

**UNIVERSITY OF GHANA COLLEGE OF BASIC AND
APPLIED SCIENCES**

**PACKAGING OF PLANTAIN FOR IMPROVED
QUALITY AND SHELF LIFE**

BY

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Emily Naa Adobea Oku-Addo towards the award of the Master of Philosophy in Food Science in the Department of Nutrition and Food Science, University of Ghana.

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ABSTRACT

Plantain is an important cash and subsistence crop for the small-scale producers in Ghana but unfortunately, the plantain industry is plagued with high postharvest losses. These postharvest problems affect plantain quality and increase losses. The main aim of this study was to improve the quality and shelf life of plantains during the postharvest handling period by using different packaging options using two parameters. The first section was conducted to evaluate the effects of treatments (use of shredded plantain pseudostem, potassium permanganate, a combination of both, and control) and packaging types (paper, wood and plastic boxes) on the sensory and physicochemical components of plantains. The second part of the study dealt with the effect of packing arrangements on transit and subsequent storage of the plantains. The five packing arrangements were; i) Fingers separated by a layer of Styrofoam ii) Fingers lying directly on top of each other (no Styrofoam) iii) Hands separated by a layer of Styrofoam iv) Hands lying directly on top of each other (no Styrofoam) v) bunches separated by a layer of Styrofoam. All samples but the bunches were placed in were in plastic boxes during transportation and storage. Significant differences were found between the bunches and the four other arrangements after transit.

Total soluble solids (TSS), reducing sugar (RS), total sugar (TS), titratable acidity (TA), and pH were determined to follow the progression to senescence. By day 22, the TSS of the plantains in the pseudostem + KMnO_4 treatment recorded 36% and 25% in the pseudostem treatment. RS recorded 1.8% for pseudostem + KMnO_4 treatment and 1.3% for the pseudostem treatment. TS recorded 3.2% for pseudostem + KMnO_4 treatment and 1.9% for the pseudostem treatment. This trend was also observed for both TA and pH. These results were general averages of the packaging types. Pulp

firmness, peel colour and level of bruising, were also analysed by sensory means and followed the same trend with the plantains in the pseudostem + KMnO_4 treatment ripening faster than those in the pseudostem treatment. The pseudostem proved to be an ideal storage material for preserving the quality and extending the green life of plantains. For the packaging types, the plastic boxes contained and protected the plantains effectively. They also provided enough air for ventilation to combat heat but not too much to facilitate the ripening of the plantains. The paper and wooden boxes were less efficient thus, the quality of the plantains was compromised. Results of the first section (Objectives 1,2,3) indicated that plastic boxes with shredded plantain pseudostem recorded the longest shelf life of the plantains at 22 days, while plantains in the paper boxes with the pseudostem + KMnO_4 recorded the lowest at 13 days, before senescence. Results from Specific Objective 4 informed that pulp firmness and level of bruising were 2.00 ± 0.0 for the bunches and 1.00 ± 0.2 for the other four arrangements. Peel colour however wasn't affected. The use of Styrofoam did not have as much or any effect on the plantains during transit as the use of packaging did. During storage, the bunches ripened and reached senescence the fastest due to a high level of bruising, exposure to direct sunlight and oxygen. Hands with no Styrofoam was the second arrangement to reach senescence, followed by hands with Styrofoam, then fingers with no Styrofoam, and lastly fingers with Styrofoam. It took a maximum of 15 days for all samples to reach senescence but by day 12, the bunches were decayed.

Consequently, the use of plastic box and shredded plantain pseudostem as a storage material prolonged the green life of the plantain and improved upon its physical quality. Plantains arranged in fingers can also be used to preserve quality and extend green life of plantain.

DEDICATION

This work is dedicated to the Glory of the Almighty God, my mother, Ms. Joyce Oku, all my family members and loved ones for their love, patience, support and words of encouragement throughout my two-year study programme.

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CHAPTER ONE

INTRODUCTION

1.1 Plantain Production in Ghana

Plantain is a member of the *Musaceae* family, which originally stems from a wild-type species of banana *Musa balbisiana* (Samson, 1980). It is grown in the humid forest zones of Central and West Africa and is one of the most essential world food commodities providing up to 25% of the required food energy to about 70 million people in sub-Saharan Africa. Plantain is an important subsistence and cash crop in Ghana, with a contribution of about 13.1% to the Agricultural Gross Domestic Product (AGDP) and an 84.4 kg per capita consumption with 90% of it being locally consumed (SRID - MOFA, 2014; FAOSTAT, 2014). Plantain is known to provide estimated available food energy (AFE) of 172 Kcal/inhabitant/day and contributes up to 9.5% of the total national calorie intake, with a per capita annual consumption of 108.8 kg per head (Lescot, 2000). It also makes up about 13.1% of the Agricultural Gross Domestic Products (FAO, 2006). Plantain production in Ghana is done under the smallholder farm units (Ampofo *et al.*, 2013) and more than 90% of the cropped area belongs to the smallholder farming system (Dzomeku *et al.*, 2011). In the 2008/2009 farming season, 311,800 hectares of cropped areas produced 3,338,000 metric tons of plantain, while in the 2009/2010 farming season, 329,000 hectares of the cultivated area increased production to 3,587,000 metric tons (CILSS, 2010).

Plantain is a widely consumed starchy, staple food in Ghana and is highly versatile in its use as it is consumed in the unripe, ripe, and overripe forms, when raw or cooked (Akinyemi and Tijani Eniola, 2000). There are 3 main varieties of plantains, which

include the False Horn plantain (with local names; Apantu, Apentu pa, Brodewuo, Osoboaso or Brode Sebo), which is the most popular in terms of cultivation and consumption, the French Horn (also locally known as Apem, Oniaba, Apempa or Nyeretia) and lastly, the True Horn (Asamienu or Aowin).

Postharvest losses as high as 10% to 30% are associated with the crop because plantains have a short pre-climacteric period of less than one week and a shelf life of about 11 days under ambient conditions (Sugri *et al.*, 2010). Improper handling during transit leads to bruises, breakages, peel darkening, fungal diseases (such as crown rot), and major postharvest losses. Plantain packaging for storage, as well as during transportation, remains a challenge in Ghana, leading to major post-harvest losses (Dzomeku *et al.*, 2016; Ayanwale *et al.*, 2016).

Research findings show that the use of moistened plantain pseudostem around the plantains extends the green shelf-life of the plantains, whereas pseudostem in conjunction with Potassium permanganate, induces ripening (Asimeng, 2018; Quarshie, 2017). An ideal packaging material, preferably local, in addition to the above findings, is much needed to aid in the postharvest losses of plantains by controlling the rate of ripening as well as providing overall protection for the them. Good postharvest handling which includes proper packing arrangements and packaging, will ensure optimum quality and storage of the plantains is maintained over longer periods.

Materials that may be used in food packaging include glass, metal, plastics, wood, paper and some other natural materials. These materials can extend the shelf life of food by preserving both fresh and processed foods right from the farm to the consumer through

the prevention or reduction of water loss (especially in fresh produce). Food items that are not packaged are exposed to a wide range of microorganisms and pests that could potentially reduce the shelf life of food items (Opara, 2013). The material used is dependent on the nature of food product since different packaging materials possess a range of performance characteristics that exerts significant impact on shelf-life (Robertson, 2011). Hence, bottles and glass jars are often used for packaging liquid food stuff while solid food products are mostly packed in plastics, wood, paper and cardboards. Paper, wood and plastics are mostly used to package agricultural produce such as plantain, which is the focus of our study.

1.2 Rationale

Annual postharvest losses of plantain have been recounted to range from 10% to as high as 35% (Sugri *et al.*, 2010; Odemero, 2013) and these losses have been reported to be caused by a lack of proper handling practices in the value chain of plantain (Adeniji *et al.*, 2010). The Ghanaian agricultural sector is predominantly made of smallholder farmers and plantain production is ranked third in the food crop sector after yam and cassava. According to Adu-Amankwa & Boateng (2011), the majority of postharvest losses is severe among farmers (smallholder farmers) who lack sophisticated storage facilities to reduce post-harvest losses. Thus, an appropriate intervention would be the use of cost-effective methods to extend the shelf-life of the plantains.

Even though previous studies, such as Quarshie (2017) and Asimeng (2018) have been made in the area of maintaining the quality of plantains by the use of shredded and moistened plantain pseudostem for preserving the freshness and green colour of plantain for about 16 days and also, the use of KMnO_4 in conjunction with the pseudostem, their studies did not include the use of packaging types. KMnO_4 and pseudostem have been widely used for chemical treatments by scholars because they are readily available and are effective reagents that when combined can induce ripening (individually prolongs the green shelf-life of plantain) through the release of ethylene gas and changes in the natural fibre content of plantain (Kalia, Kaith & Kaur, 2009; Imoisili *et al.*, 2017). It is therefore against this background that this research aims to investigate packaging types and close the gap in literature; with the above treatments, that will further maintain the quality of plantain during transportation and subsequent storage.

1.3 Objectives

1.3.1 Main Objectives

To investigate the effect of different packaging types and treatments on the quality of plantain during transportation and storage.

1.3.2 Specific Objectives

1. To determine changes in some biochemical and physicochemical properties of plantains in different storage treatments.

2. To determine the effects of packaging types and treatments on some biochemical and physicochemical properties of plantains.

3. To evaluate changes in some sensory quality characteristics (pulp firmness, peel colour and level of bruising) of plantains stored in the various packaging types and treatments over time.

4. To investigate the effects of different forms of packing arrangements on sensory quality characteristics of the plantains during transit and subsequent storage.

CHAPTER TWO

LITERATURE REVIEW

2.1 Classification of Plantain and Banana

Plantain (*Musa* spp. AAB group) is a giant perennial herb which is a natural inter-specific cross between the two wild species *Musa accuminata colla* which contributes to genome A and *Musa balbisiana colla*, contributing genome B (Simmonds and Shepherd, 1955; Stover and Simmonds, 1987). It is believed to have originated from the hot tropical region of South Asia, into the humid tropics of Western and Central Africa where some 116 named cultivars have been identified. It is also said to have a life span of about fifteen years (Swennen, 1990; Philips, 1982). Plantains require some form of processing before consumption since these are crops whose fruits remain starchy at maturity (Marriot and Lancaster, 1983; Robinson, 1996).

It is estimated that plantain production in Africa is more than 50% of worldwide production (FAO, 1990) and is the fourth most important starchy staple crop after grains, cassava and yam in Ghana, according to Copley and Morris (1993). In Ghana, plantain is usually grown using shifting cultivation and bush fallow in the moist forest belt, where the annual rainfall ranges from 1500 to 3600 mm per year (Schill *et al.*, 2000). About 80% of plantains in Africa are produced in the area stretching from the lowlands of Guinea and Liberia to the central basin of DR Congo (Aiyelaagbe *et al.*, 2001).

The family includes two main genera *Musa* and *Ensete* and sometimes the monotypic genus, *Musella* (Constantine and Rossel, 2001). Two diploid species, *Musa acuminata*

(AA), and *balisiana* (BB) gave rise to most of the identified edible-fruited cultivars. However, there are diploid, triploid and tetraploid hybrids comprising of subspecies of *M. acuminata*, and subspecies between *M. acuminata* and *M. balbisiana* (Robinson 1996; Stover and Simmonds, 1962).

The use of physical attributes such as forms, shapes or structures and colour, as well as determined traits such as the weight of a bunch enables one to characterize or classify the bananas (Stover and Simmonds, 1962). Simmonds and Shepherd (1955) gave a list of fifteen features used in the scoring of *Musa* cultivars. For each character corresponding with the wild *Musaceae acuminata*, a score of one (1) was given while those corresponding to *M. balbisiana* got a score of five (5) and intermediate cultivars were given intermediate scores. This means a cultivar could get a total score of at least fifteen (15) and at most seventy-five (75). The AA and AAA cultivars obtained scores of fifteen (15) to twenty-four (24), AAB cultivars twenty-five (25) to fifty-four (54) and ABB fifty-five (55) to sixty-four (64) (Onguso *et al.*, 2002). Age, developmental stage, or environmental effects on measured traits may reduce the efficiency of identification, although classical phenotype characteristics are still extremely useful (Bhat *et al.*, 1995).

2.2 Economic Importance of Banana and Plantains in the Food Chain

Plantain has been rated the fourth most important food crop after rice, wheat, and maize as it occupies a strategic position in world food production (Phillip *et al.*, 2009; FAO, 2014). It is a major staple food and also a cash crop supporting the socio-cultural life of both rural and urban economies in sub-Saharan Africa (IITA, 2009). In Ghana and Nigeria, plantain is rated third, following yam and cassava closely, and respectively, in terms of importance in the starchy staple community (FAO, 2014). The socioeconomic

importance of plantain and banana in most African economies where it is usually grown, is seen in the areas of food security, job creation and as a source of rural income. An example can be seen in the Ghanaian sector where only a hectare of plantain cultivation is said to provide an average of 0.75 direct employments, which when compared with the national cultivated acreage, is converted into about 350,523 permanent jobs for people (Rodriguez and Rodriguez, 2001, Dzomeku *et al.*, 2011).

Plantain is said to have a proven medical, as well as industrial relevance, other than being consumed as food (Faturoti *et al.*, 2007). Plantain, especially its peels, contains low amounts of sodium making it an ideal diet for people with kidney diseases and can also neutralize free hydrochloric acid, thereby making it a very potent medicine for treating peptic ulcers (Gowen, 1995).

This crop is described as being versatile and with a great potential of being processed into different products. Several processing industries have emerged as a result of this and are processing the crop into products such as bread, cakes and biscuits (Ogazi, 1996; Phillip *et al.*, 2009). Cooking banana and plantain are eaten either as raw (in the ripe state) or as a cooked crop and in many homes, it is the raw material for the preparation of several popular local delicacies and snacks (Aina *et al.*, 2012). In Cameroon, Ghana, Nigeria and other parts of Africa, the plantain may be boiled, fried, roasted, and sometimes even baked into a variety of food products with some of the methods requiring further processing such as slicing, cutting, mashing and grinding. In some parts of Uganda, dried forms of the unripe fruits are stored as famine food, and the flour is used in making cakes and cookies (INIBAP 2001).

The crop is also said to be a major source of carbohydrates for many people in Latin America, the Pacific, Asia, the Caribbean and Africa (Tchango *et al.*, 1999) and a fundamental source of rural income to most people in the developing world (Vuylsteke *et al.*, 1993).

2.3 World Production of Plantain

Approximately 120 countries in the world are known to cultivate plantains and bananas (Olorunda, 2000) with the estimated total world production of plantains presently around 33 million metric tons. Out of the total production, about 32% or more is produced in West Africa alone. The ten highest banana and plantain producing countries are from Africa and the Caribbean regions with the top three being from Africa. Uganda, Cameroon and Ghana produce 4.6 million MT, 3.9 million MT and 3.8 million MT, respectively. Nigeria is 5th and Cote d'Ivoire is 7th producing 3.0 million MT and 1.6 million MT, respectively (FAOSTAT, 2017). In Uganda alone, the per capita consumption of bananas as a staple food is about 223 kg per person per year (Viljoen *et al.*, 2004). These statistics emphasize the importance of sub-Saharan Africa, particularly West Africa, in the worldwide production of plantain and banana (EPAR, 2013). Available Food and Agricultural Organization Statistics (FAOSTAT) over the years also show that plantain production in Africa is much higher as compared to banana production.

In the Carribeans, plantain is usually grown in the Caribbean coastal area, largely by small-scale farmers for local consumption and also for export. Banana production absorbs half of the pesticide imports in Costa Rica whilst plantain traditionally has been less dependent on chemical treatments (Agama-Acevedo *et al.*, 2015). Plantain is a

diet very common in many Latin American countries (Barraza *et al.*, 2011). In Ghana, plantain cultivation covers about 337, 000 hectares of the available farmlands with an average farm size of around 0.8 hectares. The total household farming of plantain in Ghana is also estimated to be over 400,000, with over more than 90% of the cultivated area in smallholder farms (SRID-MOFA, 2014). Plantain, maize, rice, sorghum, millet, cowpea, cassava, yam, and cocoyam are the major food crops known to be cultivated in Ghana, which collectively contribute appreciably to the country's Agricultural Gross Domestic Products (AGRA, 2014).

2.4 Postharvest Losses in Fresh Produce

Postharvest losses (PHLs) can occur either qualitatively or quantitatively. When losses occur qualitatively, they occur as physical conditions on the plantain and manifest in the form of perceived substandard value, texture and flavour deterioration and changes in nutritional value. On the other hand, quantitative value manifests in the form of physical losses of food unfit for human consumption and as such leads to food being discarded. Economic loss is also another form of loss and occurs when high quality produce is restricted to lower markets. Comparatively, quantitative losses are easier and less complicated to assess than qualitative losses since qualitative losses are determined by a plethora of factors included in an official grading standard since loss in quality does not always translate to food loss (Morris & Kamarulzaman, 2014).

This further complicates qualitative losses and could be the reason postharvest losses information system (APHLIS) network model for grain loss assessment is quantitative losses and not qualitative. Plantain is a staple in Ghana and as such that downgrades its quality and economic value making them undesirable for certain culinary user markets.

Therefore, assessments of both quantitative and qualitative losses in plantain are of equal importance (Parfitt *et al.*, 2010).

Generally, quantitative losses are measured by a number of methods such as weight of discarded, calorific value, lost inputs, greenhouse gas (GHG) emitted and cumulative weight loss. If weighed values are obtained in each supply chain activity, the volume of PHLs can be estimated in terms of percentage losses with respect to total production volumes as described in the study by Sharma and Singh (2011). Alternatively, a “loss profile” described by APHLIS model could be obtained for plantain through collection of cumulative weight losses for each step of the supply chain with respect to the total production estimates (Parfitt *et al.*, 2010). On the other hand, qualitative losses which is more of a subjective and abstract phenomenon is difficult to measure directly and rather described in terms of or state of the product in question. Though complicated, qualitative losses should not be ignored: because PHLs may not give a complete picture without qualitative losses. For this reason, measurement of qualitative postharvest losses should not be generalized but instead simplified to include only important valued factors for each commodity (Ekunwe & Ajayi, 2010).

Many authors have had varying definitions for postharvest losses (Parfitt *et al.*, 2010). Generally, all the definitions for postharvest losses’ have revolved around anything or any condition that causes quantitative and/or qualitative decrease in the produce during the various interconnected activities from harvesting through to the final consumer that are measurable (Kader, 2002; Grolleaud, 2002; Stuart, 2009). Qualitative loss, which includes the acceptability or edibility and/or loss in the nutrient content of a given food product, is more common among developed countries (Kader, 2002)

whereas quantitative loss, resulting from a loss in the number of products are much common in developing countries (Kintinoja and Gorny, 1999).

The issue of food loss may be interchanged with food damage and food wastage. Any physical sign of deterioration that limits the use of the product/food is food damage, while food loss has to do with the food being unavailable or impossible to use (ACF, 2014). In fresh agricultural products like fruits, vegetables and tubers, these losses may occur as a result of certain natural or biochemical changes and processes that are ongoing even after harvest (Sousa- Gallagher *et al.*, 2011). Food waste also occurs when food that is appropriate for human consumption is left to spoil or is discarded whether before or after its expiry date (ACF, 2014). Wastage therefore is centered on the behaviour of consumers and food handlers, and the term “wastage” is used to include loss and waste of food. This definition, however, does not include inedible parts of food disposed of or animal feed but rather, a subset of food loss, which can be retrieved for human consumption (Hodges *et al.*, 2011).

Globally, food wastage (and/or loss) is higher in the downstream phases of the food chain in high-income countries, however, in low-income regions, more wastage and loss are recorded at the upstream phases (FAO, 2013). The population of the world in 2050 is expected to rise to about 9 billion and by this figure; there must be a corresponding rise of about 70% in the world’s food production of especially the major food crops to be able to feed this population (FAO, 2011). These high postharvest losses recorded in fresh produce, especially in Africa, could therefore be tolerated no longer, and as such diverse interventions and strategies are required (ACF, 2014).

2.5 Estimated Postharvest Losses Plantain

According to Parfitt *et al.* (2010), the global estimation of loss in all foods produced is about 1.3 billion tons and this poses a huge problem in parts of Africa, the Pacific, and the Caribbean (ACP countries), where a high percentage of about 40-50% of the total of fresh produce from these areas are wasted due to poorly developed infrastructure and further worsened by the tropical weather (SPORE, 2011). The postharvest loss of plantain is mostly due to the highly perishable nature of the plantain fruits and varies from country to country due to the difference in the organization of the market link and modes of consumption (Tchango *et al.*, 1999). In developing countries, postharvest losses in plantain are estimated to be around 35% (Adeniji *et al.*, 2010). Losses are about 10-30% in Ghana annually and even higher in Nigeria at about 40% (Sugri and Johnson, 2009; Odemero, 2013). Also, reports have shown that 50-60% of all food crops grown in Ghana fail to make it to the final consumer (AGRA, 2014). These high postharvest losses and wastes recorded in plantain as well as other fresh produce are major factors that limit the availability of crops on the market (Ayanwale *et al.*, 2016).

Plantain losses through wastage in sub-Saharan Africa are nearly non-existent due to the many uses found for plantain in this region (Ogazi, 1996; Phillip *et al.*, 2009). In Ghana, plantains are used in the preparation of several dishes and snacks, from the matured green stage right through to its almost rotten stage, where it is used to prepare '*tatale*'. However, whether it is food damage, food waste or food loss, research has shown that they are all likely to occur at any stage in the postharvest chain and sometimes even at the production stage (Parfitt *et al.*, 2010). In Cameroon, the clearest postharvest losses are recorded at the producer level in the enclave sites during the wet season (Treche, 1997).

Some factors contributing to the agitation of postharvest losses and cause of fruit quality depreciation include maturity level of produce (harvesting at different maturity close to fruit ripening), poor transportation and distribution facilities in the production site, poor storage conditions, and also, improper handling practices.

2.6 Respiratory behaviour of fresh produce and its influence on produce ripening

A process in living organisms which involves the production of energy, typically with the intake of oxygen and the release of Carbon dioxide from the oxidation of complex organic substances. It is one of the important processes in fresh produce that affects the quality and shelf-life (Fagundes *et al.*, 2013). The sugar and acid reserves, with increased metabolism activity, are the substrates consumed during respiration, which leads to the shortening of their shelf life (Chitarra and Chitarra, 2005). The respiration rate of given fresh produce is said to be inversely proportional to its shelf-life and therefore, the estimation of respiration rate is of crucial importance in shelf-life determination (Kader, 1987).

The rate at which fresh produce respire, is dependent on certain external and internal factors. Internal factors being the nature and or type of fresh produce such as variety, stage of maturity/ripening and extent of bruises/damages. Conditions in the storage environment such as temperature, gaseous composition, presence/absence of ethylene and relative humidity, count as the external factors. Bananas and plantains under ambient conditions have been reported to have a moderate respiration rate of between 10-20 mg CO₂ Kg/h compared to the high rate of between 20-40 mg CO₂ Kg/h for avocados and low rate of between 5-10 mg CO₂ Kg/h for apples, citrus, potatoes, and onions under same conditions (Kader, 1987).

Fruits and vegetables are classified as either climacterics or non-climacterics based on their distinct respiration rates (Mahajan and Goswami, 1999; Suman *et al.*, 2011). In climacteric fruits, there is a trend of decreasing respiration rate to a very low value also known as the pre-climacteric minimum. This is then followed by a sudden upsurge in the rate of respiration to the climacteric peak also termed respiratory climacteric. This respiratory climacteric is that point in time during the development of the fruit when there is a change from growth to senescence due to a series of biochemical changes and an autocatalytic ethylene production initiated by a rise in respiration rate (Sousa-Gallagher and Mahajan, 2011). This process is what makes climacteric fruits continue to ripen even when they have been harvested mature green from the mother plant. When the temperature is not controlled, there is a rapid ripening and senescence in climacteric fruits due to the rise in respiration. It also leads to the breakdown of tissues, synthesis of characteristic volatiles and moisture loss due to over-ripening. Fungal and bacterial infections can also result from high moisture and warmth (Aked, 2000).

Non-climacteric fruits and vegetables show no rise in respiration rate as well as ethylene production (Sousa-Gallagher and Mahajan, 2011) and in these kinds of fruits, the process of ripening can only be completed when the fruit is still attached to the mother plant (Kader, 2002). Unlike climacterics, their eating quality greatly suffers when picked from the parent plant before the ripening process completes since their acid and sugar contents do not increase afterward (El-Ramady *et al.*, 2015). In Table 2.1 are some examples of

both climacterics and non-climacteric fruits according to Kader (2002) and Sirivatanapa (2006).

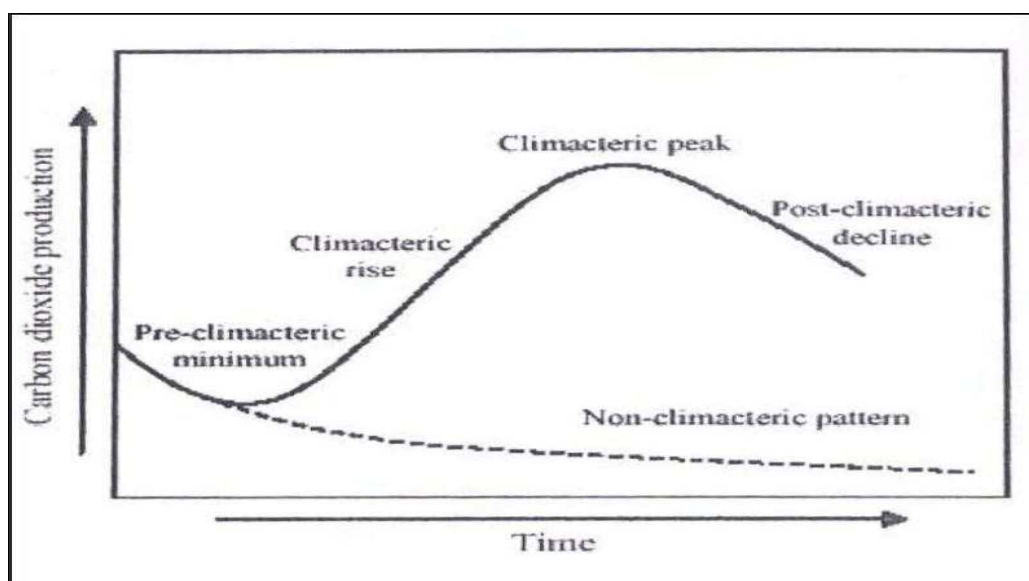


Figure 2.1: Climacteric and non-climacteric ripening (Salveit, 2004)

Table 2.1: Classification of fruits according to their respiratory behaviour during ripening

Non-climacterics	Climacterics
Lime	Guava
Grape	Papaya
Orange	Banana
Pomegranate	Plantain
Pineapple	Pear
Watermelon	Apple
Lemon	Avocado
Blackberry	Berries
Cranberry	Melons
Cherry	Plum
Raspberry	Apricot
Litchi	Kiwifruit

2.7 Ripening in Fruits

Ripening is a growth indicator used in assessing the growth of fruits (Ogazi, 1996). It is the ultimate stage of fruit development and it involves several metabolic, biochemical and physiological changes, which cause the fruit to develop key quality attributes like colour, texture, aroma, flavour as well as making the fruits sweeter and more edible (Payasi and Sanwal, 2005; Gandhi *et al.*, 2016).

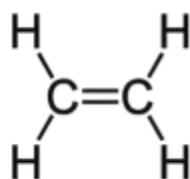
In ripening, there is a chlorophyll breakdown and the fruit becomes less green, softer and regardless of the rise in acidity, the fruit is still sweeter and more delicious to consume (Rahman *et al.*, 2008). The process of ripening in fruits is associated with the synthesis of mRNA, novel proteins, pigments, and flavour in the fruit by using the carbon skeleton blocks and energy supplied to the tissues through the respiration process. (Sampaio *et al.*, 2007). Naturally, ripening usually occurs when fruits have achieved the right physiological maturity or after the matured green stage telling of an internal genomic control mechanism and phenomenon that prevents premature fruits from ripening (Clendennen & May 1997; Seymour *et al.*, 2002).

In a conclusive work on bananas and plantains, Dadzie and Orchard (1997) showed them to be typical climacteric fruits that experience a sudden exponential increase in respiration rate and subsequent metabolic changes that result in significant transformations in colour, texture and flavour during ripening. This rise in the respiration rate of ripening fruits has been discovered to quadruple. According to Sugri and Johnson (2009), this is the main reason responsible for the faster deterioration rate of ripe plantain fruits as compared with green ones.

Some chemicals have been shown to stimulate the ripening process of fruits (Suman *et al.*, 2011; Sogo-Temi *et al.*, 2014) and these ripening agents may either be natural or artificial (Gunasekara *et al.*, 2015). While the natural ripening process is known to be controlled by genes which regulate the release of ethylene gas, (a natural agent) to initiate the ripening process (Gray *et al.*, 1992), the artificial ripening process is a commercial strategy deployed to reduce the losses during transportation, by harvesting fruits before the release of ethylene by natural processes at the matured green stage and using artificially prepared chemicals to cause ripening in the harvested fruits later in the handling process when required (Gunasekara *et al.*, 2015). Ethephon, ethrel, ethylene glycol, artificial ethylene and calcium carbide are examples of these commercially known artificial ripening agents.

2.8 Ethylene gas as ripening agent

Ethylene is a plant hormone that plays a functional role in growth regulation and climacteric fruit ripening (Liu *et al.*, 2015). It is a colourless naturally occurring hydrocarbon gas (C₂H₂) which may be produced not only in ripening fruit, but from internal combustion of exhaust engines, smoke, rotting vegetation, natural gas leaks, welding and in some types of manufacturing plants and other related processes (Argenta *et al.*, 2001). It is active in very small amounts (part per million) and is transported by diffusion from its production site to the active site (Zagory, 2009). Ethylene is sometimes represented as C₂H₂ and has the chemical structure indicated below:



Injured fruits produce ethylene that enhances faster ripening of fruits than in the uninjured ones due to the faster rate of respiration in the bruised ones. Ethylene utilization can be traced to the early years where the Egyptians used to gash figs to facilitate ripening response. It is said that the ancient Chinese were also known to burn incense in closed rooms to keep pears, where ethylene was released in the combustion process, to stimulate fruit ripening (Argenta *et al.*, 2001).

The use of ethylene gas is mainly to induce ripening and colouring of fruits like tomatoes, mangoes, citrus, pears, plantains and bananas whereas it stimulates flowering in pineapples and also improves the appearance and growth of bean sprouts when applied on the field using ethylene generator or gas emission systems (Suman *et al.*, 2011). When applied artificially to achieve these purposes, extra care has to be taken since higher concentrations could cause undesirable effects in fruits and vegetables, and can also have bad effects on human health (Hasan *et al.*, 2010).

Compounds such as 1-Methylcyclopropene (1-MCP), potassium permanganate, Aminoethoxyvinylglycine (AVG), aminoxy acetic acid (AOA) and Ozone generators (normally used in cool-rooms) can inhibit ethylene. It is mostly used commercially and poses no known toxicological and environmental hazards from its use (Argenta *et al.*, 2001).

2.9 Postharvest behaviour of Plantain

Plantain is one of the most valued crops all over the world because of its versatility in being used as food. Inadequate proper postharvest management practices may bring

about massive economic loss. Reduction of respiration rate, delay of ripening and control of disease-causing organisms during transport and storage are various postharvest management practices used to improve upon the quality and shelf-life of produce. Ripening is a growth indicator used in assessing the growth and development of fruits. Usually, the fruit is developed in size, with a green peel (which is mostly dependent on the fruit type), and at its peak of starch level at physiological maturity (Ogazi, 1996). The ripening stage of plantain is combined with several biochemical reactions such as ethylene synthesis, starch degradation, sugar accumulation and changes in other bioactive compounds (Nascimento *et al.*, 2006; Fatemeh *et al.*, 2012; Wang *et al.*, 2014). There is no known aromatic sensory characteristic at the matured green stage till the fruit loses its angularity and the bioactive compounds undergo chemical reactions and the peel colour turns yellowish. Since plantain is a climacteric fruit, storing it among other ethylene emitting produce minimizes its storage life due to the autocatalytic nature of the ethylene substance present in the produce (Argenta *et al.*, 2001).

Large-scale producers can catalyze the rate of ripening through the use of artificial processes such as controlled atmospheres (Rahman *et al.*, 2008). Under these controlled atmospheres, the plantain cultivars require low ethylene exposure ranging from as little as 100 to 150 ppm of the said gas at a temperature of about 15 °C to 20 °C and relative humidity of 90 to 95% to stimulate uniform ripening in the produce (NARI, 2003). Also, concentration levels of the CO₂ are kept below 1% as in the controlled atmosphere to prevent carbon dioxide from delaying the ethylene action. Temperatures higher than 25 °C can make the pulp undesirably soft; therefore, temperature regulation is also a key factor here and must correspond very well with the desired degree of ripening (Tchango *et al.*, 1999).

Ethylene gas is expensive and not easily accessible to market women in the local communities; therefore, to initiate the ripening process to sell their plantains in their ripen state, they pile the plantains in baskets lined with sacks or polyethylene sheets, or in drums and other containers suitable enough to exclude air circulation and accumulate heat around the produce. They also pile them in heaps on the ground sometimes (Tchango *et al.*, 1999) while others too trigger ethylene production or initiate ripening in the heaped produce by adding already ripe plantain to the pile or stored produce. These methods normally take about 3-7 days or even more depending on the maturity stage of the fruits and other environmental factors like temperature and humidity (Robinson, 1996; Daniells, 2003).

2.9.1 Shelf-Life and Postharvest losses of Plantain

Plantain is a climacteric fruit and therefore undergoes metabolic processes including respiration and transpiration even after harvest. As a catabolic process, respiration coupled with ripening processes, eventually leads increased enzymatic breakdown of available starches to simple sugars, degradation of chlorophyll and tissue softening as a result of increased pectinase activity (Daniells, 2003). Under poor storage conditions and handling methods, these processes lead to decreased quality during postharvest management. Unfavourable storage conditions allow rapid ripening and subsequent spoilage of harvested plantains. This is reported to occur most at the producer level along the supply chain (Daniells *et al.*, 2001).

2.10 Quality Attributes of Plantain Ripening

Gunasekara *et al.* (2015), describe fruit quality as the degree of excellence of the fruit for a particular purpose, which is, assessed either qualitatively or quantitatively. Qualitative assessments include, pulp firmness, peel colour, level of bruising, amongst others, and are usually measured with the use of the five sensory attributes, while quantitative assessments are used for physicochemical parameters such as; peel to pulp ratio, moisture content, pH, Total Soluble Solids (TSS), Titratable Acidity (TA), Total Sugar or Starch and Vitamin C (Dadzie and Orchard, 1997; Gunasekara *et al.*, 2015).

Superficial changes in the plantains may not be an accurate determination of the degree of ripeness due to changes occurring both internally and externally (Dadzie and Orchard, 1997) Some factors such as low relative humidity, high temperatures and other genetic factors may cause the peel colour of the fruits to remain green even when ripening has already occurred internally. Therefore, a combination of external as well as internal changes to determine the maximum eating quality of fruits is necessary for reliability (Wills *et al.*, 1998; Anthon *et al.*, 2011).

A combination of high temperature, high perishability, poor or slow market systems as well as poor handling practices and storage enable losses in the fruit quality and finally lead to a postharvest loss (Fagbohu *et al.*, 2010).

2.10.1 Changes in peel colour

One of the most important external qualities that affect a consumer's decision on the edibility of a given fruit is the change in the colour of the peel. This is due to it being a reflection of the internal changes in the pulp (Kays, 1999). Some fruits do not only

change their peel colour during ripening but their pulp colour as well. These changes indicate the degree of ripeness and subsequent postharvest life of the fruit (Ajayi & Mbah, 2007). For every fruit, there are acceptable colours for unripe, ripe and overripe. The development of these colours in fruits is greatly influenced by certain naturally occurring pigments in the fruit, which result from either the degradation of the chlorophyll structure and/or the synthesis of carotenoids (Dadzie and Orchard, 1997). These carotenoids synthesized in plants give colour to fruits and may normally occur as red, orange or yellow pigments.

In bananas and plantains, the change in the green colour with the emergence of the yellow, is indicative of ripening. This usually begins immediately after the climacteric peak in about two to seven days after harvest, depending on the fruit maturity and the temperature (Wills *et al.*, 1998; Ajayi and Mbah, 2007). At the early stage of plantain maturity, the peel is green in colour and changes to yellow, brown and finally black at the final ripening stage (Dadzie and Orchard, 1997; Wills *et al.*, 1998).

The orthodox way of determining the degree of ripeness in fruits mostly depends on the peel colour. Standard colour charts may be used to compare the changed in peel colour as a form of quick assessment (Dadzie and Orchard, 1997). Colorimeters may also be used in some instances.

2.10.2 Changes in fruit firmness

Major changes in hardness or softening of the flesh of the fruit do occur as part of the ripening process. As the peel of the fruit turns from green to yellow, it is corresponded by important textural transformations in the pulp (Smith *et al.*, 1990). At the optimal

ripening stage, the pulp becomes tenderly soft and as it moves into the overripe stage, the pulp then becomes extremely soft or mushy (Dadzie and Orchard, 1997). This textural loss has been linked to certain processes such as cell wall breakdown due to pectic substances, solubilization and also starch breakdown to form sugars (Ali and Abu-Goukh, 2005; Anthon *et al.*, 2011).

In fruits like plantain, banana, guava, tomato, and mango, fruit softening is directly proportional to increasing enzymatic activities and also follows the climacteric pattern of their respiration. These textural changes in fruits tend to greatly affect the quality, shelf-life and how fruits are handled after harvest (Ajayi and Mbah, 2007). Measurement or determination of fruit firmness is usually done by either using a texture analyzer or by the use of human instruments through sensory analysis (Dadzie and Orchard, 1997).

2.10.3 Changes in total soluble solids (TSS)

The change in total soluble solids is a quality, which essentially gives the amount of increase in soluble mineral content in fruits as they ripen. The conversion of polysaccharides to simple sugars as the fruit ripens causes an increase in total soluble solids (Kader, 1992). This parameter gives an estimated index of the level of sugar, which is also a determinant of quality and may differ between various cultivars.

As fruits ripen, the total solids remain constant while the soluble solids increase. Sugar makes up approximately 85% of the amount of these soluble minerals in the fruits (Dadzie and Orchard, 1997). Unripe plantains and bananas are high in starch and low amounts of sugar but as they ripen, the starch is converted to sugar up to the point where bananas can have as much as about 25% total sugar (Ayanwale *et al.*, 2016). TSS is an important quality for consumer preference and it is measured by the use of a

refractometer, which reads the Brix level or sugar content by weight and at the indicated temperature (Anthon *et al.*, 2011; Dadzie and Orchard, 1997).

2.10.4 Changes in titratable acidity and pH

Titratable acidity can be defined as the percentage of acid in a food substance (sample) measured by the titration with a standard base and reported in terms of one predominant acid (Pearson, 1976). The titratable acidity is usually a measure of the collective acids including all the volatile and fixed acids or all acids present while the pH gives the acidity or the alkalinity (Dadzie and Orchard, 1997). Both the titratable acidity (TA) and the pH of the pulp are attributes of importance in assessing the quality of ripening (Anthon *et al.*, 2011). The two main naturally occurring food acids in plantain are oxalic and malic acid. Oxalic acid is the most predominant acid in unripe plantain samples whereas, in the ripe plantains, malic acid is the most predominant (Dadzie and Orchard, 1997). Since taste is determined by the regulation of acid and sugar levels in the fruit and sometimes fruit maturity, the estimation of these could give a better idea of consumption quality (Anthon *et al.*, 2011).

During plantain storage, changes may occur due to both chemical and enzymatic actions and the extent of these changes is influenced by the pH rather than the titratable acidity. Generally, fruits at the immature and the matured green stage have high pulp pH and low titratable acidity but as ripening advances, there is a sharp decline in the pulp pH while acidity increases greatly. These indicators could therefore be used to ascertain the rate of ripening and evaluation of fruit taste (Silva *et al.*, 2009). The use of colour indicators or electronically using pH meters or pH electrode can measure the pH of the filtrate of the pulp. The titratable acid (TA) is also determined through titration of

the pulp filtrate against a standard base, usually, 0.1N sodium hydroxide using a phenolphthalein indicator (Dadzie & Orchard, 1997). The result is then expressed in terms of the acid that is predominant in the particular fruit.

2.10.5 Changes in starch content

The chemical makeup of plantain differs with variety, degree of ripeness, maturity as well as soil type, where the plantain was grown (Zakpaa *et al.*, 2010). Starch hydrolysis into simple sugars like glucose, sucrose, and fructose is the major chemical change that occurs during the ripening of plantain (Islam *et al.*, 2013). The starch content in the unripe stage is over 80% of the dry weight matter of the pulp (Marriott *et al.*, 1981). Amylose and amylopectin are the predominant starch in the unripe plantain but replaced by glucose, fructose and sucrose at the ripening stage due to fat hydrolysis. This conversion leads to the sweetening of the fruit due to the sugar accumulation and breakdown of starch. Changes in starch content indicate the degree of fruit ripeness. This can be seen in the starch breakdown of plantain being much slower and dragging even into the overripe stage as compared to banana where the total starch breakdown is usually accomplished at full ripeness stage (Dadzie and Orchard, 1997; Ayanwale *et al.*, 2016). The ripening process can decline the starch content of about 30% and above to about less than 2% in plantain (NARI, 2003).

The starch iodine test is said to be the easiest, fastest and the most inexpensive method in estimating starch content during ripening (Dadzie and Orchard, 1997). Some researchers have also described other methods like acid hydrolysis and titration methods but these are usually time-consuming and complex and therefore they require highly skilled personnel to carry it out (Norgia *et al.*, 2008).

2.11 Mechanisms to Delay Ripening and Extend the Shelf Life of fresh produce

An important role in the management of fresh fruits and vegetables involves storing harvested plant parts and keeping them fresh over a relatively long period than they would usually last (El-ramady *et al.*, 2015). This allows for the attainment of its greatest value and utility if their supply is extended over and beyond their harvested season (Sousa-Gallagher and Mahajan, 2011). What every storage method or equipment aims to achieve is to manipulate the primary factors that may influence undesirable processes in the stored product and extend the storage life and quality to the possible maximum.

Factors that can affect the quality and shelf-life of fresh produce have been grouped into two main; primary and secondary factors (Kader *et al.*, 1989; El-ramady *et al.*, 2015). Harvesting at the right maturity stage, proper sanitation procedure, minimizing mechanical injuries, providing optimum relative humidity and temperature are some of the primary factors and an example of a secondary factor is a modification of the CO₂, O₂, and/or ethylene gases concentrations. Strategies to manipulate these factors to delay ripening and prolong the storage life of fresh produce has become very essential and this has motivated the evolution of different methods over the years, both conventional and unconventional ones (De Long and Prange, 2003).

2.11.1 Field storage method

According to El-ramady *et al.* (2015), this practice is usually adopted among the small-scale farmers and is the simplest and the most basic system of storage. Here, crops such as yam, cassava, carrots, potatoes and other tubers are not harvested even when they have reached maturity till there is a ready market for them. Similarly, fruits like citrus,

plantain and bananas are left on the parent plant until preparations for the market are complete. This way, they are kept fresh for a certain period even though not for a longer period and their quality may be affected negatively by this method.

Sometimes, the crops are harvested and heaped in bulk on the ground or assembled at a common location which may be under a shade or no shade at all while waiting to be transported or marketed (Tchango *et al.*, 1999; NARI, 2003). Some may also be stored in bags, bins, baskets and boxes and placed on pallets but this method relies only on natural ventilation or airflow to remove the heat and the moisture generated in the produce by their respiratory activities. This is the method usually adopted by most market women and handlers of fresh produce in areas where there are inadequate or no proper storage facilities (Ajayi and Mbah, 2003; Ayanwale *et al.*, 2016). Higher levels of losses are usually recorded under this mode of storage and fruit ripening is also quite rampant, especially in the middle of the heaps.

2.11.2 Cold storage

Controlling temperature is a vital factor that affects the quality and value of fresh produce once it has been harvested. The shelf-life of fresh produce has been shown to extend when there is the rapid removal of the field heat immediately after harvest (Jobling, 2001). Low-temperature storage for fresh produce is one of the dominating and the most fundamental technologies after harvest. When the temperature in the surrounding atmosphere and inside the product is lowered, it slows down the respiration rate and reduces the resultant ethylene production as well as reducing tissues response to ethylene (Sirivatanapa, 2006). Respiration rate doubles or may even triple for every 10 °C rise in

temperature, which also suggests that shelf-life is reduced for every 10 °C rise in temperature of fresh produce (Jobling, 2001).

Each fresh produce has a temperature threshold. Ergo, storing a given fruit or vegetable above a certain critical temperature is likely to cause chilling or freezing injuries (Sousa-Gallagher and Mahajan, 2011). The geographical origin of the product often determines its ideal storage temperatures. Most tropical produce do not tolerate storage temperatures below 12 °C whereas those cultivated in the temperate climates can tolerate lower storage temperatures to as low as 0°C. For example, at 21 °C, some apple cultivars ripen within a day while at -1 °C, they ripen in 10 days (Jobling, 2001). In the NARI Technical Bulletin (2003), it is stated that, at an optimal temperature of between 12 °C and 14 °C, the transportation and storage temperature of matured green tropical plantains and bananas could be maximized and the shelf-life also prolonged, to between 4 and 5 weeks, without any chilling injury.

2.11.3 Use of ethylene absorbents/scrubbers

The use of ethylene absorbents to either reduce or completely get rid of the ethylene produced during storage has become a common technology in most commercial fruit handling (Park *et al.*, 2016). The ability to control the ethylene produced during fruit storage is very key in preventing unwanted discolouration and prolonging the postharvest life of fruits (Bhattacharjee and Dhua, 2017).

Several compounds that can be used as ethylene inhibitors such as potassium permanganate (KMnO₄), an oxidizing agent; Aminoethoxyvinylglycine (AVG), which inhibits the synthesis of ethylene and 1- Methylcyclopropene (1-MCP), which inhibits ethylene action. For bananas and plantains, KMnO₄ is the most commonly used

ethylene scrubber (Prasad and Kochhar, 2014). When the KMnO₄ is impregnated with a porous inert mineral and inserted into the storage environment, it oxidizes the ethylene produced by the fruits into water and carbon dioxide, and by this, it prolongs the postharvest life of fruits by delaying softening and other adverse effects of ethylene (Hasan and Hasan, 2014).

Glahan (2006) and Sharma *et al.* (2012), reported that the main component of ethylene absorbents is potassium permanganate (KMnO₄), which prevents the adverse effects of ethylene (C₂H₄) produced by fruits during ripening by oxidizing the ethylene to CO₂ and H₂O. This possibility is considered because Okelana (2001) and Akpabio *et al.* (2012), analyzed the plantain pseudostem and they found the pseudostem to contain several mineral elements that included appreciable amounts of potassium. Okelana (2001) reported that the plantain pseudostem contains about 6.2% of potassium (K), and at least 0.1% of other minerals like calcium (Ca), sodium (Na), phosphorus (P) and magnesium (Mg). The use of potassium permanganate to delay ripening in climacteric fruits like tomatoes, apples, plums, bananas and papayas has been reported in the literature (Park *et al.*, 2016; Bhattacharjee and Dhua, 2017). The shelf life of mature green plantains being extended to 4 weeks when stored in polyethylene bags with potassium permanganate (KMnO₄) wrapped in porous paper at a temperature of 29.4 °C and up to 7 weeks at a temperature of 12.7 °C has also been reported (ARI, 2003).

2.12 Packaging of fresh produce

Fresh bananas and plantains are sometimes packed in wooden crates and lugs, wooden baskets and hampers, pulp containers, paper and mesh bags or plastic baskets. They are often transported and stored in these packaging materials, which may provide protection,

containment and information about the product (Paine & Paine, 1992). However, since plantains and bananas are highly perishable, sometimes other forms of packaging are adopted to further prolong the quality and shelf-life of these crops.

2.12.1 Modified Atmosphere Package (MAP) / Controlled Atmosphere Package (CAP)

Modified atmosphere (MA) refers to any atmosphere varying from the normal air (20 to 21% O₂, about 0.03% CO₂, about 78 to 79% Nitrogen and trace quantities of other gases) (Yahia, 2009). This is a preservation technique that seeks to minimize the physiological and microbial decay of perishable produce further due mainly to the reduction of O₂ and/or increase in CO₂

MAP operates on the principle of establishing equilibrium in the gas composition inside the package through the interplay between the respiration rate of the product and the permeability of the package. MAP occurs in either passive or active condition. In passive MAP, the permeability of the packaging film and respiration rate of the crop are the most important parameters. Due to the respiration of food products, oxygen consumption is proportional to carbon dioxide production in the modified atmosphere packaging. After a certain time, the gas composition in the package of the fresh product reaches a definite equilibrium between respiration rate and permeability of packaging film. In this state, the total amount of carbon dioxide produced and oxygen consumed by respiration, is the same as that permeated through the membrane exchange. Active modification however involves the air migration within the pack and then replacing the atmosphere with the desired gas mixture to accelerate gas composition modification and to avoid exposure to high concentrations of unsuitable gases by the product (Zhang *et*

al., 2014). MAP employs either micro-perforated or unperforated films that have selective permeability for CO₂ and O₂ gases (Kupferman and Sanderson, 2001).

Controlled Atmosphere (CA) is used to precisely monitor and control the concentration of gaseous atmosphere around the fresh produce by altering oxygen and the carbon dioxide concentrations during the storage period (Hoehn *et al.*, 2009; Sousa-Gallagher and Mahajan, 2011). Saltveit (2003) and Rocculi *et al.* (2006) reported that reported that Controlled Atmosphere (CA) has the ability to decrease respiration rate of fruits and vegetables up to certain limits when the oxygen gas (O₂) concentrations are decreased and carbon dioxide (CO₂) concentrations are increased.

Both packaging processes are very effective in prolonging the shelf-life of fresh produce (Kader *et al.*, 1989; Kupferman and Sanderson, 2001). There are reports by several researchers indicating the use of MAP and CAP as a tool to prolong the postharvest life of several perishables like apples, cabbages, pears, cherries, raspberries, blueberries, bananas and plantains, as well as some minimally processed vegetables like lettuce, broccoli, cabbage and celery (Cameron *et al.*, 1995; Kupferman and Sanderson, 2001; Kader *et al.*, 2005; Yahia, 2006).

2.12.2 A MICOR P-Plus Modified Atmosphere Packaging technology

This works by altering the gas permeability of the flexible film to prolong the shelf-life of fresh produce by naturally creating a modified atmosphere. This technology gives an extra two days to bananas and about 4 days to plantains over the standard non-MAP bags. Recyclable material is used to produce specialized wicket bags (Kader *et al.*, 1989; Kupferman and Sanderson, 2001).

2.12.3 Vacuum packaging of bananas and plantains

Vacuum packaging delays the ripening of bananas and plantains by preventing contact with air/oxygen. This technique may delay ripening by 21 days and further ripening can be completed one week after the package has been opened. Patented methods of vacuum packaging and freezing of the produce prevent discolouration during storage (Sousa-Gallagher and Mahajan, 2011).

2.13 Packaging and Packaging Types

Food packaging is an organized system of the preparation of food for its transportation, distribution, storage as well as retailing and then end-use to satisfy the ultimate consumer with optimal cost (Coles *et al.*, 2003). Materials used in food packaging include metal, wood, glass, plastics and paper and paper board which can be broken down further.

2.13.1 Commonly available food packaging types

2.13.1.1 Paper and cardboard

Sulphate and sulphite are used on wood for the production of an interlaced network of cellulose fibres in sheets known as paper and paperboard. These fibres are pulped and/or bleached and treated with chemicals such as slimicides and strengthening agents to produce the paper product. Paper and paperboards are generally used in milk cartons, bags and sacks, corrugated boxes, folding cartons and wrapping paper. Advantages of this product include mechanical strength, biodegradability and good printability. In addition to their poor barrier properties to oxygen, carbon dioxide and water vapour other disadvantages include being porous, opaque, and not heat sealable. To improve their poor barrier properties, coatings such as polymeric materials or waxes can be used (Raheem, 2013).

2.13.1.2 Wood

These are used for storage or as shipping containers and have been in use for several years for storage needs. The wooden boxes as a means of storage are one of the best ways to give protection for the objects that are being stored as these boxes are not easily damaged or broken. They are often used for heavy-duty packaging when high strength is needed for heavy and difficult loads or when large size is required. Local manufacturing and relative resistance to water and harsh weather conditions are some advantages of the wooden crates. Most wooden boxes have also good ventilation (Paine and Paine, 1992).

2.13.1.3 Plastic

Plastic materials are made up of large sized carbon-containing molecules that can be formed into a variety of useful products. These plastics are easy to print, fluid, heat sealable and moldable (Marsh and Bugusu, 2007). The use of plastics in packaging has increased worldwide with an estimate of 280 metric tonnes (Paine and Paine, 1992). The packaging industry is the largest user of plastics. The major drawback of plastics is their variable permeability to gases, light, low molecular weight molecules and vapours.

2.14 Postharvest Management and Value Addition on Plantains

It is suggested that plantains should be transported in packages, be it wooden, paper or plastic, which should be padded with either polythene bags or plantain leaves to prevent scuffing. A fungicidal treatment can be applied to cut ends to prevent stem-end rot (Yahia, 2006). During packing, the curved side of the hands should be kept facing upwards making sure that the crown of the upper hands does not damage the plantains

underneath. During cold storage, plantains should be stored at a temperature of 13-14 °C with 90-95% relative humidity (Sousa-Gallagher and Mahajan, 2011).

2.15 Synopsis of Literature Review

This review has highlighted the importance of plantain to the national economy contributing in the areas of food, job security and a source of rural income. Despite these benefits derived from plantain, postharvest losses still hover around 35% in developing countries like Ghana, which is quite disturbing. These losses have been identified to occur at various stages in the value chain and more so with the handlers who are of the wrong view that plantains do not necessarily go to waste due to their versatility in use at any stage of ripening and the comparatively robust nature of the plantain.

Undoubtedly, the major problems encountered with plantain postharvest are concentrated in the areas of transportation, packaging and how to extend the green life. There are also several factors, both inherent and external, that predispose the plantain to deterioration which when not controlled can be devastating. These have been basically because plantain is fresh produce and unlike the durables, its handling is quite delicate and complex. The processes of respiration and ethylene production are also of great importance in their handling.

Handlers of plantain, especially, on the local markets are faced with major difficulties of getting proper storage materials and ripening (either slowing or increasing) methods, to help them overcome these difficulties. Certain ways introduced to them may have come across as cumbersome or expensive and they may have adopted make-shift methods which may have adverse effects on the plantains.

The gap of coming up with affordable but effective means dealing with some of these postharvest problems especially in packaging, storage and the ripening processes that local handlers could adopt with ease still exists, hence the objective of this study.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 The Plantain Sample

Matured green -*Apantu* a locally known cultivar of the false Horn variety of plantain cultivated at a farm in Dodowa, in the Greater Accra region of Ghana, was obtained for Specific objectives 1, 2 and 3 of this study. This variety was used because of its market predominance and consistent agricultural performance.

All the samples of the plantain used for the study were at least 90 days after flowering and their physiological maturity was also examined as stated by Dzomeku *et al.* (2016). The second and third hands of the cultivars were used for the study for homogeneity.

3.2 Sample Preparation

3.2.1 Experimental design

A 3×4 factorial design was used. The plantain samples were subjected to four different treatments (pseudostem, KMnO₄, pseudostem+KMnO₄ and the control which had no treatment) in three different packaging types (corrugated paper, wooden and plastic boxes). The experimental factors were packaging types (3) and their different treatments (4). The factors and their various treatment included the following

- I. Packaging Type (corrugated paper, plastic and wooden boxes)
- II. Treatment (pseudostem, potassium permanganate (KMnO₄), pseudostem +KMnO₄ and a control (no treatment)).

Samples were stored in their respective packaging type with their treatments at room temperature (26 °C-27 °C) till there was a clear indication of the shelf-life of plantains from their green state till senescence. Experiments were performed in triplicates with the mean values presented in graphs during storage time.

3.2.2 Packaging types

Corrugated Paper boxes (23x25x38 cm), Plastic boxes (32x33x51 cm) and Wooden boxes (28x33x38 cm) with these dimensions, were used to house the plantains. The corrugated paper boxes had no holes for ventilation (only holes for handles) whereas both the plastic and wooden boxes had holes and spaces throughout the packaging. This was done not only for experimental purposes but to represent packaging types as they are traditionally made for storage.

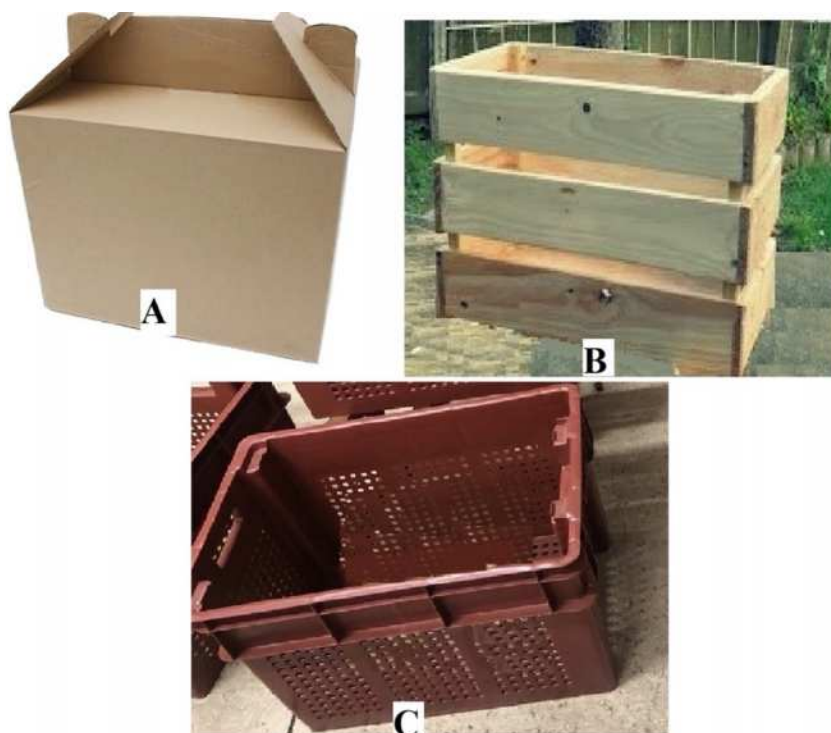


Plate 3.1 Packaging types for plantain storage: A – Corrugated paper box, B – Wooden box, C- Plastic box

3.2.3 Treatments

3.2.3.1 Shredded plantain pseudostem treatment

For the shredded plantain pseudostem preparation, plantain pseudostems of freshly harvested plantains were cut and chopped into smaller sizes to facilitate drying. It was dried in the sun at a temperature range of about 32 °C to 34 °C for four continuous days when almost all the moisture was lost. The pseudostem was shredded and chopped into smaller sizes with a pair of scissors. When it was ready to be used, it was then moistened with pipe-borne water of pH 7 to raise the moisture content to about 75%. About 4.0 kg of pseudostem was weighed and used to store the sample.



Plate 3.2 Plantain pseudostem preparation in stages: A- Freshly harvested plantain pseudostems B- Freshly chopped plantain pseudostems C- Dried shredded plantain pseudostems

3.2.3.2 Potassium permanganate (KMnO₄) treatment

For each KMnO₄ treatment, the amount used was 0.69-0.71% of the average weight of the Apantu samples which was in the range of 8849.0 – 8857.0 g per box. The KMnO₄ was put in a polyethylene sheet of 0.05mm thickness, which was untied for effective absorption of the ethylene gas.



Plate 3.3 A - Plantains covered in pseudostem in a plastic box B - Plantains with KMnO₄ and pseudostem before being covered with more pseudostem.

The SALTER AND EP-12KA weighing scale was used in weighing the samples (plantains, plantain pseudostem and KMnO₄). Laboratory procedure used was adopted using standardized procedures as stated by Rajuva and Joy (2014). Before using the weighing scale, the balance was calibrated using standard weights. The weighing boat was then placed and tared till it became zero. To get the final weights of the samples, it was ensured that the symbol ‘g’ was stable next to the weight shown. It was also ensured that no part of the samples spilled on the weighing pan.

3.3 Packaging of the plantain samples

The plantains were harvested around 6:30 a.m. They were then transported from the farm at Dodowa to the Nutrition and Food Science Laboratory, University of Ghana main campus. The journey took approximately an hour and a half. The samples were immediately assessed through physicochemical and sensory analysis. During the packaging, the plantain samples were completely covered with the shredded pseudostem for those solely undergoing the pseudostem treatment. For the KMnO_4 treatment, the weighed KMnO_4 put in a polythene bag, was inserted in the center of the plantains and left open. The pseudostem + KMnO_4 treatment incorporated both methods by putting the weighed KMnO_4 into the middle of the plantains and completely burying them in shredded pseudostem. The control sample just had the plantains arranged in the boxes. The boxes were then carefully wrapped with a transparent polyethylene sheet and the edges sealed with a masking tape. They were then kept in the Laboratory throughout the experimental period at room temperature of (26 °- 27 °C).

Physicochemical and Sensory assessments were done on a regular basis at 3-to-4-day intervals till senescence occurred in all the treatments. Before the analysis on the first day, temperature readings within the packages were initially measured 26 – 27 °C (± 1), followed by a random sampling of the plantain samples.

The mercury-filled clinical thermometer (Fisher brand, UK) was used to determine all temperature readings in the various packaging types (corrugated paper, plastic and wooden boxes) with treatments (pseudostem, KMnO_4 , or both pseudostem and KMnO_4) and without treatment (control). This was done by putting the thermometer into the

various boxes without having any contact with the bottom and sides of the boxes for several seconds till the mercury thread was steady. The reading was then noted and taken.

3.4 Biochemical and Physicochemical analyses

This section provides the methodology used for the different biochemical and physicochemical analysis in this section. All laboratory procedures were done through the use of standardized procedures as stated by Rajuva and Joy (2014). Two plantains randomly selected from each of the 12 boxes were used in conducting the biochemical and physicochemical analysis making them 24 in total per session. Three sessions were conducted per (test) day.

3.4.1 Extraction of Plantain filtrate

Ten grams (10 g) of the peeled sample (5g each from the two plantains) was homogenised in 100 mL of distilled water using a Waring commercial blender and filtered with a grade 4 Whatman qualitative filter paper.

The filtrate was used to determine total soluble solids, reducing and total sugar, titratable acidity and the pH of the plantain samples.

3.4.2 Total Soluble Solids

Total soluble solids (TSS) of a given sample represent various chemical substances present in its insoluble form. It indicates a measure of sugars present in the sample. The amount of TSS present in a food sample is also considered to be a reliable index in judging its maturity. Following the harvest – the maturity of many food items is assessed by considering the TSS of their juices. Total soluble solids TSS were assessed using the Abbe's handheld refractometer.

Before each reading was taken, the lid and the prism-plate were carefully washed with a jet of clean water to ensure that they had no stain on their surface. Water adhered on the surfaces was completely wiped off with blotting paper. After ensuring the scale was calibrated and clearly visible, the plantain filtrate was taken in the dropper. A drop was then carefully placed on the prism plate. Reading of the sample as “Brix” was obtained and the amount of TSS was expressed accordingly.

3.4.3 Reducing sugar and Total Sugar

The Lane and Eynon method as described by James (1995) was used in determining the total sugar content and reducing sugar. This involved the addition of the plantain filtrate to a flask of boiling copper sulphate solution and a methylene blue indicator. The reducing sugars in the carbohydrate solution reacted with the copper sulfate present in the flask. Once all the copper sulfate in the solution had reacted, any further addition of reducing sugars caused the indicator to change from blue to white. The volume of sugar solution required to reach the endpoint was recorded.

3.4.4 Titratable Acidity

The titration method described by Dadzie and Orchard, (1997) in the INIBAP Technical Guidelines 2, was used to determine the titratable acidity (TA) of the samples. This involved an amount of filtrate against an alkali solution of known normality. It was expressed as an equivalence of malic acid.

Fifty millilitres (50 mL) of the filtrate was titrated against a standard solution of 0.1 N NaOH. The titre value was used to calculate titratable acidity of the plantain pulp as percentage malic acid using the formula:

$\% \text{ Titratable acidity} = 6.4 \times \text{titre value} \times \text{Normality of NaOH} / \text{weight of sample.}$

3.4.5 pH

The pH of the samples was also determined using digital pH meter Model No WTW 422. After the pH meter was turned on, the electrode was lifted and the tip was cleaned by pressing with tissue paper. The instrument was carefully calibrated using buffers of pH 4, pH 7 and pH 9. After calibration, the electrode was then placed in the plantain filtrate solution to determine the pH.

3.5 Sensory evaluation of samples

A sensory evaluation of the quality attributes of the plantain was performed. The quality parameters assessed were pulp firmness, peel colour and level of bruising at every three- or four-day interval till senescence occurred in all samples. Three plantains randomly selected from each of the 12 boxes were used in conducting the sensory analysis making them 36 in total per session. Three sessions were conducted per (test) day.

3.5.1 Training of quality-grading panelists

Four consecutive training sessions were arranged for a seven-member grading panel at Sensory Laboratory, Department of Nutrition and Food Science (University of Ghana). This panel consisted of students, with a significant amount of sensory analysis experience, who were available for training and test days. The trained panelists were used for all the subsequent sensory analysis in the study, which was subjected to only physical quality measurements, such as firmness, level of bruising, and colour.

3.5.1.1 Generating a grading scale for assessing the pulp firmness

Before calibrating a scale for evaluating the firmness, different food items, which had varying forms of hardness, were presented to the panelists to assess and classify them according to their degree of hardness (firmness). This was done on a scale of 1-5. The extremely firm received a score of 5 and the extremely soft was given a score of 1 to show to decreasing level of pulp firmness of the plantains. All the panelists were allowed to touch and press gently each of the items presented for them to give a score based on the scale. Several samples were presented to the panelists including banana (of varied ripening states), candies, boiled and peeled egg, overripe mango fruit with brown speckles and 500ml Sachet water. Afterward, the panel discussed and came to a consensus on the actual score for each of the items presented and then grouped them to serve as a scale for the final evaluation. The intensity scale agreed on and used by the panelists for grading the pulp firmness is as shown in Table 3.1.

Table 3.1: Quality-grading scale for pulp firmness

Quality parameter	Description	Score
Firmness	Very firm	5
	Firm	4
	Soft	3
	Very soft	2
	Extremely soft	1

3.5.1.2 Generating a grading scale for assessing the colour

For colour grading, the unripe (all green colour) and overripe (dark brown colour with a trace of yellow) plantain fingers were used as the endpoints to calibrate the quality scale for ripeness. Plantains at different stages of ripeness were also presented to the panel for them to score according to peel colour. The level of ripening was scored based on the intensity and the degree of the spread of the green colour. In the end, a scale of 1 to 9 was used for grading colour.

Table 3.2 shows the scale used for grading the colour. The Colour chart for grading the ripeness of bananas (Plate 3.4, adapted from Geest, UK) was used to facilitate both the training and the test sessions.

Table 3.2: Quality grading scale for the peel Colour

Quality parameter	Description	Score
COLOUR	All green	1
	Green with a trace of yellow	2
	More green than yellow	3
	More yellow than green	4
	Yellow with a trace of green	5
	All Yellow	6
	All yellow with brown speckles	7
	More spread of brown in yellow	8
	Dark brown with yellow traces	9

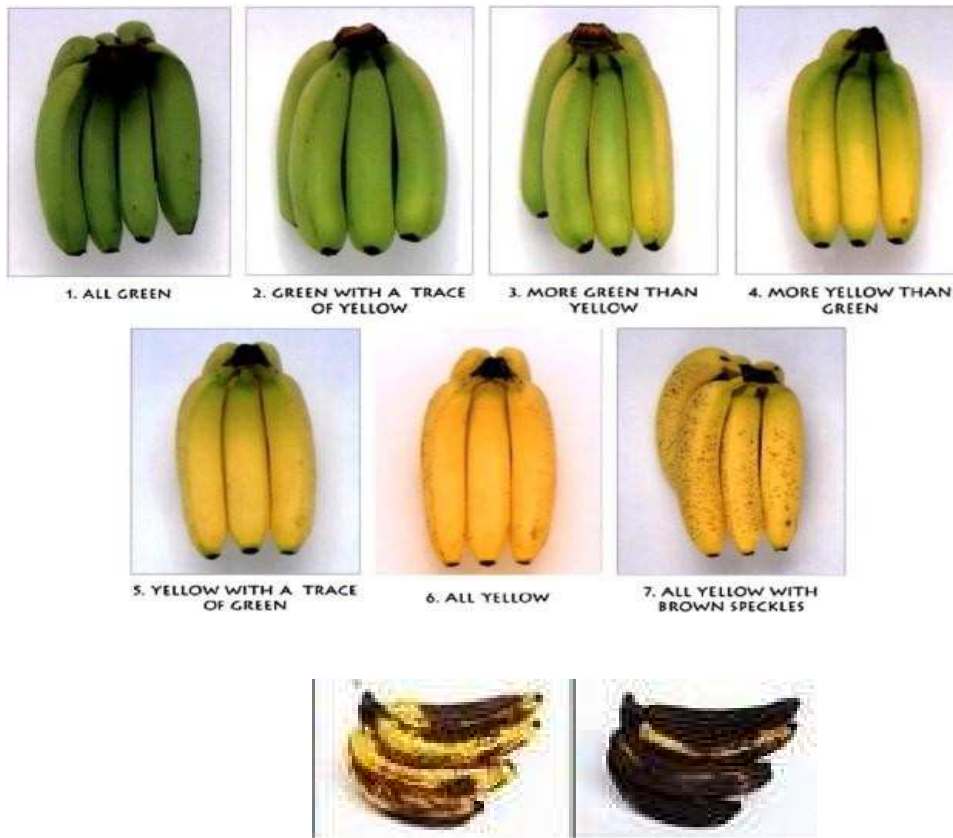


Plate 3.4 Peel Colour chart (adapted from Geest, UK) used for training of panelists

3.5.1.3 Generating a scale for assessing the level of bruising

On bruising, the panel was shown the difference between a defective (poor quality) and a non-defective (high quality) plantain by presenting to them a highly bruised plantain finger and one without any bruise/damage. For grading, any kind of mechanical damage on the plantain fingers such as scratches, breakages, abrasions, skin darkening, and any kind of damage was scored as a bruise. The panel was also shown the differences between mechanical damages and physiological damages, as well as mechanical damages that occurred before harvest. It was also agreed that both physiological damages such as peel splitting, sunscald, varietal variation in the intensity of the green colour and mechanical damages that did not occur during the postharvest period such as damage by birds, rodents, and other animals on the field (if they were found on the plantain)

did not qualify as postharvest damage (bruised). Quality grading in terms of bruising was scored on a scale of 1-5, judging from the percentage damage on the total surface area of the fruit. Table 3.3 shows the scale used for grading the level of bruising.

Table 3.3: Scale used for grading the level of bruising

Quality Parameter	Description	Score
Level of bruising	Extremely low/None	1
	Low	2
	Medium	3
	High	4
	Extremely high	5

3.6 Material Preparation for Plantains transported and stored.

For Specific Objective 4, (To investigate the effects of different forms of packing arrangements on sensory quality characteristics of plantains during transit and subsequent storage) matured green plantain -*Apantu* cultivated at a farm in Techiman, in the Bono East region of Ghana, was obtained. The choice of location was mostly influenced by distance (375 km from Accra) since a longer distance from Accra would better inform us of the efficiency of the packaging type and packing arrangements during transit. This *Apantu* variety was used because of its market predominance and consistent agricultural performance.

3.6.1 Packing arrangements of plantains for transportation

The plantains were harvested around 6:30 a.m. All the samples of the plantain used for the study were at least 90 days after flowering and their physiological maturity was also examined as stated by Dzomeku *et al.* (2016). The second and third hands of the cultivars

were used for the study for homogeneity. The plantains were arranged in 5 specific patterns as seen in Table 3.4.

The arranged plantains were then transported from Techiman to the Nutrition and Food Science Laboratory, University of Ghana main campus. The journey took approximately seven hours.

Table 3.4: Packing arrangements for plantains transported and stored

Groups	Arrangements
Fingers	Neatly arranged and lying directly on top of each other with crowns facing the base of the box separated by a layer of Styrofoam
Fingers	Neatly arranged and lying directly on top of each other with crowns facing the base of the box dividing the layers with no layer of Styrofoam.
Hands	Neatly arranged and lying directly on top of each other with crowns facing the base of the box separated by a layer of Styrofoam.
Hands	Neatly arranged and lying directly on top of each other with crowns facing the base of the box dividing the layers with no layer of Styrofoam.
Bunches	The bunches at the bottom were placed in the center and overlapped with the adjacent hands with crowns facing the floor and separated by a layer Styrofoam.

All the sensory parameters (pulp firmness, peel colour and level of bruising) used in the prior study (Specific objectives 1, 2 and 3) were repeated for this study, using the same scales and colour charts by the same trained panelists.

3.7 Data Analysis

Data entry was done using Microsoft excel, 2010 and statistical analyses were done using Minitab Version 14 (Minitab Version 14, LLC. State College, Pennsylvania) and SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). For the sensory analysis, an intensity scale for pulp firmness and level of bruising was used and a colour grading (colour chart) was used for peel colour. The general linear model (ANOVA) determined the statistical differences between treatments $P < 0.05$. Factors with significant differences were submitted to the means test (Fishers). The data was presented in charts, graphs and tables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Biochemical and physicochemical properties of plantains in different treatments and packaging types during storage over a period of time.

Changes in some biochemical and physicochemical properties of plantains stored in three types of boxes (corrugated paper, wooden and plastic) were determined, with either plantain pseudostem, KMnO₄, a combination of plantain pseudostem and KMnO₄ or no treatment (control) for the storage period (unripe till senescence).

Physicochemical and biochemical analyses are useful parameters that provide an overview of quality and the degree or magnitude of ripeness (Borges *et al.*, 2019). Several factors influence and accelerate fruit senescence, with postharvest senescence impacting the quality of plantain, i.e., aspect, texture, taste, aroma and nutritional characteristics, leading to consumer rejection and important economic losses for the fruit industry. These can be evaluated through by performing sensory and physicochemical analysis (Adi *et al.*, 2019).

Plantain, as a climacteric fruit ripens with time. This ripening process is characterized by changes such as conversion of starch to sugars, changes in the total soluble solid content, pH and titratable acidity (Aquino *et al.*, 2017). Sampaio *et al.* (2007) postulates that, starch and sugar content in plantain are important factors used in assessing fruit maturity, ripeness and other sensory parameters like taste, firmness and peel colour. In this study, some biochemical and physicochemical analyses that aid in a quantitative determination of acidity and sugar were conducted, as the plantain samples were studied under the

different treatments and packaging types. These analyses included total soluble solids (TSS), reducing sugar (RS), total sugar (TS) titratable acidity (TA) and pH. As such these analyses provide not just a measure of the maturity of the plantain but also an understanding of the plantain quality, since these processes affect the final eating quality of the plantain.

4.1.1 Total Soluble Solids (TSS)

Total soluble solids (TSS) signify the proportion (%) of dissolved solids in a solution as measured using the refractive index. It is the sum of sugars, acids and other minor components in the fruit pulp (Balibrea *et al.*, 2006; Kader, 2008). Though imprecise, it is still widely used as it is cheap, fast and correlates sufficiently with the plantain sugar levels and therefore good for comparison of several plantain samples. For this study it was observed that in all the packaging types, there was an increase in total soluble solids as the plantains ripened (Figure 4.1).

On day 1, all the TSS values were less than 5%. The low TSS recorded at the early stages of storage was because the available starch was yet to undergo enzymatic degradation to be converted into sugars (Kader, 2008). By the 15th day, the plantains in the pseudostem + KMnO₄ treatment recorded values as high as 35%, whereas, the highest value recorded for the plantains in the pseudostem treatment alone was only 15%. Both values were recorded in the corrugated paper box (Figure 4.1A). The increase in the total soluble solids (TSS) of the plantains was gradual over the ripening period at the various ripening stages. TSS varied significantly ($p < 0.05$) over the storage period and at the different ripening stages. Degradation of stored starch in the pulp to sugars increases the total soluble solids of the pulp.

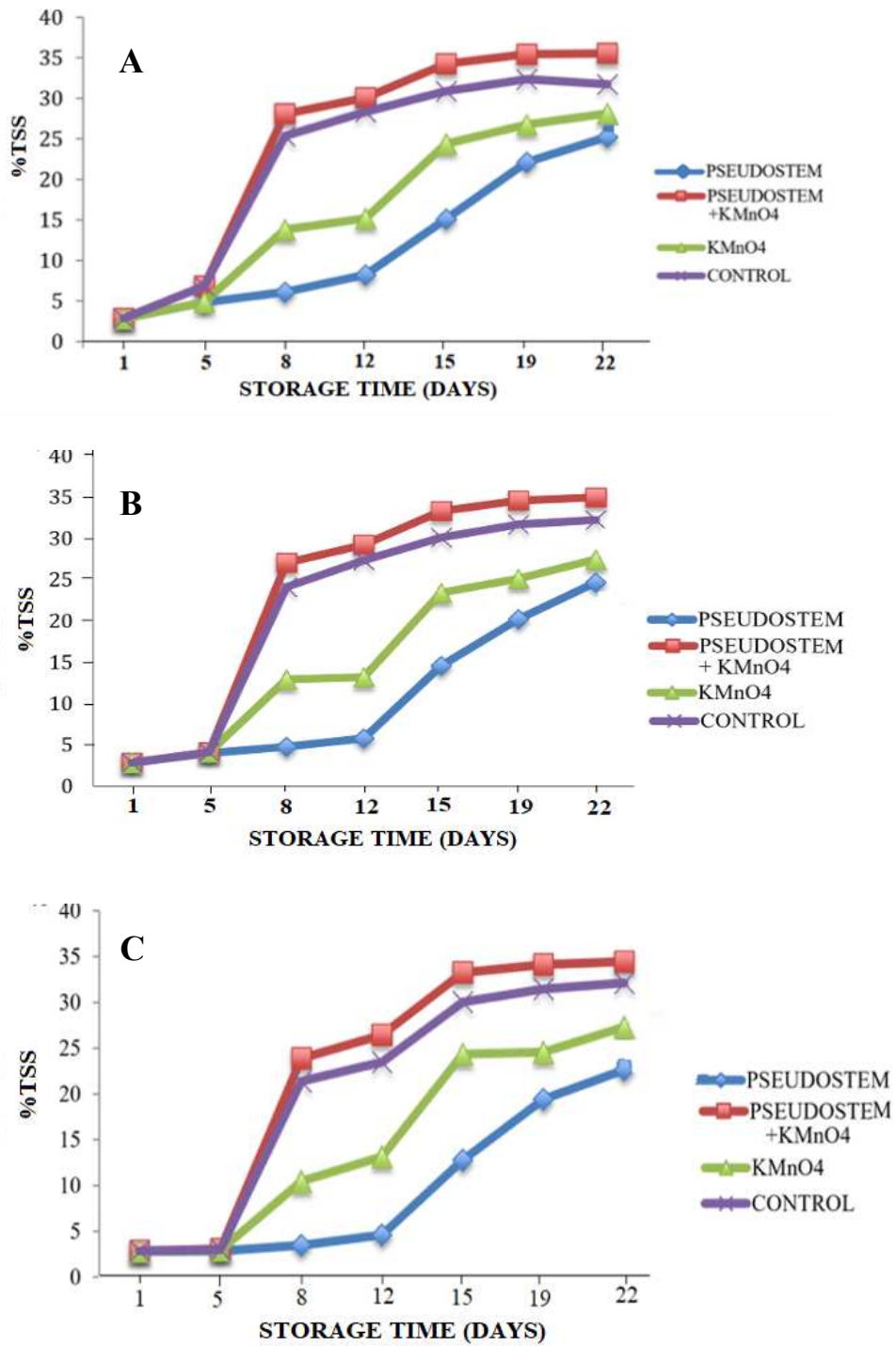


Figure 4.1: Changes in Total Soluble Solids (TSS) of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

As starch degrades, there is sugar buildup, which causes the total soluble solids to increase at ripening till senescence (Zakpaa *et al.*, 2010). Thus, the TSS is directly proportional to the degree of fruit ripening (Balibrea *et al.*, 2006). On day 22, pseudostem + KMnO₄ treatment had an average TSS value of 35% and pseudostem treatment had an average of 24% for all packaging types.

TSS levels dropped slightly on the last day in the case of the plantains stored in the paper box with the control treatment (Figure 4.1A). TSS accumulation is strongly related to ripening but could cause a fall off owing to decaying.

4.1.2 Reducing sugar and Total Sugar

Percentage reducing sugar and % total sugar in the stored plantain increased as the days progressed due to the hydrolysis of starch content in the plantain fruit resulting in the predominant conversion of starch to sugars in plantain at the fruit ripening stage (Zakpaa *et al.*, 2010).

As shown in Figure 4.2, there was a steady increase in % reducing sugar from day 1 to day 22 with the pseudostem + KMnO₄ treatment in the corrugated paper box (Figure 4.2A) having the highest values of 2 % and 1.8 % and 1.7% in the wooden (Figure 4.2B) and plastic boxes (Figure 4.2C) respectively. The pseudostem treatment had the lowest values of 1.5 % in the corrugated paper box, 1.4 % in the wooden box and 1.3 % in plastic box.

In Figure 4.3, the plantains packed in the corrugated paper box, with pseudostem + KMnO₄ treatment showed the highest rise in total sugar, moving from 0.4% on day 1

to 3.2% by day 22. The plastic box package with pseudostem treatment had the lowest rise from 0.4% to 1.7% as observed in Figure 4.3C.

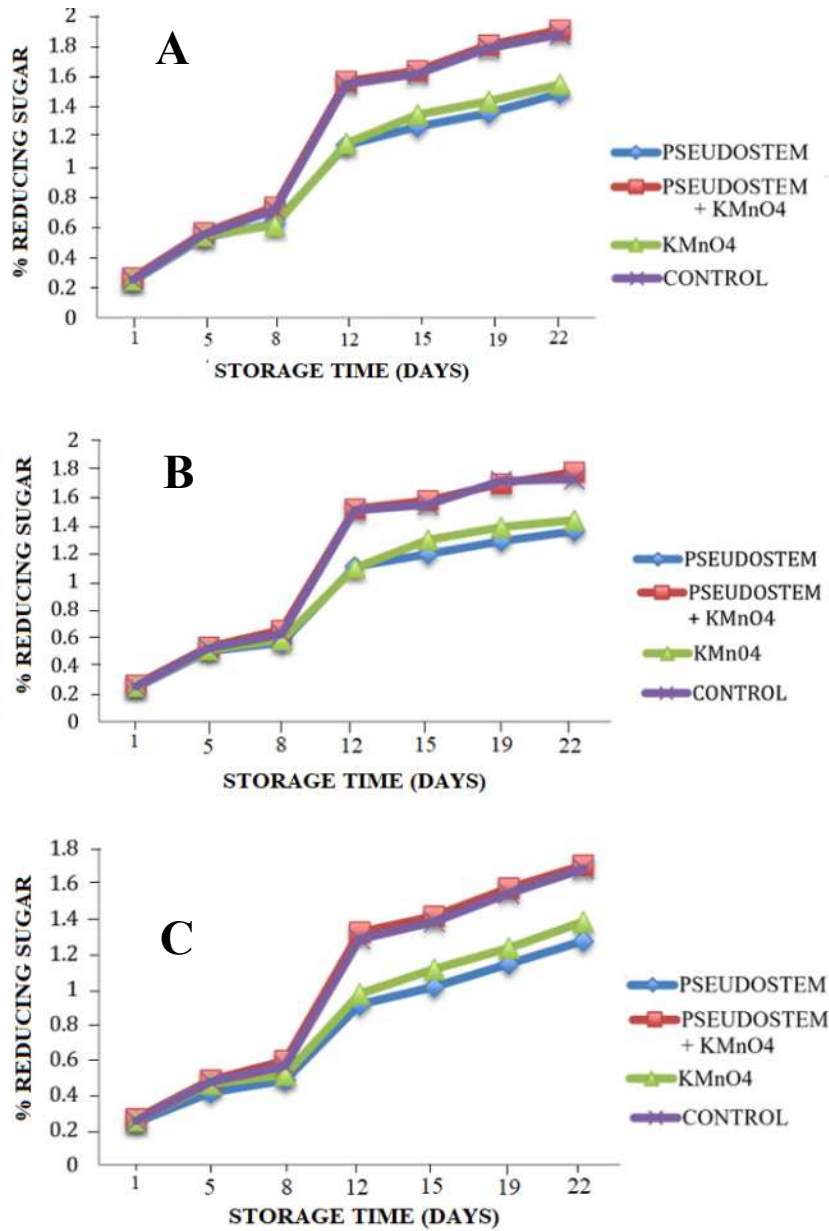


Figure 4.2: Changes in Reducing Sugar (RS) of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

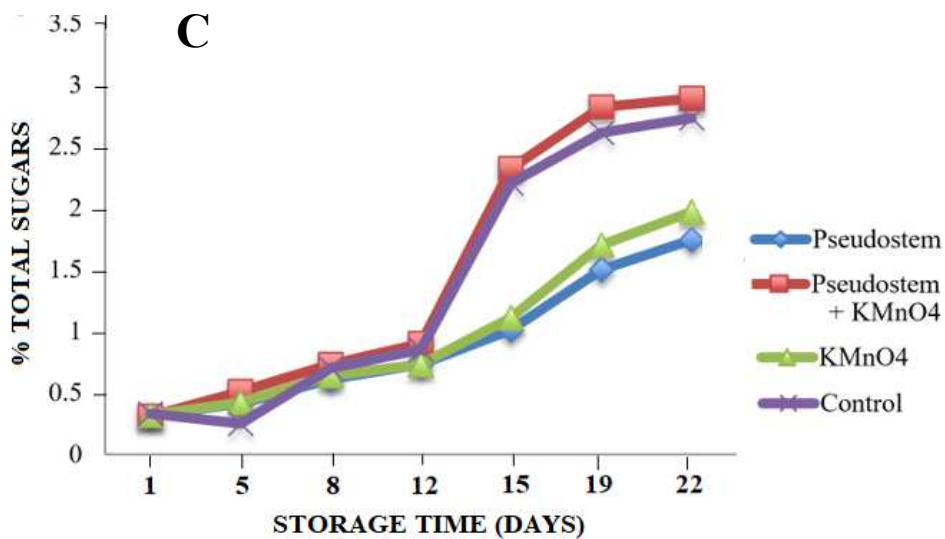
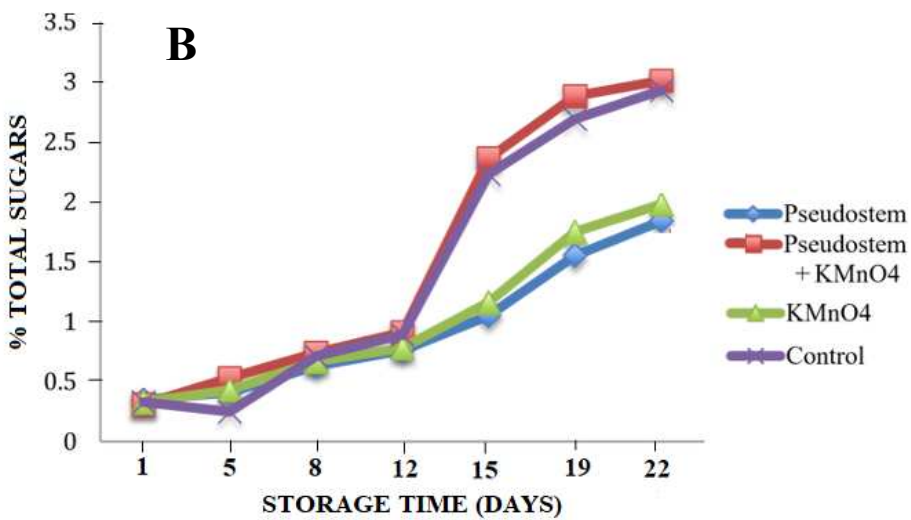
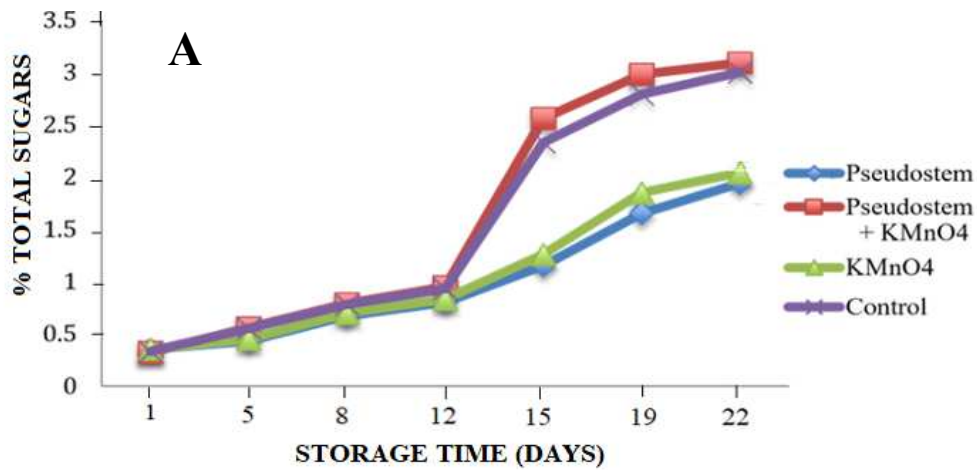


Figure 4.3: Changes in Total Sugars (TS) of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

4.1.3 Titratable Acidity (TA) and pH

The pH values give a measure of the acidity or alkalinity of a product, while titratable acidity gives a measure of the amount of acid present. Assessment of pH and titratable acidity of banana, cooking banana and plantain are used primarily to estimate consumption quality and hidden attributes. They could be considered as indicators of fruit maturity or ripeness. Acids make an important contribution to the postharvest quality of the fruit, as taste is mainly a balance between the sugar and acid contents, hence postharvest assessment of acidity is important in the evaluation of the taste of the fruit (Aquino *et al.*, 2017).

Generally, titratable acidity (expressed as Malic acid), increased steadily till the 15th day and then declined, in all the plantain samples (Figure 4.4). An average of value of 0.2 to 1.1 occurred in the plantains in the pseudostem treatments and 0.2 to 2.1 in the plantains found in the combination of pseudostem and KMnO₄ treatments throughout all the packaging types. Youryon and Supapvanich, (2017) reported a similar trend of titratable acid content in ripening bananas. They proposed that increase in titratable acidity in ripening fruits has an impact on ethylene secretion in climacteric fruits and declines when ethylene production reduces or ceases. This can be observed in Figure 4.4.

A critical look at the trend of the titratable acidity levels for all the samples shows that the gradual increase generally occurred between the unripe stage and the fully ripe stage but declined between the fully ripe and the overripe stages. Siriboon and Banlusilp (2004) reported that the increase seems to positively correlate with peak ethylene production and thereafter drops gradually to lower levels. It can then be said that titratable acidity in plantain tends to increase gradually as the fruit moves from the unripe

to the fully ripe stage, the same period where respiration rate and ethylene production is also on the increase, and gradually declines as the plantain moves from fully ripe to the overripe stage through to senescence. This is the same period when ethylene production and respiration rate are also decreasing. If this holds, then %TA levels in plantain could be used as an indicator in predicting ethylene production and respiration rates in plantains.

It has been reported that fruits at the matured green stage have high pulp pH but as ripening progresses, the pH drops (Silva *et al.*, 2009). From Figure 4.5, it was observed that the pH decreased as the days progressed and then started to increase again. This could be a result of titratable acidity increasing with ethylene production and then subsequently declining slowly when production decreases or stops (Osman & Abu-Goukh, 2008). High pH implies low TA and vice versa. This is the trend observed throughout the experiment for all packaging types and treatments. The pH levels however all stayed in the range of 5.82-5.99 for all the samples.

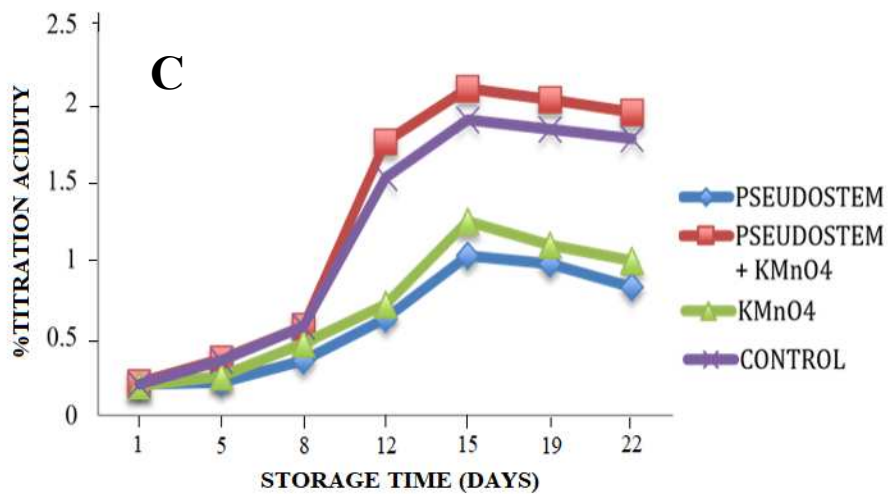
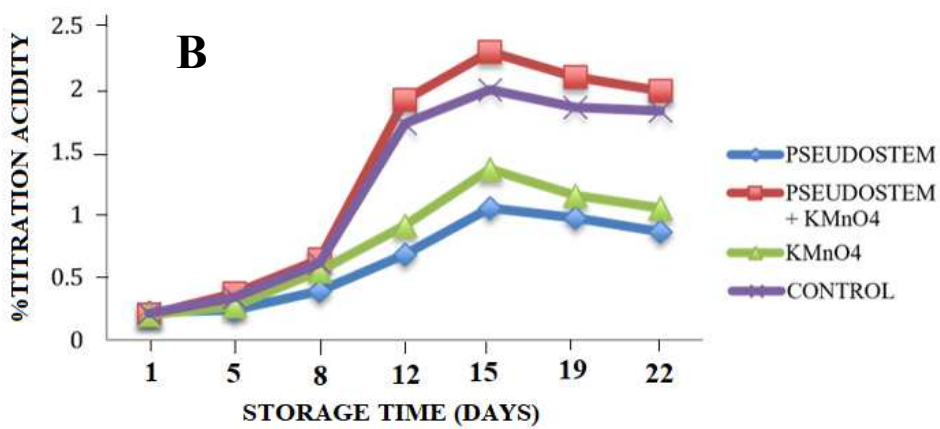
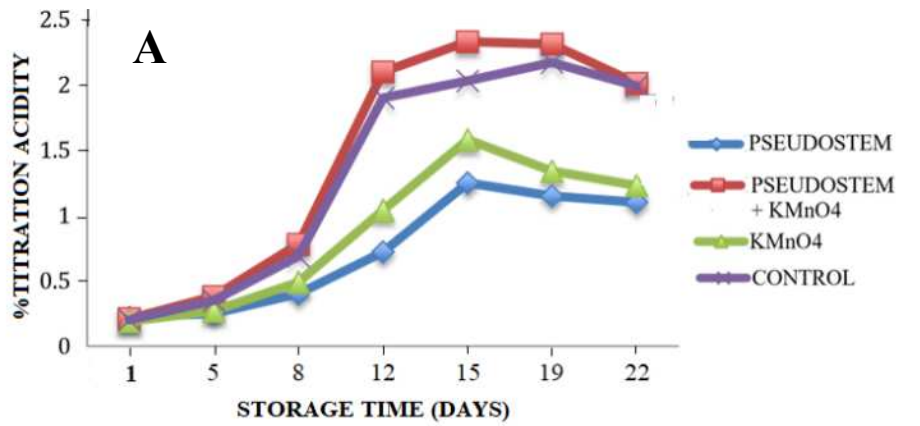


Figure 4.4: Changes in titratable acidity (TA) of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

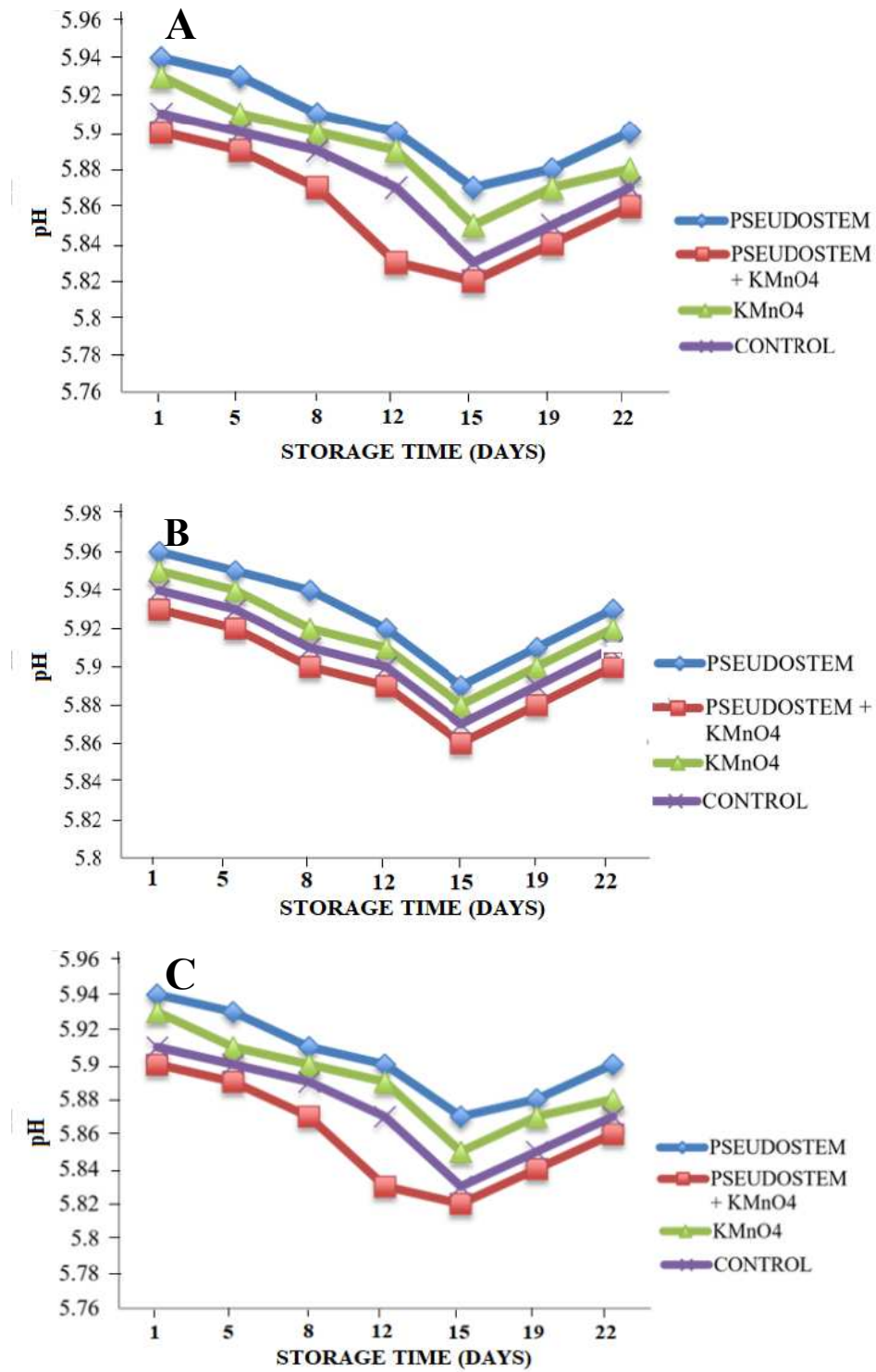


Figure 4.5: Changes in pH of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

4.2 Effect of packaging conditions on the Pulp Firmness, Peel Colour and the Level of Bruising on the plantain samples.

Sensory assessment of pulp firmness, peel colour and level of bruising was done to assess the quality of the plantains from green life till senescence. Peel colour is the easiest noticeable parameter consumers used in assessing fruit quality and is a reflection of pulp colour change (Wills *et al.*, 1998). Fruit firmness and level of bruising are also another dependable parameter used in assessing fruit quality with reduction in firmness being viewed as one of the most perceptible attributes, resulting from the ripening process. Fruits with higher firmness are more resistant to transport and durable after the harvest, however, excessive loss of firmness as a consequence of overripening can prompt physical damage and pathogen attack, and consequently lead to an important decrease in fruit quality (Pereira *et al.*, 2004). Usually, these three parameters are used during the quality grading of fruits, both climacteric and non-climacteric. The plantain peel colour is an essential buying indicator for consumers, and it usually determines its potential usage (Adi *et al.*, 2019).

Results shown in Figures 4.6, 4.7 and 4.8 indicated differences between the pulp firmness, the peel colour and level of bruising, respectively, among the various treatments in the different package types.

4.2.1 Pulp Firmness

Softening is a very important aspect of ripening syndrome. Loss of turgor, degradation of starch, and enzyme-catalyzed changes to wall structure and composition, are the mechanisms that lead to fruit softening. Excessive loss of firmness as a consequence of overripening can however, prompt physical damage and pathogen attack, and consequently

lead to an important decrease in fruit quality. According to Finney (1967), textural change in banana and plantain fruit during ripening is predominantly due to the changes in the chemical structure of starch grains.

The pulp firmness decreased steadily in the samples throughout the storage period (22days). For all packaging types the trend observed was the same (Figure 4.6). The pseudostem + KMnO₄ and control treatments ripened faster thereby moving from very firm (5) to extremely soft (1) by day 19 in all packaging types. The pseudostem and KMnO₄ treatments were observed to have slowed down the ripening process of the plantains and some of the samples with these treatments went on to day 22 before reaching a score of 1.

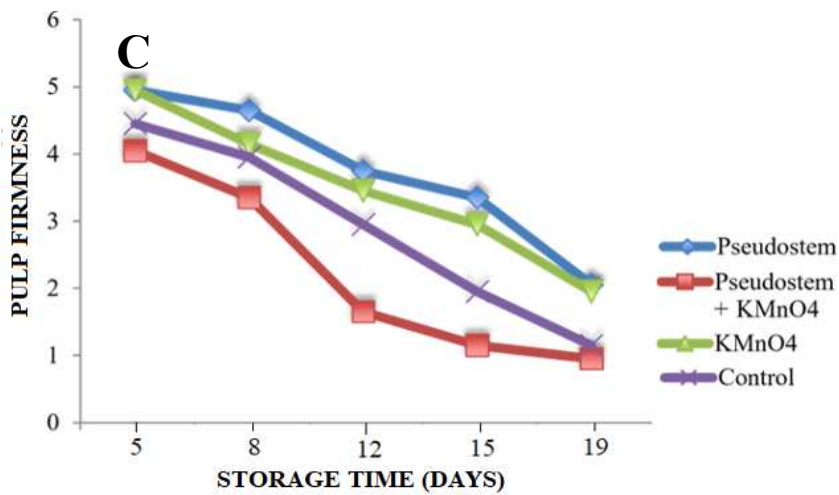
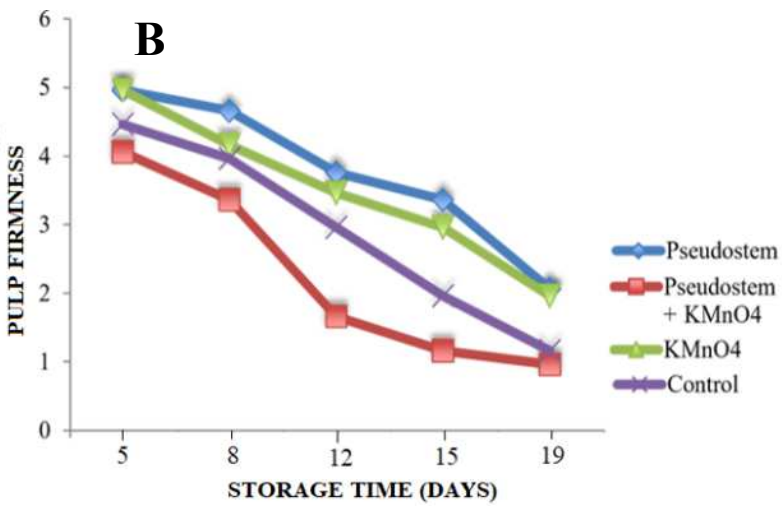
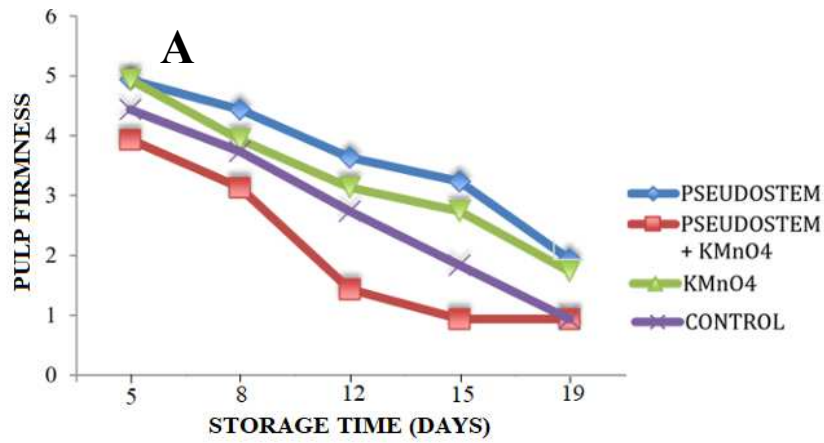


Figure 4.6: Changes in Pulp Firmness of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

4.2.2 Peel Colour

The most important compounds responsible for the change in peel colour are chlorophylls and carotenoids. During ripening chlorophyll levels decrease till they are completely absent when fully ripe (Zakpaa *et al.*, 2010).

For this study it was observed that, peel colour changed from full green to at least all yellow (score of 6) by day 19 for all samples in all the packaging types and treatments. In the pseudostem + KMnO₄ treatment samples however, the samples were dark brown (score of 9) by day 19. Control treatments in all the packaging types were also increasing at a fast rate, slightly behind the pseudostem + KMnO₄ samples and hovering between scores of 8 (yellow with more spread of brown) and 9 (dark brown). This is observed in Figure 4.7.

The KMnO₄ treatment had a much slower colour change as by day 19, the plantains had a score of 7 (All yellow with brown speckles) as shown in Figures 4.7 A and B. Figure 4.7 C showed a score of 6 (All yellow) which indicates the plantains had just fully ripened and were not at the senescence stage unlike those in the pseudostem + KMnO₄ and control treatments. The pseudostem treatment had the slowest ripening rate hence slowest color change. This was evident with the average samples scoring 6 (All yellow) in all the packaging types, by day 19. By day 22 however, all samples had reached the dark brown point (9).

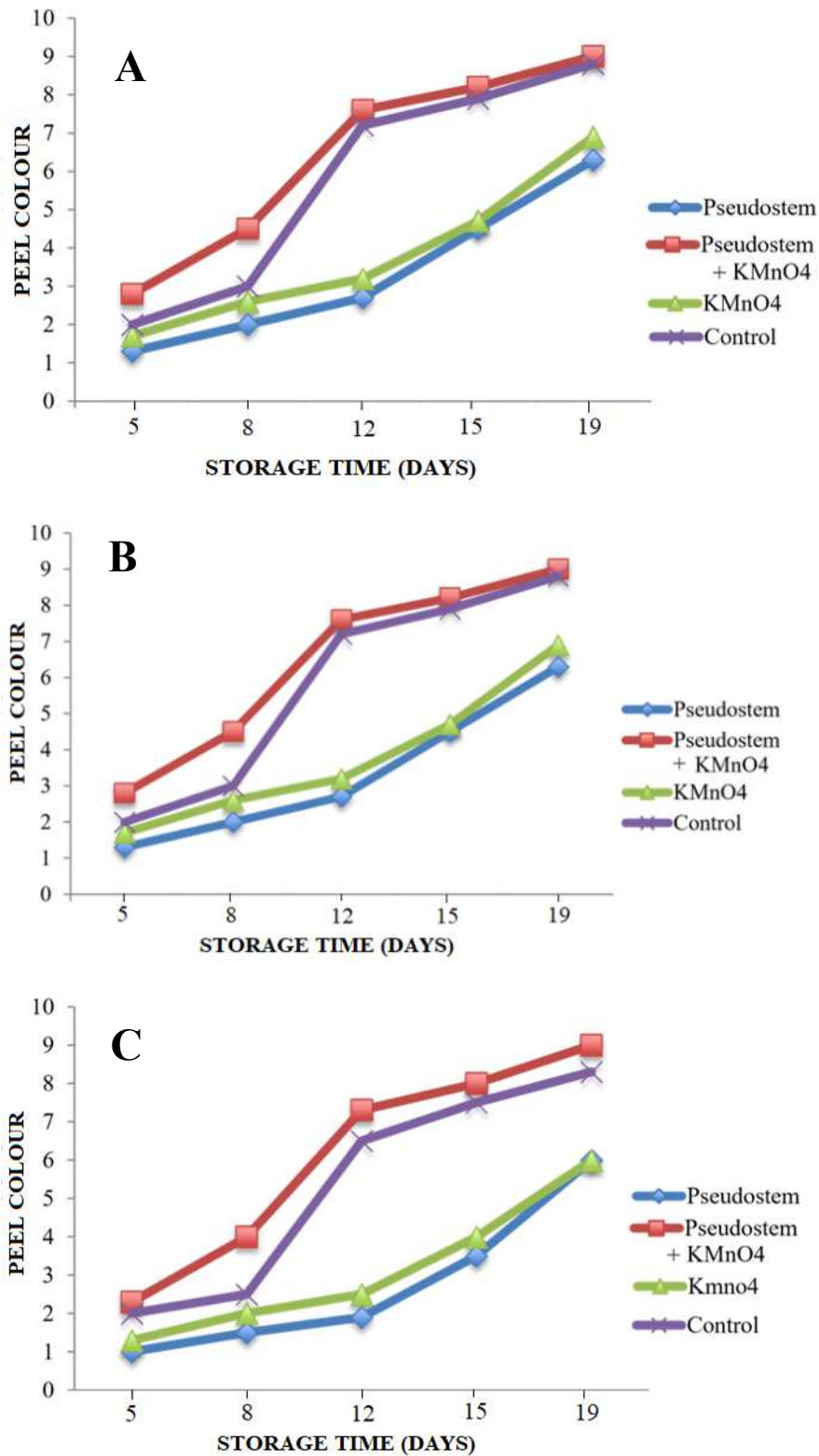


Figure 4.7: Changes in Peel Colour of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) over the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box.

4.2.3 Bruising

A bruise is an indicator of cellular damage. The level of bruising in the plantains increased over the 22 days in all the samples (Figure 4.8). This could be as a result of peel softening due to ripening, making bruising easier and it occurred in all the packaging types. Bruising was highest in Figure 4.8 A, the corrugated paper box. Figure 4.8 C; plastic box, reported the least amount of bruising.

Ripened plantains are more susceptible to bruising due to softening of the pulp (Finney, 1967). This tends to be in line with the study where it was found that the samples under the treatment that caused early ripening; pseudostem + KMnO_4 , and the control treatment recorded the highest cases of bruising. This reported trend can be observed in Figure 4.8. The pseudostem treatment recorded the least level of bruising for all packaging types.

It can therefore be said that the pseudostem + KMnO_4 treated samples in the corrugated paper box (Figure 4.8A) had the highest level of bruising while the pseudostem treated samples in the plastic box (Figure 4.8C) the lowest level of bruising.

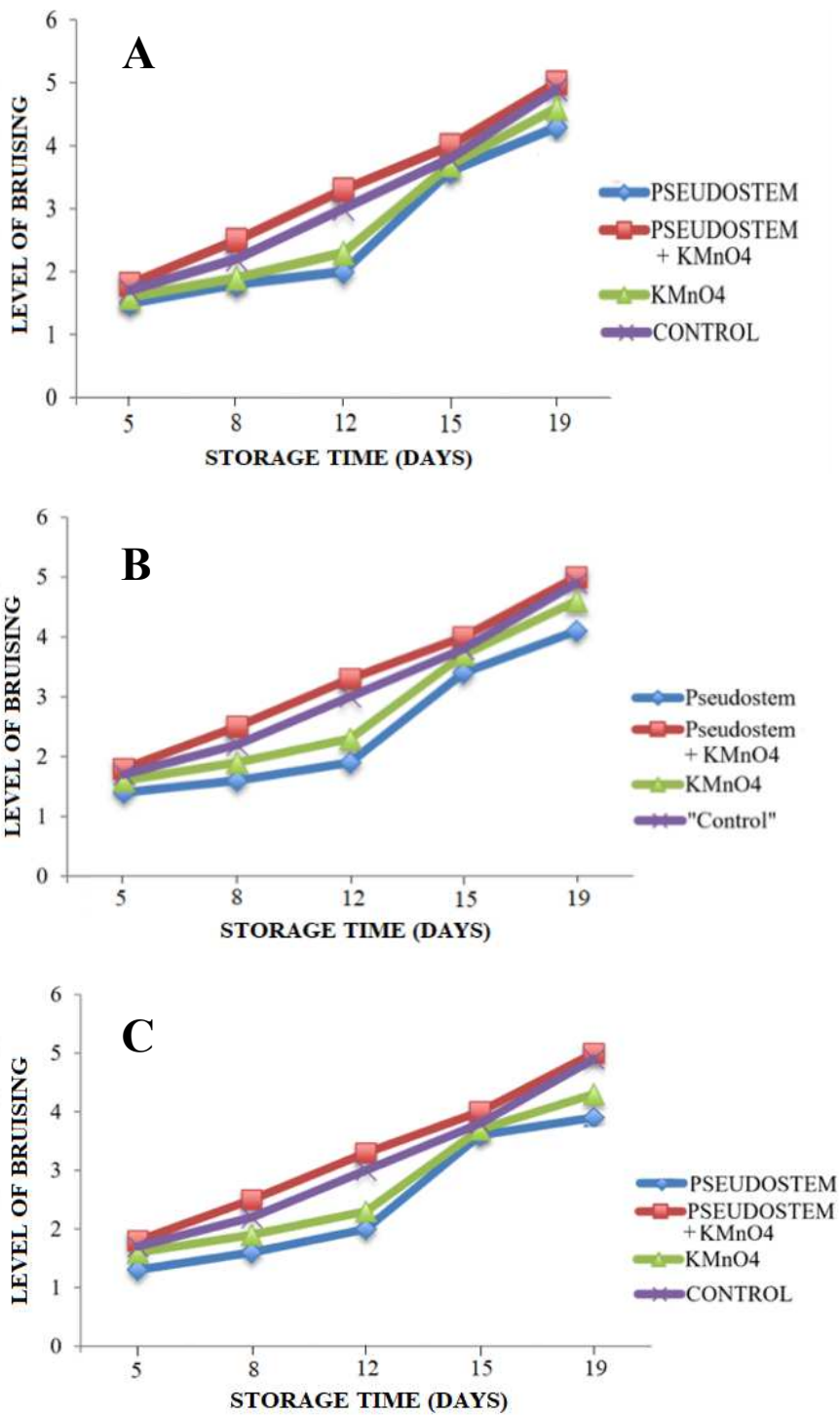


Figure 4.8: Changes in Bruising of fingers of plantains in four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control) the storage period. A – Corrugated Paper Box, B – Wooden Box, C – Plastic Box

4.3 Effects of packaging types and treatments on the plantains during storage for optimum shelf-life

4.3.1 Effects of the packaging types on the plantains

Among the primary roles of food packaging are protecting the food products from external influences and damage and containment of the food products (Coles *et al.*, 2003). The three packaging types (corrugated paper boxes, wooden boxes, plastic boxes) performed these functions with varying degrees of efficiency. The ability of a packaging type to protect the plantains and how well it contains them were some parameters used to determine the ideal packaging type for optimum shelf-life of the plantains

Food packaging aims to contain food in a cost-effective way that satisfies both industry requirements and consumer desires while maintaining the safety of the food and minimizing environmental impact (Chiellini, 2008). The ideal packaging type should not be too expensive and should be readily available. Other parameters such as aeration and its effects on the plantains as well as the durability, portability and appearance of the boxes were also taken into consideration. These were measured by physical observation during handling and storage periods.

From the results in the previous sections, Figures 4.1- 4.5, the graphs representing the physicochemical (and biochemical) analysis of the plantain samples followed similar trends in all packaging types. The plantain samples in the plastic boxes had a longer green life of 2-3 days and were of better physical quality with regards to pulp firmness, peel colour and level of bruising (Figures 4.6 – 4.8) as opposed to those in the corrugated paper and the wooden boxes.

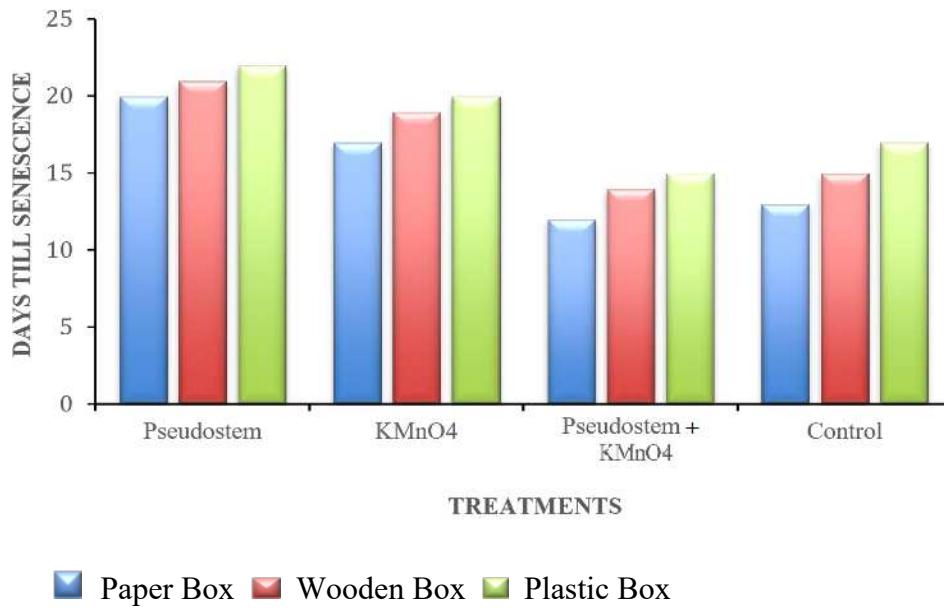


Figure 4.9: Number of days till senescence of plantains in three packaging types (corrugated paper, wooden and plastic boxes) undergoing four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control)

The plantains in the pseudostem treatment lasted for 20 days, while those in the KMnO₄, pseudostem + KMnO₄ and control treatments lasted for 17, 12 and 14 days respectively in the paper box (Figure 4.9). The corrugated paper box, had no holes (except those for carrying the box) and therefore trapped heat, causing the plantains to ripen faster than the other packaging types. Elevated temperatures cause ripening and shorten the shelf life of fresh produce at postharvest storage (NARI, 2003). This packaging type was also not suitable for carrying the heavy plantains and caused deformities due to the extreme pressure from the plantains and the fragile nature of the boxes. For packaging of certain heavy items, corrugated paper boxes may not be suitable because of their relatively less endurance to mechanical stresses (Fagbohu, *et al.*, 2010). In the case of having to transport the plantains in the paper boxes the task may be met with some difficulty.

In the wooden box, the plantains in the pseudostem treatment lasted for 21 days. It took 19, 14 and 15 days for the plantains in the KMnO_4 , pseudostem + KMnO_4 and control treatments to reach senescence, respectively (Figure 4.9). Though the plantains in the wooden box had a relatively longer shelf life than those in the paper boxes, the structure of the box did not allow for optimum storage and shelf-life of the produce. The wooden box had huge airspaces (big holes), increasing the availability of oxygen into the system. Oxygen facilitates respiration, which in turn facilitates ripening (NARI, 2003). Untreated wood can easily become contaminated with fungi and bacteria however, treatment of wooden crates with paint or other chemicals may cause produce deterioration (Fagbohu, *et al.*, 2010). The wooden box was left untreated in order not to affect the plantains being stored and after the first week, beginning signs of fungal growth was observed in two of the wooden boxes. The wooden boxes were relatively expensive to make as compared to the two other packaging types, though they were locally manufactured. They were aesthetically pleasing but the large spaces did not make it practical for storage of plantains or any perishables over any period of time as the spaces leave the produce easily susceptible to harmful external factors such as rat and insect infestation.

In the plastic box, the plantains in the pseudostem treatment lasted for 22 days. Those in the KMnO_4 treatment lasted 20 days while pseudostem + KMnO_4 and control treatments lasted for 15 and 17 days, respectively (Figure 4.9). The plastic boxes had numerous small-sized holes, which reduced the heat in the boxes that could have aided in accelerated ripening. The design of the plastic container, its water resistance and ability to keep its shape over a long period was better for containing and protecting the plantains compared to the other packaging types. For plantain storage, the external factors play a

major role in the ripening of the sample more than the internal or intrinsic factors (Fagbohu, *et al.*, 2010). It was also light and easy to carry around despite not being empty.

Though the wooden box was a better packaging type than the paper box, it was quite heavy to carry around as compared to the plastic. It is also more expensive to make. This eliminates it from being the most ideal packaging material, along with the earlier stated reasons. All in all, the plastic was able to protect the plantains from accelerated ripening and harmful external factors, relatively inexpensive and aesthetically pleasing. Due to the plastic box's provision of optimum aeration and ability to properly protect the plantain samples throughout the 22 days, it can be observed in Figure 4.9 that irrespective of the treatment for each box, the plastic box provided longer shelf-life.

4.3.2 Effect of treatments on the plantains

The shredded plantain pseudostem showed an ability to delay ripening of the plantains, followed by potassium permanganate while the combination of shredded plantain pseudostem and potassium permanganate hastened the ripening rate of the plantain compared to the control.

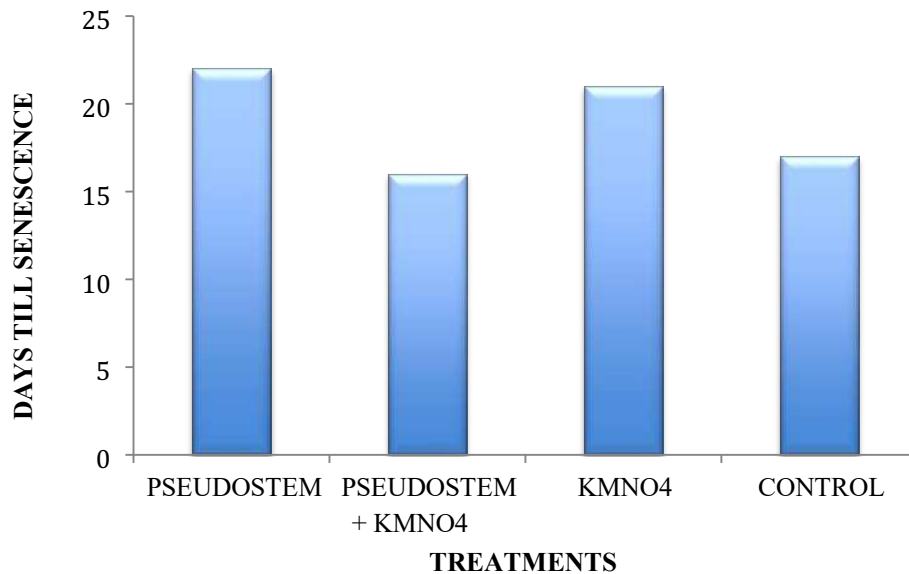


Figure 4.10: Average number of days taken till senescence of all plantains in all packaging types (corrugated paper, wooden and plastic boxes) undergoing the four treatments (pseudostem, KMnO₄, pseudostem + KMnO₄ and control).

The plantains packaged in the pseudostem lasted for an average of 22 days in the plastic boxes, 21 days in the wooden boxes, and 20 days in the paper boxes till senescence occurred. Those plantains packaged in the combination of pseudostem and potassium permanganate lasted for an average of 17 days in the plastic boxes, 15 days in the wooden boxes and 13 days for the paper boxes till senescence (Figure 4.10).

The ability of sawdust of moisture content 50% to increase the pre-climacteric and post-climacteric storage life of Apantu (false horn plantain) to 26 and 32 days respectively under ambient conditions has been reported by Sugri and Johnson (2009). They attributed this efficiency of the moist sawdust being able (under tropical conditions) to increase the storage days to the combination of humidity and the velocity of the wind, creating the necessary cooling conditions that are below the ambient air temperatures. All the conditions were similar to this study, except the plantain pseudostem in place of

the sawdust, which makes it logical to also assert that the same reasons might have been responsible for the observation in this experiment.

The plantain pseudostem has mineral elements or chemical compositions that can oxidize ethylene produced by the plantain, which may have resulted in the observed delay in ripening with an average of 22 days as shown in Figure 4.10. It can therefore be said that the plantain pseudostem behaved as an ethylene absorbent just like potassium permanganate (Golden *et al.*, 2014).

Another possible explanation to this observation could also have resulted from a possible competition for the limited oxygen (O₂) that was trapped in the boxes between the plantain fingers and the shredded pseudostem, which hindered the rate of respiration of the plantains and therefore delayed senescence of the plantain fingers in storage. This assertion is premised on the fact that plantain is fresh fruit, and as such requires oxygen for its respiration process (Fonseca *et al.*, 2002), which also leads to biochemical changes and initiation of ethylene production (Golden *et al.*, 2014). As the shredded plantain pseudostem began to decompose, it was likely to have some molds, which are known to consume oxygen (Ofor *et al.*, 2010). Since the fresh plantains and the shredded pseudostem were put together in boxes and sealed, the mold growth on the surface of the decomposing shredded plantain pseudostem might have consumed available oxygen in the box, creating a reduction in the optimum O₂ level required by the plantain fingers for respiration and hence the observed delay in ripening.

This phenomenon of lowering the O₂ levels a little below the threshold (and raising the CO₂ level a little above optimum) has been the basis for the success of modified

atmosphere package (MAP) in extending the postharvest shelf life of fruit and vegetables (Sandhu and Singh, 2000; Dou-ShiJuan *et al.*, 2002 and 2003; Bhande *et al.*, 2007). This could have been a possible occurrence in the paper boxes, which had no holes and provided an enclosed environment.

The next important trend observed during this experiment is the result of the combination of the shredded pseudostem and the KMnO_4 used in the packaged plantain. This treatment stored the plantains for an average of 15 days. While the shredded pseudostem and the KMnO_4 were individually able to delay ripening better than the control, their combination rather caused a shorter shelf-life, faster than the control. This could have resulted from the possibility of some of the mineral elements present in the plantain pseudostem having an adverse effect on potassium permanganate (KMnO_4) or interacting with it to form a different compound(s) that could have altered their individual effects on ripening (Akpabio *et al.*, 2012; Okelana, 2001). Examples such as Bhattacharjee and Dhua (2017) treating bitter gourds with Silica gel-permanganate and elite- permanganate mixture under ambient storage conditions of 27.2°C -31.4 °C and 69-72% RH, recorded faster rates of spoilage and Sharma *et al.*(2012) using different combinations of potassium permanganate (KMnO_4) together with other materials (sachet, absorbed in chalk and absorbed in a newspaper) and also recording varying rates of spoilage under uniform storage conditions, showed that potassium permanganate may be effective as an ethylene absorbent when used alone but becomes less effective when its structure is altered or absorbed into a material, possibly due to an interaction with the material.

In conclusion, it could be stated that for improved quality and the shelf life of the plantains, the best combination observed was the plastic packaging type with the pseudostem treatment, and this run throughout for all the biochemical and physicochemical as well as sensory analysis conducted.

4.4 Effects of different forms of packing arrangements on plantain quality during transit and subsequent storage.

The last objective was to investigate the effect of different forms of arrangements on plantain quality during transit and storage.

Table 4.1: Effect of transit on Pulp firmness, Peel Colour and Level of Bruising on plantains in different forms of packing arrangements as assessed through sensory evaluation

Arrangement	Firmness	Peel Colour	Bruises
Fingers with Styrofoam	5.00±0.00 ^b	1.00±0.00 ^a	1.10±0.00 ^a
Fingers without Styrofoam	5.00±0.00 ^b	1.00±0.00 ^a	1.15±0.00 ^a
Hands with Styrofoam	5.00±0.00 ^b	1.33±0.58 ^a	1.20±0.00 ^{ab}
Hands without Styrofoam	5.00±0.00 ^b	1.67±0.58 ^a	1.20±0.00 ^{ab}
Bunches	4.00±0.00 ^a	2.33±0.58 ^a	2.00±0.00 ^c

Data are presented as means±SD, means within a column with different superscripts are significantly different at $P \leq 0.05$.

Firmness was graded on a scale of 5- Very firm to 1- Very soft. Peel colour was graded from 1- All green to 9- Dark brown with yellow traces and bruises was graded from 1- Extremely low/None to 5- Extremely high for the plantain samples.

From the results in Table 4.1, introducing some form of packaging (plastic box in this case) for plantain during transportation reduced the level of mechanical damage that was inflicted on the plantains during transit. The high level of bruising observed in the bunches at 2.00 ± 0.00 is significantly higher than that of the other packing arrangements. Also, packing smaller numbers of plantains (fingers and hands) led to less mechanical damage through friction or hitting against each other, hence the relatively low level of bruising for the fingers 1.10 ± 0.00 (with Styrofoam), 1.15 ± 0.00 (without Styrofoam), and the hands, with or without Styrofoam; (1.20 ± 0.00). The pulp firmness was compromised for the bunches and scored an average of 2.00 ± 0.00 . The firmness for the hands and fingers, however, remained at 1.00 ± 0.00 . The colour was however unaffected in all samples.

Significant differences were found between the bunches and the four other arrangements for firmness and bruising, at a confidence level of 95%. It could be said that though the Styrofoam may have provided a form of protection, possibly the prevention of scuffing, it did not make much of a difference as opposed to the added effect of protection the packaging of the plantains in the plastic box had on all those that were packaged.

4.4.1 Changes in Pulp firmness, Peel Colour and Level of bruising for plantain samples after subsequent storage.

Improper handling during transit leads to bruises, breakages, peel darkening, fungal diseases (such as crown rot), and major post-harvest losses (Ayanwale *et al.*, 2016). The packing arrangements of the plantains had an effect on their quality and shelf life.

Four packing arrangements (not including the bunches) saw to the reduction of post-harvest losses by including packaging; greatly reducing the adverse effects of transit on the plantains. Also, reduction of the number of the plantains (reducing the bunches to hands and reducing the hands to fingers) lessened the effects of mechanical damage. The bunches, which had no packaging, had Styrofoam which may have prevented further scuffing.

Results from the experiment showed a significant difference between the pulp firmness, peel colour and level of bruising, among all the various treatments at 5% level probability (95% significant level). In Figures 4.11 A and B, it can be observed that the fingers with the Styrofoam layer stayed green and firm the longest. It also had the least bruising in Figure 4.11 C.

Post-harvest losses as high as 10 to 30% are associated with plantains because they have a short pre-climacteric period of less than one week and a shelf life of about 11 days under ambient conditions (Sugri *et al.*, 2010). The packaging type (plastic boxes) and the arrangements (fingers) of the plantains extended the shelf life of some of the plantains to about 15 days before senescence. This was in the case of the fingers with Styrofoam. However, in the arrangement with bunches, senescence was reached by day 12 for all the plantains.

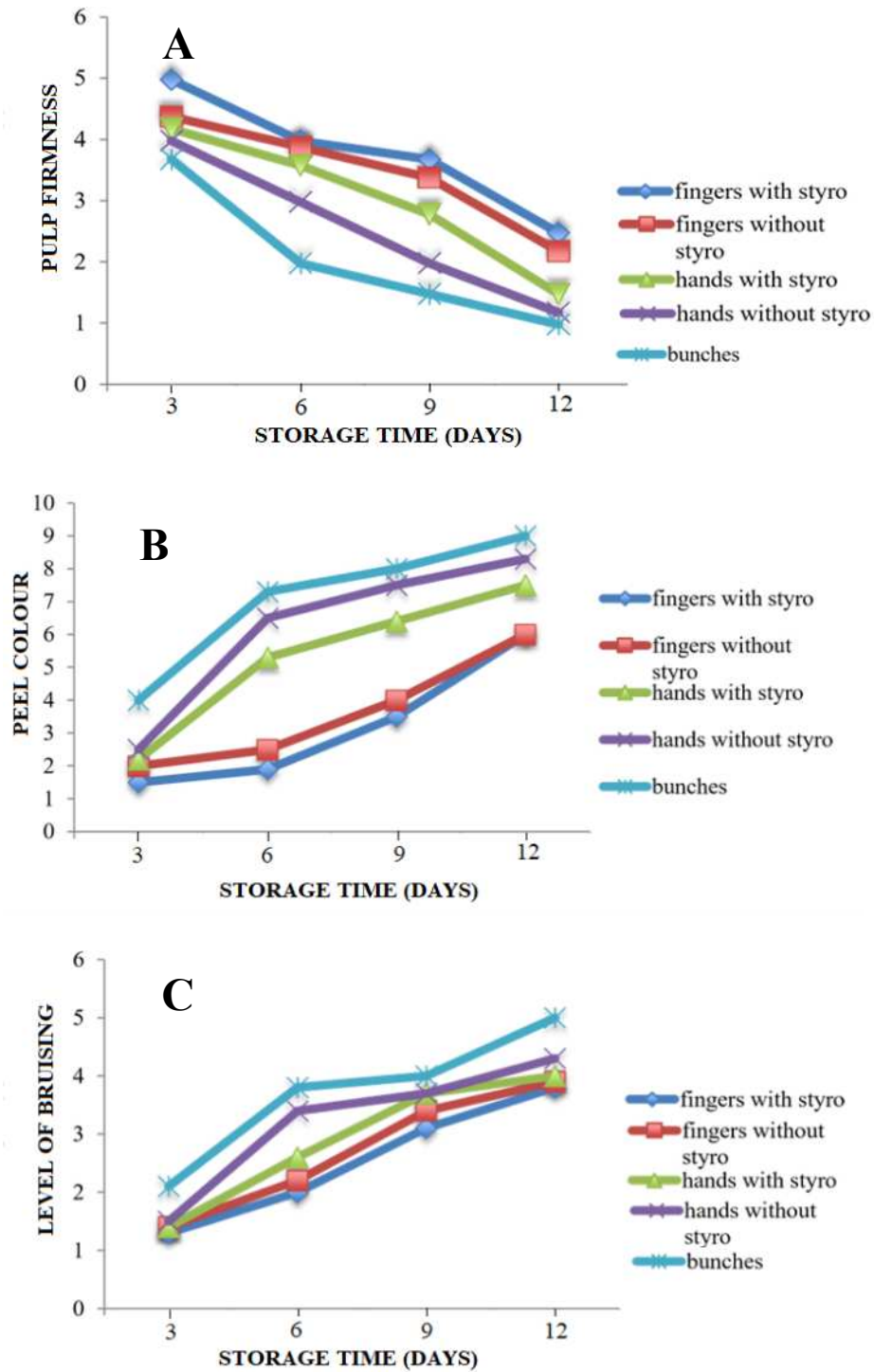


Figure 4.11: Changes in sensory quality characteristics of plantains packed in different ways for transportation and subsequent storage till senescence (fingers with Styrofoam, fingers without Styrofoam, hands with Styrofoam, hands without Styrofoam, bunches with Styrofoam). A- Pulp firmness, B – Peel Colour, C – Level of Bruising

4.5 Evaluating the best packing arrangement during transit and after subsequent storage for improved quality and shelf- life

The best packing arrangement was determined after results from the previous experiments concluded that plastic was the most optimum packaging type as compared to wooden boxes and paper boxes. This experiment further went on to use the plastic boxes to house the arranged plantains for maximum quality storage. All but the bunches were packed in the plastic boxes. These arrangements were used to store the plantains which were assessed immediately (on arrival) and subsequently (every 3 days till senescence) using sensory analysis.

Generally, it was observed that the plantain bunches ripened the fastest, followed closely by the hands without Styrofoam, hands with Styrofoam, before the fingers without Styrofoam and then the fingers with Styrofoam. This could be because ripening occurred in one or few plantain samples and due to the proximity of the other plantains, there was an autocatalytic ethylene production, which hastened the ripening process, spreading it across all the plantains close by causing a chain reaction. This reaction is commonly found in climacteric fruits (Youryon and Supapvanich, 2017).

The fingers separated by the Styrofoam lasted a maximum of 15 days before senescence whereas all other groups completely decayed between 12-14 days (bunches by day 12). Plantain responds to ripening indices at elevated temperatures faster than that of the normal room temperature (Ogazi, 1996) and this may have also contributed to the faster ripening in the grouped plantains (bunches and hands) than in the separated ones (fingers). There was also bruising on arrival found especially on the bunches since they

had no packaging and this influenced the rate of ripening as bruising leads to high respiration rate which in turn causes accelerated ripening.

Plate 4.1 shows the different stages of ripening with the different packing arrangements. “A” denotes fingers separated with a layer of Styrofoam on day 6, and here, the various stages of ripening can be observed in one box. It can be observed that while some of the plantains were almost yellow with more spread of brown (score of 8) indicating near senescence, some were yet to ripen and turn yellow (scores of 4, 5). This means unlike in the case of the grouped plantains (hands and bunches) where ripening of one or more plantains can lead to autocatalysis of ethylene production to ripen all the plantains rapidly, these individual plantains were allowed to ripen at their own pace without necessarily affecting the others. This ensures longer shelf life of the plantains. It could therefore be stated that plantain fingers packed with a layer of Styrofoam, has the ability of improving the quality and prolonging the shelf life of plantains better than any of the other packing arrangements.



Plate 4.1: Different stages of ripening of plantains in packing arrangements: A - Fingers separated with a layer of Styrofoam on day 6, B - Hands separated with a layer of Styrofoam on day 3, C - hands lying directly on top of each other with no Styrofoam layer on day 3, D - bunches on top of each other, separated with a layer of Styrofoam on day 3.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The conclusions are stated as per the objectives of the study.

The shredded plantain pseudostem as a storage material for plantain preserved the green state of plantain for a relatively long period, more so than potassium permanganate. However, the combination of the shredded plantain pseudostem and the potassium permanganate as a storage material for plantain rather hastened the ripening process. So, to extend the green life of produce, the shredded plantain pseudostem is an ideal storage material whereas to increase the rate of ripening, the combination of the shredded plantain pseudostem and the potassium permanganate should be employed.

The plastic box was proven to be the most ideal packaging material, as it is not only hardy and easy to handle but also gave the best results from the observations made, with regards to improving and maintaining the quality of the plantains over the study period. The plastic box should be used in packaging to improve upon the quality and shelf life of produce to 22 days.

Packaging is the main factor needed to minimize the level of mechanical damage during transportation of the plantains. Packing the plantains in fingers with Styrofoam prolongs the green life of the plantain best as opposed to packing plantains in hands or bunches. Packing plantains in bunches increases the rate of ripening. To extend the green

life of plantains, they must be arranged in fingers. Arranging them in bunches increases their ripening rate.

5.2 Recommendations

An additional step in evaluating packing arrangements for transportation of the plantains, which would include using different storage materials such as pseudostem (for extending green life) and pseudostem + KMnO_4 , (for enhanced ripening) should be studied. A limitation during the packing arrangement study was my inability to include the pseudostem in the packaging conditions from the farm, to prolong the green life of the plantains.

Studies need to be conducted on the mechanism of how storing plantain with a combination of potassium permanganate and shredded plantain pseudostem hastens ripening while when they are used separately, they each delay ripening.

Biochemical analysis of shredded plantain pseudostem should be done to uncover the minerals and other substances, which aid in the ability of the shredded pseudostem to delay ripening in the plantain.

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APPENDICES

Worksheet and Ballot Sheet for Sensory Evaluation

THE UNIVERSITY OF GHANA, LEGON DEPARTMENT OF NUTRITION AND FOOD SCIENCE SENSORY EVALUATION OF THE PLANTAIN SAMPLES

PROJECT TOPIC: Project PowerPuff girls

OBJECTIVE: To determine the quality of plantain through descriptive sensory evaluation of plantain samples based on pulp firmness, peel colour and level of bruising.

PANEL TYPE: Quality descriptive panel

NUMBER OF PANELISTS: 6

ACTIVITY ONE: TRAINING OF PANELISTS

OBJECTIVE: To familiarize the panelists with the plantain samples and to come up with a scale for grading.

Samples needed include:

- Banana at all stages of ripening.
- Peeled egg
- Candies
- Mango at different stages of ripening
- Sachet water

Protocol for Training of Sensory Panelists.

Generating a Grading Scale to Assess Pulp Firmness.

Before calibrating a scale for evaluating the firmness, various food items, which have various forms of hardness, will be presented to the panelists to assess and classify them according to their degree of hardness (firmness). This will be done on a scale of 1 - 5. The very firm will receive a score of 5 and the softest will be given a score of 1. All the panelists will be allowed to touch and press gently each of the items presented for them to give a score based on the scale. Several samples will be presented to the panelists including mango fruit (of varied Colours), banana (of varied Colours), candies, boiled and peeled eggs, and 500ml Sachet water. Afterward, the panel will discuss and come to a consensus on the actual score for each of the items presented and then this will be grouped to serve as a scale for the final evaluation.

Quality Grading Scale for Pulp Firmness

Quality parameter	Description	Score
FIRMNESS	Very firm	5
	firm	4
	Soft	3
	Very soft	2
	Extremely soft	1

Generating a Grading Scale for Assessing Peel Colour.

The unripe (all green Colour) and overripe (dark brown Colour with a trace of yellow) plantain fingers will be used as the endpoints to calibrate the quality scale for ripeness. Plantains at different stages of ripeness will also be presented to the panel for them to score according to peel Colour. Scoring for the Colour will be done based on the degree of ripeness. A scale of 1 to 9 will be used for grading the peel Colour. The Colour

chart for grading the ripeness of bananas (adapted from Gee st, UK) will be used to facilitate both the training and the test sessions.

Quality Grading Scale for Peel Colour

Quality parameter	Description	Score
COLOUR	All green	1
	Green with a trace of yellow	2
	More green than yellow	3
	More yellow than green	4
	Yellow with a trace of green	5
	All Yellow	6
	All Yellow with brown Speckles	7
	More spread of brown in yellow	8
	Dark brown with yellow	9

(adapted from Gee st, UK)

****This session should last for about 60 to 90 minutes.**

ACTIVITY TWO

BALLOT SHEET FOR PANELISTS Instructions

The samples to be assessed are twelve, from twelve different storage treatments. The sensory analysis is to assess the quality of the samples based on their peel colour and pulp firmness. The test will be conducted at every five days interval with a test duplicate in each session.

You are to carefully look at the sample presented and grade the peel Colour according to the ripeness level, that is, colours like all green, green with a trace of yellow, more green than yellow, more yellow than green, all yellow, yellow with brown speckles, brown with yellow speckles, browner than yellow and dark brown with a trace of yellow

will be graded following the generated scale. You should score the colours on the said scale from 1 to 9 depending on the ripeness level of the plantain.

The assessment of the firmness will also be measured on a scale of 1 - 5. You are to gently touch the sample and press them to assess their firmness. The scores for the firmness will also be graded following their degree of firmness on the generated scale; very firm, firm, soft, very soft, and extremely soft. For the colour, all green is 1 and 9 is dark brown with a trace of yellow. The rest of the colours will be graded between 2 and 8. For the firmness also, 1 is very firm and 5 is extremely soft (with pulp juice oozing out). The other touch indicators like firm, soft, and very soft will be scored between 2 and 4 depending on the firmness. You will be provided with 12 samples. Assess the samples provided from left to right.

- Evaluate the samples by observing/examining (feeling) the entire surface area of each of the individual samples in a set carefully before scoring.
- Use the colour chart provided to aid in the grading for the peel colour of the samples.

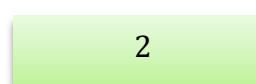
Peel colour

Sample code

A



All green



Green with a trace of yellow



More green than yellow



More yellow than green

5
Yellow with a trace of green

6
All yellow

7
All yellow with brown speckles

8
More spread of brown in the yellow

9
Dark brown with yellow traces

Pulp Firmness

Sample Code

A

1
Very firm

2
Firm

3
Soft

4
Very soft

5
Extremely soft

Level of Bruising

Sample Code

A

1

Extremely low/none

2

low

3

medium

4

High

5

Extremely high

ACTIVITY THREE: WORKSHEET FOR THE QUALITY

ASSESSMENT TEST Type of sample: Plantain fingers

Test type: Quality grading

Test location: Department of Nutrition and Food Science

Samples served: Twelve plantain fingers with different storage condition

Each panelist receives **12** plantain samples at a time. Each sample is coded with a random number. The sample codes are given below:

Q1: Pseudostem treatment in a paper box

Q2: Pseudostem treatment and KMnO_4 in a paper box for the Apantu

Q3: KMnO_4 treatment in a paper box for the Apantu

Q4: Apantu in paper box without any

treatment (control)

D1: Pseudostem treatment in a plastic box for

the Apantu

D2: Pseudostem treatment and KMnO_4 in a plastic box for the Apantu

D3: KMnO_4 treatment in a plastic box for the Apantu

D4: Apantu in plastic box without any

treatment (control)

S1: Pseudostem treatment in a wooden box for

the Apantu

S2: Pseudostem treatment and KMnO₄ in a wooden box for the Apantu

S3: KMnO₄ treatment in a wooden box for the Apantu

S4: Apantu in wooden box without any treatment (control)

Sample Codes and Order of Presentation.

Test sessions	1	2	3	4	1	2	3	4	1	2	3	4
Session one	92	78	48	96	70	12	82	00	91	88	70	62
	86	51	15	55	36	10	41	78	65	82	10	29
Session two	96	29	74	05	87	63	15	25	00	56	92	15
	35	50	38	61	71	89	89	21	61	64	59	92
Session three	75	55	24	64	77	32	94	45	70	21	87	22
	94	37	12	01	24	87	10	07	62	54	72	68
	27	37	38	04	55	88	22	02	94	11	11	00
Session four	35	74	36	04	30	27	82	53	37	13	04	40
	22	43	34	68	51	05	21	98	64	99	48	30
	16	23	00	22	77	28	88	31	49	47	25	32
Session five	87	71	36	41	11	82	48	34	49	13	56	32
	65	62	27	27	23	64	31	66	83	73	63	74
	67	89	53	67	29	92	98	57	02	92	11	41
	44	30	82	66	09	45	58	12	25	36	50	77
	85	42	30	93	38	35	03	69	84	92	02	02

APPENDIX TABLE 1: ANOVA TABLE FOR TOTAL SUGAR (GENERAL LINEAR MODEL)

ANALYSIS	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Treatment	10.66	3.55	11.20	0.00
Days	69.96	23.32	73.54	0.00
Packaging	0.25	0.13	3.40	0.03
Error	42.81	0.32		
Total	123.67			

APPENDIX TABLE 2: ANOVA TABLE FOR REDUCING SUGAR (GENERAL LINEAR MODEL)

ANALYSIS	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Treatment	3	2.33	0.78	3.99	0.03
Days	3	277.01	92.34	355.59	0.00
Packaging	2	11.46	5.73	22.07	0.00
Error	135	35.06	0.26		
Total	143	325.86			

APPENDIX TABLE 3: ANOVA TABLE FOR pH (GENERAL LINEAR MODEL)

ANALYSIS	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Treatment	3	0.11	0.04	3.73	0.04
Days	3	15.10	5.03	103.37	0.00
Packaging	2	2.26	1.13	23.24	0.00
Error	135	6.57	0.05		
Total	143	24.04			

APPENDIX TABLE 4: ANOVA TABLE FOR BRIX (GENERAL LINEAR MODEL)

ANALYSIS	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Treatment	3	13.70	4.55	3.35	0.02
Days	3	17244	3.08	4222.03	0.00
Packaging	2	6.20	0.13	2.26	0.01
Error	135	17447.60	1.36		
Total	143	123.67			

APPENDIX TABLE 5: ANOVA TABLE FOR TOTAL SOLUBLE SOLIDS**(GENERAL LINEAR MODEL)**

ANALYSIS	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Treatment	3	0.12	0.00	3.98	0.04
Days	3	2.71	0.90	220.38	0.00
Packaging	2	0.11	0.05	12.85	0.03
Error	135	0.55	0.00		
Total	143	3.39			