging materials (MAP) in combination with low temperature provided better quality maintenance (reduced weight loss and chilling injury, firmness maintenance and green colour retention) in fresh green chilli pepper fruits (*Legon 18* and *KA2*).
2. Modified Atmosphere Packaging (MAP) using non-perforated/perforated LDPE, non-perforated/perforated PP and microperforated films under ambient temperature reduced weight loss; maintained firmness and green colour in green *Legon 18* and *KA2* chilli peppers compared to unpackaged fruits.
3. Changes in ascorbic acid, carotenoids and phenolic contents occurred in *Legon 18* and *KA2* chilli pepper fruits after MAP storage under both low (4.3°C, 10°C) and ambient (26-34°C) temperatures.
4. The combined effect of packaging films (MAP) and storage temperature at 10 °C produced the best results in terms of reduced weight loss and chilling injury, firmness and green colour maintenance in both varieties of fresh green chilli pepper.

6.2 Recommendations

Based on the findings of this study, the following are recommended:

1. The optimum storage temperature of 10°C in combination with MAP is most beneficial in maintaining the quality and thus extending the shelf-life of fresh green chilli pepper fruits. However, for storage of fresh green chilli pepper fruits in a refrigerator (around 4°C) as commonly done in households, packaging the fruits in plastic films (MAP) also maintains the quality and promotes extended storage life.
2. Storage of fresh green chilli pepper fruits for short periods under MAP in ambient conditions maintains the quality and thus extends the shelf life of the produce.
3. The simplicity of this method of packaging could considerably expand the scope for exporting high-quality chilli pepper fruits to distant markets.
4. Efforts should also be targeted at reducing condensation inside the package probably by the use of a desiccant.
5. Pungency levels (where requisite laboratory instruments are available for analyzing the capsaicinoids content - a major quality characteristic in chilli peppers) in MAP-stored chilli pepper fruits should be included in future studies.
6. Paper cardboard boxes (export boxes) lined or overwrapped with the films should be considered in future studies.

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