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EFFECT OF GA_3 AND POLYETHYLENE FILM LINING ON THE POSTHARVEST CHARACTERISTICS OF TWO VARIETIES OF PLANTAIN UNDER AMBIENT STORAGE CONDITIONS

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BY

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DECLARATION

I hereby declare that, except for literature reference to other people‟s work which I have duly acknowledged, this work submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi,

Ghana as a dissertation for the Master of Philosophy (Post Harvest Technology) Degree is the result of my own original work and that this thesis has not been presented for any degree in this University or elsewhere.

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DEDICATION

I dedicate this piece of work to the omnipotent God for guiding me through with the Holy Spirit.

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ABSTRACT

Plantain is an important crop in the tropics. The crop, however, faces persistent perishability problems leading to high postharvest losses and eventual shortage and high prices of the crop and its products. The study attempted to solve this problem by providing a means of extending the shelf life of the crop particularly during the short lean period. In this regard, the post-harvest effect of GA_3 and polyethylene lining on two varieties of plantain, *Apem* and *Apentu*, under ambient temperature, was investigated in a factorial experiment. Four rates of GA_3 (0 mg/lit, 375 mg/lit, 750mg/lit and 1000mg/lit) were applied and three lining methods were used on card boxes as packaging materials. The three lining methods were the control/ no lining, perforated lining and unperforated lining. It was observed through the analysis that the effect of plantain variety on all the eight quality characteristics (days to ripening, weight loss, pulp to peel ratio, firmness, total soluble solids, pH, total titratable acidity, sugar to acid ratio) that were investigated were significantly different ($P<0.01$) except for sugar to acid ratio. Whereas *Apem* took a mean of 49 days to ripen (level 7 on the Dole Banana Guide), it took *Apentu* a mean of 23 days to ripen on the same scale. The four GA_3 concentrations recorded significant differences ($P<0.01$) on all the eight characteristics of the plantain fruits. Plantain fruits stored longer as the concentration of GA_3 was increased. The control (0mg/lit) recorded the lowest mean number of 28 days to ripening while the highest concentration of 1000mg/lit recorded the highest mean number of 42 days. Increasing the concentration of GA_3 from 375mg/lit to 1000 mg/lit decreased mean weight loss from 12.37 % to 11.23 % respectively, however, the untreated fruits had the lowest

mean weight loss of 9.30 %. Furthermore, pulp firmness increased as fruits were treated with GA_3. The highest concentration of 1000mg/lit recorded the highest mean firmness of 5.78N as the control recorded the lowest mean of 4.72N. Total titratable acidity for fruits treated with GA_3 was lower than those that were not treated. The highest mean total titratable acidity (3.94mEq) was obtained from applying 0mg/lit GA_3 with 1000mg/lit recording the lowest of 2.46mEq. GA_3 concentration of 375mg/lit also recorded total titratable acidity (2.56 mEq) similar to the lowest that was recorded. Polyethylene lining recorded significant differences ($P<0.01$) on all parameters except pH. Lined fruits stored longer than unlined ones. Fruits in unperforated lining stored longest (45 days) with fruits in unlined boxes having the lowest mean number of 22 days. Fruits in unlined packaging materials lost more weight than those in lined boxes. The highest weight loss (20.10 %) was obtained from the unlined fruits while the unperforated lining produced the lowest mean weight loss of 4.3 %. The unlined fruits became pulpier than the lined ones. The control unlined fruits recorded the highest mean pulp to peel ratio of 1.78 while the perforated lining recorded the lowest mean pulp to peel ratio of 1.13. Unlined fruits accumulated more sugar than the lined ones. The control recorded the highest mean of 3.72 (ºBrix) with the lowest 1.08 (ºBrix)) coming from fruits in perforated lining. Acidity in fruits that were lined was lower than the unlined fruits. The highest total titratable acidity (3.51 mEq) was observed from the control while the perforated lining recorded the lowest mean of 2.67 mEq. Combinations of all factors also produced significant differences ($P<0.01$) except for pH. GA_3 was effective in delaying ripening of both types of plantain outside or within lined packaging

materials at ambient temperature with higher concentrations recording longer delay in ripening. Furthermore, lined packages delayed ripening longer than unlined ones with the unperforated ones having highest influence. The combination of lining and the application of GA_3 further delayed ripening of both types of plantain. Polyethylene lining and GA_3 could increase shelf life of plantain fruits.

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1.0 INTRODUCTION

Plantain (*Musa Spp.*) is one of the important crops in the tropics. It is estimated that close to seventy million people in West and Central Africa derive about 25% of their carbohydrates from plantain. Plantain is thus an important source of food energy in the African lowland humid forest zone (Swennen, 1990). About 82% of the crop in Africa is produced in Guinea, Liberia and the Democratic Republic of Congo. It is estimated that West and Central Africa produce 61 and 21%, respectively (F.A.O., 1986).

Preserving plantain fruits in the green state is difficult. A lot of plantain fruits spoil in the hot weather within which it is produced and distributed (Chia and Huggins, 2003).

In the attempt to find solution to the problems of preservation, researchers have used chemical substances like the gibberellins to delay ripening of plantain. René *et al.* (2011), in the study of the effect of gibberellins, soaked plantain fruits in gibberellins for 5 minutes and noticed an effect on ripening of plantain. Other researchers have used other means like polyethylene film lining to create modified atmosphere for the delay of ripening. Elamin and Abu-Goukh, (2009) were able to reduce the number of days from harvest to ripening of banana fruits using perforated and unperforated polyethylene lining.

Crop variety is one of the factors that affect ripening. Therefore in the study of the effect of gibberellins and polyethylene film lining on plantain, it is appropriate to look at the two main varieties of plantain used in Ghana. In Ghana the two most commonly cultivated and utilised varieties of plantain belong to the French (*Apem*) and False horn-type (*Apentu*) subgroups. The fruits of the two have different characteristics and therefore may respond differently to the application of the two treatments (Akter *et al.*, 2013).

Plantain production is characterized by a period of abundance and a period of shortage (Kuperminc, 1988; Sery, 1988). During the shortage period, there is an increase in the prices and in the period of abundance prices are very low leading to low incomes for farmers (René *et al.*, 2011).

Plantain fruits comparatively have higher rate of respiration than banana and are highly perishable. At ambient tropical temperatures, plantains have an average market life of 1-10 days, compared with several weeks for yam (Zewter *et al.*, 2012).

Methods to improve the storage life of a crop must make economic sense to the user. It is possible to improve the storage of plantain fruits by means of a temperature-controlled system but such a system is not affordable to traditional plantain growers and consumers. There is therefore the need for appropriate and affordable alternative technology for the storage of the crop (Watkins and Nock, 2012).

Most experiments to investigate the effect of gibberellins on banana in particular have been done under controlled temperature environment. In the absence of temperature controlled storage facilities to traditional growers of plantain it is most appropriate to look at how GA_3 and polyethylene film lining will affect different varieties of the crop at ambient conditions under which the crop is mostly stored (Watkins and Nock, 2012).

The use of gibberellins and polyethylene lining on plantain is economical and convenient to all stakeholders involved in the handling of plantain. The main objective of the study was, therefore, to determine to what extent the application of GA_3 and polythene film lining could delay the ripening of two local varieties of plantain. The specific objectives were to:

- study the effect of GA_3 on the physico-chemical properties of the two varieties of plantain during ripening; and
- evaluate the interaction between GA_3 concentration and polyethylene film lining on the two varieties of plantain.

2.0 LITERATURE REVIEW

2.1 CULTIVATION OF PLANTAIN

2.1.1 Requirements

Plantains require climates that are hot and humid. Rainfall should be at least 1000 mm (39.4 in) for the high humidity requirement to be created. Temperatures of about 27°C (98.6°F) are required for best performance. The soil must be deep and well drained with high organic matter content and good aeration. Soil pH must range between 5.5 and 7.0. Plantain suffers a lot from wind damage. They must therefore be planted in block or protected with wind break (C.A.B.I., 2008).

2.1.2 Planting materials

Plantain is basically planted by vegetative means. Suckers or corms that come from the base of the plantain plant are the main vegetative materials used. Technology (the split corm technique) has made it possible to grow more than one plant from a single sucker or corm through a nursery practice (Faturoti *et al.*, 2014).

Three different types of suckers can be obtained from the mother plant. They are the water suckers, maidenheads, and sword suckers. The three types have different characteristics. Water suckers have short pseudostem and broad leaves. They are not very strong and are therefore not the preferred choice for the cultivation of plantain. Maidenheads and sword suckers are, however, very good for propagation. The former has large pseudostem with the later having a narrow base, short pseudostem and narrow blade-like leaves. Plantain is mostly intercropped with other crops that have similar requirements. They provide shading for shade loving plants such as cocoa and papaya (Crane *et al*., 2005).

2.1.3 Planting of plantain

Depending on the cultivar or hybrid, the planting distance used is normally 3m x 3m or 2.5m x 2.5m. The crop is planted deep (30cmx30cmx30cm) into the soil with soil firmed around it (Y. A. D. I., 2015). In Ghana the recommended time for planting *Apem* is the major season that is from March to June and in the minor season from

August to November. This planning of planting is to enable the plants escape toppling during April winds that normally characterize Easter rains.

2.1.4 Weeding

Frequent weeding is necessary. It must be done until plants are tall enough to smoother out common weeds that compete with plants. Weeding normally start about 6 weeks after planting depending on the type of weed or the method that was used for land preparation (I.I.T.A., 2014).

2.1.5 Water and nutrient requirement

The plantain plant itself contains a lot of water. It therefore requires adequate moisture in the soil to grow. However, the soil must be well drained. Supplementary water through irrigation must be supplied during the dry period.

Frequent addition of nutrients is necessary for the fast growing crop (Sauls, 2003).

2.2 COMMON PESTS AND DISEASES

2.2.1 Rhizome rot

Rhizome rot is a disease of plantain that attacks the rhizome or corms leading to rotening. Two species of Erwinia are known to cause Rhizome rot. They are *Erwinia carotovora* and *Erwinia chrysanthemi.*

2.2.1.1 Symptoms

When plantain plants are attacked by rhizome rot, the disease is characterized by breaks from the rhizome. This can lead to failure of the rhizome to germinate with internal tissue becoming yellow/brown and watery (Anon., 2002).

2.2.1.2 Causal agent

The causal agent of the disease is a bacterium. The bacterium is soil born and can enter the rhizome through wounds. Disease incidence is high during humid and wet conditions.

2.2.1.3 Management

The disease can be avoided by selecting healthy plants for propagation. The disease can also be transmitted through tools used for propagation. Tools must therefore be disinfected after use. Drying of seed pieces before they are planted can also reduce the incidence of the disease (Ploetz *et al.,* 1994).

2.2.2 Moko disease

The disease is caused by *Ralstonia solanacearum*. The parts of the plant attacked by the disease are the leaves leading to reduction of photosynthesis.

2.2.2.1 Symptoms

Older leaves become chlorotic, wilted and collapse. Symptoms later spread to the entire canopy leading to the collapse of pseudostem (Alvarez *et al*., 2015).

2.2.2.2 Causal agent

The causal agent is a bacterium. The disease can be spread by insects or farm tools such as the machete.

2.2.2.3 Management

Monitoring for the presence of the disease and destroying infected plants. Removal of male buds can also control the disease. Furthermore disinfection of tools can reduce the spread of the disease. Finally, the use of resistant varieties can also control the disease (Ploetz *et al*, 1994).

2.2.3 Black sigatoka

Black sigatoka is a disease that affects the leaves of plantain thereby reducing photosynthetic activity. It is caused by *Mycosphaerella fijiensis.* It is the most important disease of plantain (Ploetz, 1999).

2.2.3.1 Symptoms

Notable symptoms are red/brown spots on both underside and top of leaves. The spots are characterised by dark or yellow border and grey centre. The disease may lead to death of leaves and reduction of sizes of bunches (Jones, 1990).

2.2.3.2 Causal agent

The causal agent is a fungus. The fungi thrive well in high humidity or moisture conditions.

2.2.3.3 Management

Fungicides exist for the control of the disease. Increase in spacing to improve air circulation and humidity and removal of affected leaves can reduce disease incidence (Ploetz *et al.*, 1994).

2.2.4 Anthracnose

Anthracnose is a disease that affects the fruits of plantain. It is caused by *Colletotrichum musae.* Infection of fruits reduces the quality of fruits. The disease is spread by rainfall.

2.2.4.1 Symptoms

It is characterized by numerous small circular and brown to dark brown spots (Gowen, 1995)

2.2.4.2 Causal agent

The causal agent is a fungus that thrives very well in wet conditions.

2.2.4.3 Management

The disease can be controlled by using a recommended fungicide. Commercially produced fruits must be washed and dipped in fungicide prior to shipment. Also, protecting fruits from mechanical damage and removal of flower parts which harbour the fungus can control the disease (Ploetz *et al.*, 1994).

2.2.5 Panama disease (Fusarium wilt)

Panama disease also known as Fusarium wilt is a disease that affects the leaves of the plantain plant. It is caused by *Fusarium oxysporum.* It is a deadly disease that spread in the soil or through running water (Ploetz, 2000).

2.2.5.1 Symptoms

Symptoms include yellowing of older leaves, splitting of leaf sheath, wilting of leaves and buckling leading to death of entire plant.

2.2.5.2 Causal agent

The causal agent is a fungus.

2.2.5.3 Management

No effective treatment method exists. The disease can, however, be controlled by using resistant variety or using disease free planting materials (Ploetz *et al.*, 1994).

2.2.6 Bunchy top

The disease attacks the leaves of the affected plant. It is caused by the Banana Bunchy Top Virus (BBTV).

2.2.6.1 Symptoms

Dark green streaks appear on leaves. The leaves become chlorotic and leaf margins become upturned. The leaves become brittle, erect and plant develops a „bunchy top‟. The disease can lead to reduced or no production of bunches. Symptoms normally appear after two more leaves are produced (Ferreira *et al*., 1997).

2.2.6.2 Causal agent

The disease is caused by a virus and transmission by aphids.

2.2.6.3 Management

Disease incidence can reduce by planting tolerant varieties. Destroying infected plants can prevent spread of the disease (Ploetz *et al*., 1994).

2.2.7 Banana aphid (*Pentalonia nigronervosa*)

The insect feed on leaf sheath and cause destruction to them. The aphid is the vector that transmits the Banana Bunchy Top Virus (BBTV). The insect is a soft bodied and red-brown to almost black in colour. Colonies they form are most of the time tended by ants and their populations can increase rapidly when the weather is warm (Modarres, 2012).

2.2.7.1 Symptoms

Leaves of affected plants become curled and shriveled. With severe infestation, galls appear on leaves. Colonies of aphids are usually present in the crown of the plant at the base of the pseudostem or between the outer leaf sheaths.

2.2.7.2 Management

Chemical control does not provide protection against transmission of banana bunchy top and direct feeding damage is not usually severe enough to warrant spraying. Insecticidal soaps can help control aphid populations. Plants infected with bunchy top should be removed and destroyed to prevent spread (Ploetz *et al.*, 1994).

2.2.8 Coconut scale (*Aspidiotus destructor*)

Coconut scales are insects that suck sap from the leaves of plantain and reduce productivity. Coconut scale also attacks other hosts such as sugar cane, coconut, palms, avocado, cassava, papaya and guava (Anon., 2004).

2.2.8.1 Symptoms

They are small, flat, whitish scales. They are normally found on the underside of the leaves. They can also attack the petioles, peduncles and fruit of the plantain plant. Attacked leaves become yellowish.

2.2.8.2 Management

Biological control is the best control measure. They can be effectively controlled with the lady beetle (Ploetz *et al.*, 1994).

2.2.9 Banana weevil (*Cosmopolites sordidus*)

Banana weevil is an important pest of plantain. The adult is free leaving but commonly found between leaf sheaths. It is nocturnal and very susceptible to desiccation.

2.2.9.1 Symptoms

Attack by the insect leads to reduced plant growth and fruit production. They create tunnels in the corm leading to wilting and toppling of plants, destruction of the roots and death of plants (Umeh *et al.*, 2010).

2.2.9.2 Management

The pest can be controlled by planting healthy suckers. Hot water treatment can be applied to parred suckers to kill eggs and grubs. Applications of neem powder have been found to be effective in reducing weevil numbers. Appropriate insecticidal application at planting can help reduce the numbers of the weevils (Ploetz *et al.*, 1994).

2.3 HARVESTING PLANTAIN

Harvesting of plantain takes about 3 months from the beginning of flowering or flower set. Plantain produces multiple flowers but not all flowers mature into edible fruits. A mature bunch of plantain fruits normally weigh between 30 to 100 lbs. Fruits are green in colour and change at physiological maturity to a yellow colour during ripening. However, plantain is harvested when the peel of the fruit is green in color so that the fruits can withstand the rigours of handling, transportation and distribution. Internally the composition of fruits changes during plantain ripening (Anon., 2003).

The fruit become fully developed in size with full green peel color, highest starch content at physiological maturity. During ripening the starch becomes changed into sugar. Delayed harvesting sometimes lead to splitting especially when irrigation water or rainfall supplies water to the crop. Premature ripening can occur when fruits are not handled well i.e. when mechanically damaged (Tchango *et al.*, 1999).

Plantain is usually harvested with a cutlass. Harvesting is normally done in traditional growing areas by making a cut halfway into the pseudostem about 2m above the ground. The weight of the matured fruit allows it to bend over. The fruit now comes to a lower level that can be cut with the cutlass. This mode of harvesting allows for little damage to the crop (Morton, 1987).

After harvesting, the bunch is then carried to a nearby collection site or packing area. From here, the bunches are taken to a Collection area, or consolidation site. At this stage sorting and grading takes place. This is done to eliminate diseases and over ripening. The fruits packed for transportation should as much as possible avoid direct sunshine, rain and wind to avoid deterioration (Anon., 2003).

2.4 FIELD DEHANDING

Dehanding of plantain is the separation of the hands of fruit from the bunch stem. After dehanding latex exude from the cut surface. The cut surface is the point of infection of crown rot pathogens (Thompson, 1981).

Field dehanding was first developed in the Windward Island in an attempt to reduce mechanical damage to fruits that takes place when whole bunches are transported. In this technique, the hands are separated while the fruit is attached to the mother plant or dehanding may be done when fruits are hanged from a frame beside the plant for convenience with the former being more effective in reducing mechanical damage than the latter (Morton, 1987).

Initially, the hands were packed into specially designed plastic boxes lined with leaves, and transported to the pack house, but later on the hands were put directly into fibre board boxes in the field and sent readily for export. This became possible because a solution had been found to the problem of staining of fruit from latex and the crown rot. The problem was solved by treating the hands after washing with chemicals at the packing station. It was reported by Burden (1969) and Thompson (1981) that turning the hands crown downwards on plantain leaves in order to prevent the latex from staining the fruit and placing an absorbent pad paper that was impregnated with potassium permanganate and fungicide on the cut crown surface solved the problem of staining and crown rot. This technique helped to coagulate the latex and controlled crown rot.

Additionally, there were problems with cockroach and ant infestation on the field. The menace was also dealt with by fumigation with a broad spectrum insecticide to control the insects that attacked the boxed plantain fruits. Permethrin was one of the broad spectrum insecticides that were used. According to Burden (1969) and

Thompson (1981), field dehanding is now a common practice in many growing areas and has resulted in an increase in the percentage of quality fruits marketed.

2.5 PACKING STATION OPERATION

Field dehanding of fruits does not need the construction of a packing station. This has the advantage of saving the cost of putting up the structure and the cost of operating such a facility. However the technique of field dehanding and direct export has found a limited use.

Many establishments that grow plantain continue to use packing stations despite the advantages of field dehanding and direct export. There have been several designs for packing stations. A packing station may vary from a simple thatched structure to a well-designed building. Although packing stations vary in design and structure, the basic operations required for the preparation and packing of plantain for export are the same despite the type of structure used. The basic operations that normally take place include dehanding, washing, selection and grading, fungicide application and packing (Burden, 1969 and Thompson, 1981).

2.5.1 Dehanding

Most plantain bunches arrive at packing station in the form of bunches. In places where the bunches are brought through cableways the bunches are brought to the dehanding sight still suspended on hooks. To avoid damage to fruits, the bunches must not be piled up if brought by other means. Bunches must be hanged close to a washing tank so that the fruits can be washed immediately after dehanding. Hanging must be done in such a way that the larger fruits are always on top in order to facilitate dehanding. The cutting must be done close to the bunch stem, leaving enough crown so that fingers cannot easily detach during subsequent operations (Tchango *et al.*, 1999).

The knife used for dehanding comes in different shapes from one country to the other. In some places a kind of chisel is used. Others may appear as curved sharp knife, the curvature mainly to facilitate the operation. Whatever be the shape or design of the knife used to dehand, it must be sharp to give a smooth cut. Dehanded hands must be placed immediately into a tank containing water (Burden, 1969 and Thompson, 1981).

2.5.2 Washing, selection and grading

Immediately after the removal of the hands from the bunch, the hands are placed in water and washed. The washing is to make sure that all dirt and latex that comes from the cut surface is removed. The water in the tank should flow in order to avoid accumulation of fungal spores and dirt which can possibly infect the crown (Wills, 1988). This is achieved in Jamaica by diverting the course of flow of water through the tank. It is also possible to keep the water flowing by means of a pump. If it is not possible to have flow of water, then chlorine and alum can be added to remove the dirt and to destroy microorganism. Normally, the water flow from the dehanding end of the tank, in order that the hands of plantain can be moved to the far end, where workers can select and grade before fungicide application.

In some places separate washing and de-latexing tanks are used, such that the dehanded fruits are washed for 4 minutes before de-latexing for 10 minutes. More often a single tank is normally used, such that the hands are left for 15-20 minutes to remove any latex that may stay on it. Latex will not have any physiological effect. Leaving it on the surface of the fruit can, however, cause unsightly staining that can affect the market value of the fruits (Burden, 1969 and Thompson, 1981).

2.5.3 Packaging

Packaging is the final handling of plantain in the packing station. Almost all bananas that have been exported outside their production region are packed in fibreboard boxes of average weight 14 to 18 kg depending on the preference of the market. Boxes are most of the time fully telescopic slotted in nature and often comes with a divider that improves the strength of the stacking. The boxes are either glued or stapled with varying dimensions. Nowadays boxes must conform to international standard i.e. there is modular dimensions for palletized handling. In addition, the boxes have to be strong enough to withstand the pressures of stacking.
Sometimes the stacking weight can be as much as 250 kg in some instances (Tchango *et al.*, 1999).

It is important to design the boxes in such a way that good ventilation can be achieved. Ventilation holes must be large enough and well located such that free air flow throughout the whole contents of closely stacked boxes can be achieved. Free air movement ensures that good and even temperature is maintained for the fruit during refrigeration in shipment. It must be noted that the sizes of ventilation holes can possibly affect the stacking strength of the fibreboard boxes and there a compromise needs be reached in order to optimize ventilation as well as stacking strength (Burden, 1969 and Thompson, 1981).

It is also possible to use polyethylene film liners for export in order to reduce moisture loss, delay ripening and provide some form of protection from damage during handling and transport. This procedure of lining varies with different exporters and the distance to transport the produce. The polyethylene materials may be used differently. Some exporters may fold the sheets of polyethylene materials around the fruit, others pack the fruits in a sealed polyethylene bags whereas few may use individual small bags each holding one hand of fruits. Vacuum packing is usually used when the transport destination is far. Vacuum packing modifies the atmosphere around the fruit and extends their green life (Tchango *et al.*, 1999).

Sometimes polyethylene film lining is used in place of refrigerated shipment. Scott *et al.* (1971) observed that plantain hands sealed in polythene bags at ambient temperatures could delay ripening. Plantain fruits should be packed in such a way that they will not move so that mechanical damage can be reduced or avoided. The pack must, thus, be full enough but movement of the content must be avoided (Burden, 1969 and Thompson, 1981).

2.6 TRANSPORT OF BOXED PLANTAIN

Boxed plantains are normally loaded into refrigerated containers. Upon arrival at the port, individual boxes are put directly into separate refrigerated holds. At times, the boxes are placed on pallets at the pack house and the pallets are transported and transferred into ships. When boxes are put on pallets, comparatively fewer boxes can be loaded into the ship holds.

Upon arrival in the consuming countries, boxed fruits are transported by road to ripening rooms in refrigerated containers. Sometimes Reefers are used to export plantain in certain countries (Anon., 2012**),** but it has been found out that break bulk shipment is comparatively cheaper and therefore preferred when available. If green plantains are the preferred choice, it is preferable to ship under refrigeration in order to avoid ripening before the fruits arrive at their destination (Burden, 1969 and Thompson, 1981).

Stacking of boxes of plantain in ship holds or containers needs to be done with great care to ensure adequate ventilation to all boxes. This is particularly important where pallets are used because if the boxes are solidly stacked on pallets, air circulation will go around the boxes leaving some of the fruits not adequately cooled (Anon., 2012**)**. A technique to make sure that air is adequately circulated through the boxes is that of using stapling strips of fibre board in between pallets or using inflatable bags around the pallets (Burden, 1969 and Thompson, 1981).

Plantain may be shipped under controlled temperature of 13-14 degrees celsius. For controlled atmosphere shipment there must be regular changes of fresh air during transportation so as to avoid damage due to increase in carbon dioxide concentration.

Pre-cooling is necessary before loading. In a practice in the Caribbean where neither the plantains nor ship hold were not pre-cooled before loading, it was noticed that the temperature in the ship hold rose quickly during loading. Temperatures were so high that workers were not even willing to enter the ship to perform their duty. Thus the ship should have the capacity to cool the fruits rapidly to maintain adequate temperature for the storage of the fruits (Baird *et al*., 1988). It is desirable, however, that when plantains are despatched in reefer containers along with integral or clip-on refrigeration units, boxes of fruit and the containers must be pre-cooled and loaded quickly. This is due to the fact that many containers in refrigerated units have been designed to only maintain low temperatures. They are not designed for the rapid removal of field heat (Burden, 1969 and Thompson, 1981)**.**

2.7 BOTANY OF PLANTAIN

Plantain is a plant that measures about 3–10 metres tall. It has broad leaves which are 1.5 to 3 m long and about 0.5 m wide that are spirally arranged. The fruit are green and normally larger than banana. The classification of plantain is complex and has sometimes been considered as a subspecies of banana and at times the reverse is the case (Manzo-Sánchez *et al.*, 2015).

Plantain belongs to the genus Musa, a word created by Linnaeus similar to several arabic words for fruit. Plantain is at times referred to in the Koran as the “Tree of Paradise," therefore one form of it was named as *Musa paradisiaca*. Another form was named *Musa sapientum* because the sages of India depended so much on it

(Mbida *et al.*, 2000)

There are more than 50 genus that may be used as ornamentals, food or fibre in the tropics. In the tropics, the genus now cultivated is bananas and plantains. There are several species of the Musas among which are *Musa acuminata*, *Musa balbisiana*, and *Musa textilis* (Anon., 2016).

The plantain plant is monoecious. The male flowers occur at the tip. Behind the male flowers are several sterile and female flowers. Pollination takes place in wild species, but the formation of fruits in cultivated forms is parthenocarpic. In the parthenocarpic development of fruits, there is abortion of ovules and the fruit is formed by the enlargement of ovarian tissues.

Cultivated banana and plantain belong to *Musa x paradisiaca*. More than 300 forms and cultivars of *M x paradisiaca* exist. Polyploidy, through hybridization, naturally occur in the cultivated forms. The forms and cultivars that exist now are obtained from hybridization between a diploid *M acuminata* (AA) and a tetraploid M balbisiana (BB) resulting mostly in triploid forms such as AAB and ABB (Manzo-Sánchez *et al.*, 2015).

2.8 THE ORIGIN OF PLANTAIN

The plant is believed to have originated from Southeast Asia. Generally there are three groups of plantain, the French horn, the Horn plantain and the False horn plantain. The French and the Horn plantains are believed to have a common origin.

Both types and forms grow in India, Africa, and Tropical America. The French forms also occur in Indonesia and the Pacific Islands (Mbida *et al.*, 2000).

Available evidence shows that the plantain triploids (AAB) were the earliest to be cultivated in the area between Nigeria and Gabon and therefore this area happens to be a centre of diversity for plantains (Adheka, 2014).

2.9 CULTIVATION AND DISTRIBUTION

Plantain can grow as far as Florida, the Canary Islands, Egypt and Southern Japan. In the southern hemisphere, the limit is Natal and South Brazil. The crop is, however, mostly cultivated in tropical Africa (Crane *et al.*, 2008).

2.10 UTILIZATION AND PRESERVATION

Plantain is mostly utilised in the green state. Because the pulp contains more starch than banana it is cooked fried or roasted before eating. In some areas, especially, West Africa, the boiled plantain is pounded and served with soup or served with stew after cooking. Also in West Africa, plantains may be boiled in their skins and then peeled and eaten (Johnston, 1958; Tezenas du Montcel, 1979).

In times of glut, plantain fruits are seldom dried and processed into flour. The flour may be used to prepare different forms of dishes.

In some parts of East Africa, the Chagga people use plantain to prepare beer. In some places the partly ripe fruit are chopped and put into soup to give flavour and sweetness (Encyclopaedia Britannica, 2016).

Frying of plantains in palm or groundnut oil is popular in Africa (Boscom, 1951; Johnston, 1958). In Ghana, pancake (*Tatale*) can be prepared from a mixture of pounded ripe plantain and maize flour (Dei-Tutu, 1975). Another meal called *Krakro* can also be prepared from pounded ripe plantain and maize flour by frying (Eshun, 1977).

In East and West Africa peeled or unpeeled fruits are put into fire or in an oven for roasting (Boscom, 1951; Goode, 1974; Tezenas du Montcel, 1979; Whitby, 1972). Whereas unripe fruits are dried into chips, ripe fruits are dried and used to make meats known as figs (Goode, 1974; Hayes, 1941; Mukasa and Thomas, 1970; Simmonds, 1966).

In Uganda, dried plantain chips are called *Mutere* and are used as a buffer against famine (Goode, 1974; Mukasa and Thomas, 1970) In Polynesia ripe fruits are dried and then wrapped in leaves and stored (Massal and Barrau, 1956).

The leaves can be used to form mats and bags for packing. Finer leaves can be used as cigarette papers.

The use of plantain for its medicinal property is limited. Banana root, however, is anthelmintic and has been reported to be useful in reducing bronchocele. The juice from plantain is at times used for snake-bite, reported by the Lancet in the East (Grieve, 1995).

2.11 IMPORTANCE OF PLANTAIN

Bananas are very rich in carbohydrates, vitamin C, A, B and minerals such as potassium, copper, magnesium, calcium, and iron (Sadik, 1988).

2.12 STORAGE AND RIPENING OF PLANTAIN

2.12.1 Storage

Plantain fruits require cool temperatures of about 57 degrees F to store. They are therefore shipped to temperate areas in refrigerated containers. Also only durable plantains are shipped.

In 1899 when the United Fruit Company developed a system to bring shipments of fresh bananas/ plantain to U.S. markets, banana/plantain became a focal point for development of Central America thereby controlling the destinies of those countries hence the so-called banana republic (U. F. C., 1922).

2.12.2 Ripening

Ripening of plantain leads to changes in phisico-chemical properties. Some of the changes that occur during ripening include peel and pulp colour, conversion of starch to sugar, pulp to peel ratio, pulp firmness, total soluble solids content, pulp pH, total titratable acidity, peel and pulp moisture, dry matter content, respiration rate, ethylene production, phenolic content, pigments, flavour and aroma (Imsabai *et al.*, 2006).

2.12.3 Peel and pulp colour changes

Some of the changes that occur during ripening are the loss of peel green colour and increase in yellowing of the peel. Green colour loss is due to the degradation of chlorophyll. As external changes occur so does pulp colour change during ripening (Aboua, 1991).

2.12.4 Conversion of starch to sugar

During ripening, hydrolysis of starch takes place leading to accumulation of sugar i.e. sucrose, glucose and fructose (Loesecke, 1950; Palmer, 1971). In dessert Cavendish banana the process of breakdown of starch is completed at full ripeness but in plantain the starch breakdown process is slow and continues in over-ripe and senescent fruits (Marriott *et al*., 1981).

2.12.5 Changes in pulp to peel ratio

Pulp to peel ratio is another index for ripening in plantain. The ratio increases as ripening progresses. Changes in pulp to peel ratios leads to changes in moisture content of the peel and pulp. The increase in the sugar in the pulp leads to a change in osmotic pressure. The peel then loses water both by transpiration to the atmosphere and also to the pulp by osmosis (Stover and Simmonds, 1987) leading to an increase in the fresh weight of the pulp as the fruit ripens. This results is an increase in the pulp to peel ratio during ripening.

2.12.6 Changes in pulp firmness

Under normal storage, plantain undergoes textural transformations as ripening progresses. The fruit turns into yellow and the pulp becomes tender and soft. Loss of firmness during ripening varies with cultivar/hybrid. Smith *et al*. (1989) noted that as ripening progresses, pulp firmness declines. Generally, the triploid cultivars such as AAB and ABB are firmer than the tetraploid hybrids such as BBBB (Dadzie, 1994).

2.12.7 Changes in total soluble solids content

During ripening of plantain fruits, there is increase in total soluble solids. However, the extent of increase depends on cultivar or hybrids or stage of ripeness. In some hybrids, soluble solids content increases to a peak and then declines. The decrease in total solids may be due to the conversion of sugar to alcohol. The amount of sugar accumulated is another index for determining ripeness (Blankenship *et al.*, 1993).

2.12.8 Changes in pulp pH and total titratable acidity

Pulp pH and total titratable acidity can also be used to evaluate the ripeness of plantain fruits. In most plantain cultivars/hybrids there is a decline in pulp pH as ripening takes place. However the magnitude of decline is type/cultivar dependent.

The decline in pH is due to the decline in organic acids as they are respired or converted to sugar (Wills *et al*., 1989). Organic acids are responsible for the desired sugar-to-acid balance or taste during ripening. Titratable acidity in most plantain cultivars/hybrids shows increases as ripening progresses and therefore can be used as an index of ripening.

2.12.9 Changes in peel and pulp moisture and dry matter content

Moisture and dry matter content in the pulp or peel can also be used to evaluate ripening of plantain. During ripening the peel loses water to the atmosphere and to the pulp. The moisture content of the peel thus decreases while that of the pulp increases. In most cultivars/hybrids, the dry matter content of the peel and pulp during ripening may not change significantly (Hailu *et al*., 2014).

2.12.10 Changes in respiratory rate and ethylene production

Plantain is climacteric. Therefore there is a rise in ethylene production. This increase in ethylene production is associated with an increase in respiration. The rate of respiration and ethylene production usually depends on storage temperature, age of fruit and cultivar/hybrid (Kader, 1987).

2.13 CULTIVARS/ VARIETIES OF PLANTAIN

2.13.1 Cultivars

Almost all edible bananas and plantains come from two diploid species; *Musa acuminate Colla* (AA) and *Musa balbisiana Colla* (BB) of the genus Musa and most are triploids believed to have been formed through hybridization.

Simmonds (1966) developed a classification based on the genetic makeup of hybrids. Plantain or banana may thus belong to one of the groups AAA, AAB and ABB. The AAA are the sweet cultivars of banana with low starch and high sugar content when ripe such as the Cavendish sub-group which dominates the international trade. The

AAB group consists of the plantain sub-group which is starchy and the ABB group consists of the starchy cooking bananas known as
“bluggoes” in the Caribbean (Morton, 1987)

2.13.2 Varieties of plantain

There are two primary groups of plantains, French and Horn. There are subgroups of each depending on the particular variety that is mostly dependent on size or growing style.

Based on their bunch type true plantains are divided into four groups: French (eg *Apem*), French horn, False Horn (e.g. *Apantu*) and Horn plantains (Swennen *et al*., 1995).

2.14 USE OF PRESERVATIVES

The use of preservatives is not popular in plantain. Only a small proportion of the world's plantains are preserved for storage- most of the fruits are cooked for immediate consumption (Simmonds, 1966).

Little or no post-harvest technology exists in most societies that depend on them. The shelf life of plantain is only a few days. The fruits may be cooked when green, half ripe or when fully ripe and so if not used while green, are still available for use at a later stage of ripeness (Coursey, 1981). Thus, within traditional societies, there is seldom a high degree of wastage, although there may be in modern urban markets.

2.15 MATURITY INDICES OF MUSA SPP

Plantain requires about three months from flowering to harvesting. Maturity standards for plantains are less precise than they are for bananas. Several characteristics can be used to determine plantain maturity. They include fruit diameter, bunch age, angularity, fruit length, and peel color (Johnson *et al*., 1998).

The stage of harvest depends on the intended market destination (Johnson *et al*, 1998). Fruits meant for the local market can be harvested at advanced stage compared to those meant for the external market. Ogazi (1996) noted that fruits destined for external market should be harvested the day before or the same day of shipment. Ogazi (1996) also noted that plantain maturity is related to the diameter of the fingers. The diameter of the fruit is measured at the midpoint with calipers.

Another method for estimating plantain maturity is to record the age of the bunch. The time from when the fruit bunch first becomes visible (shooting) is recorded.

Bunches can be tagged with different coloured ribbons at the time of shooting and subsequently harvested after the appropriate time for the particular cultivar, based on the season of the year and experience (Johnson *et al.*, 1998).

Another way to determine maturity is by using shape (fullness) or angularity of the fruit. Immature fruit is angular in cross-section and has distinct ridges (Ogazi, 1996). However, the degree of roundness differs between cultivars and location of the hand on the bunch. The fullness of the fruit is normally measured from the middle hand. Again, the right shape to harvest depends on market distance. Fruits intended for domestic market must be nearly round (Johnson *et al.*, 1998).

Besides size or shape, length of pulp from fingers in the middle hand can also be used. The length must be at least 15cm for the local market and 18cm for the external market (Johnson *et al*, 1998). Peel colour changes from green to yellow when fruits reach physiological maturity. Fruits must be harvested green to withstand the rigours of handling.

2.16 EFFECT OF GIBBERELLINS

GA_3 induces elongation of the pseudostem, floworal parts abscission, fruit size increase and delay of fruit senescence (Lahav and Gottreich 1984; Satyanarayama 1985; Kumar and Reddy 1998; Desai and Deshpande 1978; Rao and Chundawat 1984; Rao and Chundawat 1988; Rao and Chundawat 1991; Acharya and Kumar 1998; Patil and Hulmani 1998a, 1998b). Other similar postharvest effects of GA_3 are documented for the fruits of the subgroup AAB (George and Marriott 1983; George 1987) and for the silk subgroup (Mary and Sathiamoorthy, 2003).

Gibberellic acid is widely used to manipulate fruit development and ripening. The growth regulator has been demonstrated to retard the rate of fruit softening in a number of fruits. Weksler *et al.* (2012) used gibberellic acid to delay fruit softening in melting flesh peaches and nectarines.

George and Marriott (1983) noticed that dipping plantain fruits in $GA_{4/7}$ or GA_3 could delay ripening of fruits up to 50 %. It was also noticed that when fruits were vacuum infiltrated with $GA_{4/7}$ (10^{-5} M), an extension of 37% in the preclimacteric period was achieved under high humidity.

Studies on the effect of gibberellins on the germination of treated seeds have also been done. Gibberellins have been observed to affect germinability and germination capacity of treated seeds. Ono *et al.* (2000) observed that as the storage period increased, the germination capacity of lychee seeds were lost, and the seeds had a short germinability after a 30-day storage period.

2.17 MODIFIED ATMOSPHERE (MA) AND CONTROLLED ATMOSPHERE (CA) STORAGE OF PLANTAIN

Plantains respond very well to modified atmosphere storage. Modified atmosphere storage is used commercially during export of plantains. “Banavac” are polyethylene bags that have been used to store plantains that provide a modified atmosphere.

For Control Atmosphere storage, optimum gas levels for plantain is 2 to 5% O2 and 2 to 5% CO2 (Bishop, 1990; Kader, 1992; Kader, 1994; Kader, 1997, Wei and Thompson, 1993).

In addition to delay of ripening, control atmosphere and modified atmosphere storage reduce the incidence of crown rot and put the fruits in fresher condition. Kader (1992, 1994, 1997) observed that O2 levels below 1 to 1.5% can lead to peel discoloration, improper ripening and off flavors. Furthermore it was noted that if CO2 levels are above 6 to 8%, pulp softens with the peel remaining green and having poor texture and flavour (Wei and Thompson, 1993; Kader, 1994; Kader, 1997).

It has also been observed that removal of ethylene by using absorbers or GA_3 has additional benefit of further delaying ripening (Scott *et al*., 1970; Liu, 1976; Scott, 1977; Turner, 1997). Stover and Simmonds (1987) observed an under peel discoloration on green bananas when transported over long distances under CA conditions.

3.0 MATERIALS AND METHODS

3.1 SETTING UP THE EXPERIMENT

Three matured bunches of *Apem* and seven matured bunches of *Apentu* plantains of about 120 and 90 days old, respectively, were harvested early morning from a farmer at Juaso in the Ashanti Region. The main maturity characteristics used for the selection were the angularity of the cross-section of fruit fingers, finger length or diameter, firmness of the fruit and blackening of the apex of the fruits i.e. fruits are physiologically matured after the emergence of the bud, when the apex of the fruits has obviously blackened. The fruits were transported to Kumasi for ambient temperature storage in a store room measuring 5.2 meters by 5.4 meters. Fruits from similar sized bunches free from blemishes were then selected. The bunches were dehanded with a knife and separated into clusters of at least four fingers. After that clusters of similar fruit sizes were selected by rejecting those with smaller and larger fruits, especially, those from the ends of the bunch. The selected fruits were washed with running water from a tap to remove latex. Four concentrations of GA_3 95% TC (0mg/lit, 375mg/lit, 750mg/lit and 1000mg/ lit) obtained from Xiantan New Sunshine Trade Co. Ltd. were prepared in four plastic buckets. Then nine clusters of *Apem* fruits were dipped in each of the four concentrations of GA_3 for 3minutes. Similarly, nine clusters of the *Apentu* fruits were dipped in each of the 4 concentrations of GA_3. The fruits were removed and air dried.

Forty-eight transparent polythene bags of size 34 by 24 cm and thickness 0.05mm capable of being sealed with a zip had already been purchased from the Kumasi market. Twenty perforations were made in 24 of the polythene bags with a paper perforator. After the treated fruits had dried, 12 clusters of *Apem* and 12 clusters of *Apentu* were placed in the perforated polythene bags i.e. the four treatments were thus replicated 3 times. Then 12 clusters of *Apem* and 12 clusters of *Apentu* were put into the unperforated polythene bag, again with the four concentrations having 3 replications. After that the remaining 24 clusters were subjected to the same arrangements but the fruits were not put in polythene bags. Each cluster of fruit (whether in polythene bag or not) were put into a paper box of size 14 by 8 by 6 inches.

The boxes were labeled as follows

- AC1L1 ---- *Apem* with no GA_3 treatment and no polyethylene lining
- AC1L2 ---- *Apem* with no GA_3 treatment in perforated polyethylene lining

- AC1L3 ---- *Apem* with no GA_3 treatment in unperforated polythene lining
- AC2L1 ---- *Apem* treated with 375mg/lit GA_3 with no polythene lining
- AC2L2 ---- *Apem* treated with 375mg/lit GA_3 in perforated polythene lining
- AC2L3 ---- *Apem* treated with 375mg/lit GA_3 in unperforated polythene lining
- AC3L1 ---- *Apem* treated with 750mg/lit GA_3 treatment with no polythene lining
- AC3L2 ---- *Apem* treated with 750 mg/lit GA_3 in perforated polythene lining
- AC3L3 ---- *Apem* treated with 750mg/lit GA_3 in unperforated polythene lining
- AC4L1 ---- *Apem* treated with 1000mg/lit GA_3 with no polythene lining
- AC4L2 ---- *Apem* treated with 1000mg/lit GA_3 in perforated polythene lining
- AC4L3 ---- *Apem* treated with 1000mg/lit GA_3 in unperforated polythene lining
- BC1L1 ---- *Apentu* with no GA_3 treatment and no polythene lining
- BC1L2 ---- *Apentu* with no GA_3 treatment in perforated polythene lining
- BC1L3 ---- *Apentu* with no GA_3 treatment in perforated polythene lining
- BC2L1 ---- *Apentu* treated with 375mg/lit GA_3 with no polythene lining
- BC2L2 ---- *Apentu* treated with 375mg/lit GA_3 in perforated polythene lining
- BC2L3 ---- *Apentu* treated with 375mg/lit GA_3 in perforated polythene

lining

- BC3L1 ---- *Apentu* treated with 750mg/lit GA_3 treatment with no polythene lining
- BC3L2 ---- *Apentu* treated with 750 mg/lit GA_3 in perforated polythene lining
- BC3L3 ---- *Apentu* treated with 750mg/lit GA_3 in non-perforated polythene lining
- BC4L1 ---- *Apentu* treated with 1000mg/lit GA_3 with no polythene lining
- BC4L2 ---- *Apentu* treated with 1000mg/lit GA_3 in perforated polythene lining
- BC4L3 ---- *Apentu* treated with 1000mg/lit GA_3 in non-perforated polythene lining.
- Where A stands for *Apem*, B stands for *Apentu* and C stands for concentration of GA_3.

The experiment was then set up in a completely randomised design (CRD). Each treatment combination was replicated three times making a total of 72 experimental units.

3.2 DETERMINATION OF COLOUR CHANGES/ NUMBER OF DAYS TO RIPENING.

Using a banana colour guide (DOLE, 2004), the colour changes of each experimental unit was determined every two days on a scale of 1 to 7

3.3 DETERMINATION OF DAILY ROOM TEMPERATURE AND RELATIVE HUMIDITY VALUES.

Using a digital device (Data Logger, EL-USB-2) three daily temperatures (morning, afternoon and evening) were recorded and the average for each day was found. The same device also recorded daily humidity values.

3.4 LABORATORY STUDIES OF PHYSICO-CHEMICAL CHANGES OF PLANTAIN FRUITS

Samples from replicate S1 and S2 of each treatment were collected at the beginning and then every week and analyzed at the laboratory.

3.4.1 Total soluble solids

The plantain pulp was cut into pieces and thirty grams weighed using an electronic balance. The pulp was blended with 90ml distilled water using a blender. The mixture was then filtered with cheese cloth. A drop of the filtrate was placed on the prism of a refractometer (HANNA, HI 96801) to determine total soluble solids.

3.4.2 pH

The pulp was cut into pieces and thirty grams of the pulp weighed using an electronic balance. The pulp was blended with 90ml distilled water using a blender. The mixture was filtered with a cheese cloth. The filtrate was then poured into a test tube and a pH meter (ELICO, L1617) electrode washed in distilled water and placed in the filtrate. The pH value of the filtrate was read and recorded after the reading had stabilized.

3.4.3 Total titratable acidity

The pulp was cut into pieces and thirty grams of the pulp weighed using an electronic balance. The plantain pulp was blended with 90ml distilled water using a blender. The mixture was then filtered using a cheese cloth. Then 25ml of the filtrate was taken with a pipette into a conical flask and 25ml of distilled water was added. Using four drops of phenolphthalein as indicator, the filtrate was titrated against 0.1N sodium hydroxide (NaOH).

3.4.4 Weight loss

Weight losses were determined by weighing clusters from replicate S3 every two days using an electronic balance (Intell-Lab, PC-30000).

Weight losses were calculated as percentage of the initial weight.

$$\text{Weight loss (\%)} = \frac{W1 - W2}{W1} \times 100$$

Where W1 = initial weight, and W2 = final weight.

3.4.5 Pulp to peel ratio

Pulp to peel ratio of treated plantain samples was determined by weighing the pulp and peel separately using an electronic balance (Intell-Lab., PC-30000). The pulp to peel ratio was calculated as pulp weight/peel weight.

3.4.6 Pulp firmness.

The peels of each sample were removed. A penetrometer (FT001 (0-11), Italy) was used to measure the firmness of each sample.

3.5 EXPERIMENTAL DESIGN

A three factor factorial experiment, made of two levels of plantain type, four levels of GA_3 concentration and three levels of lining was established using a completely randomized design (CRD). There were twenty-four treatment combinations. Each treatment combination was replicated three times giving seventy-two experimental units.

Analysis of variance (ANOVA) was done using Tukey statistical software at probability level of 1%. Treatment means were separated using HSD at probability level of 1%.

4.0 RESULTS

4.1 EFFECT OF PLANTAIN TYPE ON QUALITY CHARACTERISTICS OF FRUITS.

Table 4.1 shows how different treatments impacted on some quality characteristics of plantain fruits under ambient temperature storage. As summarized in the table, the effects on the two plantain types were significantly different (P<0.01).

Apem stored longer (49days) than *Apentu* (23 day), lost more weight (14.20 %) and became firmer (5.66) than *Apentu* (4.70). *Apem* also recorded a higher pH (5.35) than *Apentu* (5.14). *Apentu* on the other hand recorded higher pulp to peel ratio (1.71) than *Apem* (1.00). *Apentu* also recorded higher total soluble solids (3.73) than *Apem* (0.84) and higher total titratable acidity (3.69) than *Apem* (2.40). The sugar to acid ratios for the two plantain types were, however, not significantly different (P>0.001).

Table 4.1: Effect of plantain type on quality characteristics of fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
Apem	49a	14.20a	1.00b	5.66a	0.84b	5.35a	2.40b	0.36a
Apentu	23b	8.13b	1.71a	4.70b	3.73a	5.14b	3.69a	1.01a
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

Means with the same letter are not significantly different (P < 0.01)

Mean separation by Highest Significant Difference

Figures 4.1 and 4.2 show *Apentu* fully ripened on day 15 with *Apem* still green on the same day. Both *Apem* and *Apentu* were treated with GA_3 concentration of 1000mg/lit and were put in boxes lined with perforated polyethylene materials.

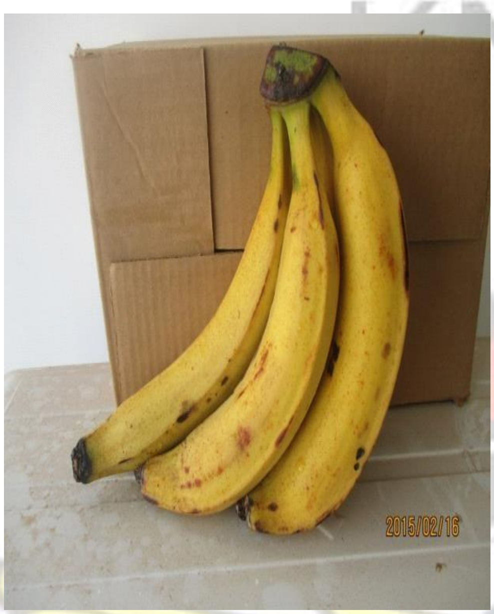

Figure 4.1: *Apentu* ripened on day 15 **Figure 4.2: *Apem* with same treatment green on day 17**

4.2 EFFECT OF GA_3 CONCENTRATION ON QUALITY CHARACTERISTICS OF PLANTAIN FRUITS

As shown in Table 4.2, the four concentrations recorded different effects (P<0.01) on all the quality characteristics under consideration.

Table 4.2: Effect of GA_3 concentration on quality characteristics of plantain fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (milliequi-valent)	TSS: TTA
0mg/lit GA_3	28d	9.30d	1.35c	4.72d	2.74b	5.09b	3.94a	0.59b
375mg/lit GA_3	36c	12.37a	1.52a	5.21b	3.09a	5.41a	2.56c	0.85a
750mg/lit GA_3	38b	11.67b	1.41b	5.03c	2.28c	5.26ab	3.22b	0.86a
1000mg/lit GA_3	42a	11.23c	1.16d	5.78a	1.03d	5.20ab	2.46c	0.44c
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

Means with the same letter(s) are not significantly different ($P < 0.01$)

Mean separation by Highest Significant Difference

Increasing the concentration of GA_3 successively increased mean number of days to ripening. The highest mean number of days (42 days) was recorded when the highest concentration of 1000mg/lit was applied. The lowest mean number of days (28 days) was recorded when no GA_3 (0mg/lit) was applied. Increasing the concentration of GA_3 from 375mg/lit to 1000mg/lit decreased mean weight loss from 12.37 % to 11.23 % respectively. However, the untreated fruits recorded the lowest mean weight loss of 9.30 %. Furthermore, the treated fruits were firmer than the untreated ones. The highest mean firmness of 5.78N was recorded when the highest concentration of 1000mg/lit was applied. The lowest mean firmness (4.72N) was recorded when no GA_3 (0mg/lit) was applied. It was also noticed that the mean total titratable acidity for the control was higher than the treated fruits.

The highest total titratable acidity (3.94mEq) was recorded for the untreated fruits (0mg/lit) while the lowest (2.46mEq) was obtained for fruits treated with the highest concentration of 1000mg/lit GA_3. However, no noticeable trends were observed for mean pulp: peel, total soluble solids, pH and Sugar: acid.

Figures 4.3, 4.4, and 4.5 show *Apem* with different GA_3 treatments but all lined with unperforated polyethylene materials. Fruits in Figure 4.3 that were treated with 0mg/lit GA_3 ripened on day 44 with fruits treated with 375mg/lit and 750mg/lit still green on the same day in figures 4.4 and 4.5.

Figure 4.3: ***Apem*** **without GA_3 ripened day 44**

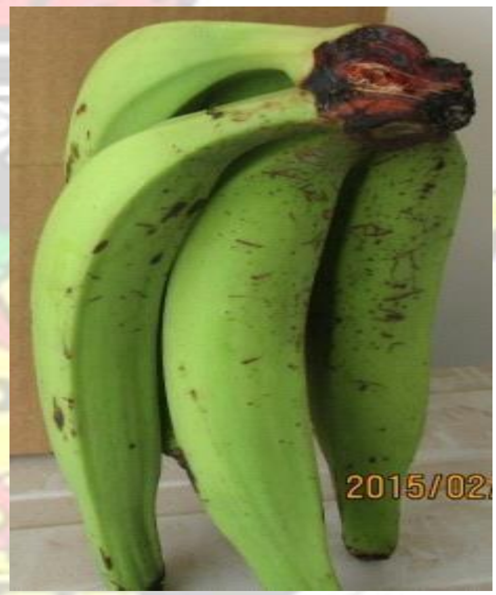

Figure 4.4: ***Apem*** **treated with 375mg/lit on GA_3, green on day 44**

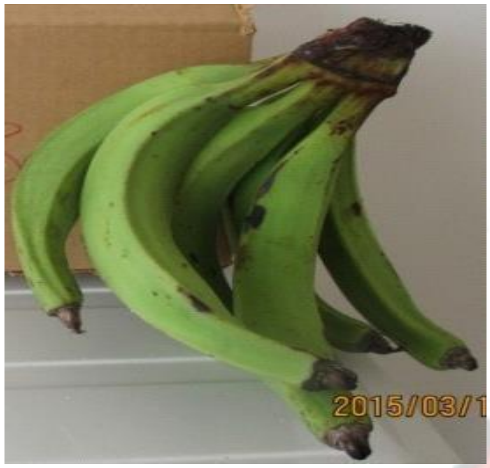

Figure 4.5: ***Apem*** **treated with 750 mg/lit GA_3 green on day 44**

4.3 EFFECT OF PACKAGING TYPE ON QUALITY CHARACTERISTICS OF PLANTAIN FRUITS.

Table 4.3 shows the effect of packaging type on some quality characteristics of the plantain fruits under storage.

Packaging type had significant effect ($P<0$) on all the physicochemical properties that were studied except pH. Plantain fruits in lined packages stored longer than those in unlined packages with those in unperforated lined packages lasting longest and becoming firmest. Plantain in unperforated lining recorded the highest (45days) mean number of days to ripening. The lowest (22 days) was observed for the unlined fruits. It was also observed that fruits in the unlined packages had higher weight loss, pulp to peel ratio and total soluble solids than fruits stored within lined boxes.

Table 4.3: Effect of packaging type on quality characteristics of plantain fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
L1	22c	20.10a	1.78a	4.84c	3.72a	5.20a	3.51a	0.63b
L2	41b	9.03b	1.13c	8.67a	1.08c	5.29a	2.67c	0.47c
L3	45a	4.30c	1.17b	5.04b	2.05b	5.24a	2.96b	0.96a
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

L1=unlined card box, L2=card box with perforated lining, L3= card box with unperforated lining

Means with the same letter are not significantly different ($P < 0.01$)

Mean separation by Highest Significant Difference

The highest mean weight loss (20.10%) was observed when the fruits were not lined. The lowest of 4.3 % was recorded for fruits stored in unperforated lining. The highest pulp to peel ratio (1.78) was observed for unlined fruits while the lowest (1.13) was obtained for fruits stored in boxes with perforated lining. With respect to total soluble solids, the highest mean value (3.72ºBrix) was recorded when the fruits were unlined whereas the lowest of 1.08ºBrix was recorded for the fruits stored in perforated lining. Unlined fruits had the highest mean total titratable acidity of 3.5 mEq while unperforated lining recorded the lowest of 2.67mEq. For pH and sugar to acid ratios no noticeable effects or trends were observed.

In Figures 4.6, 4.7 and 4.8 below, the fruits in Figure 4.6 were unlined, fruits in figure 4.7 were lined with perforated polyethylene materials while fruits in figure 4.8 were lined with unperforated materials. It was observed that though all the fruits were treated with the same GA_3 concentration of 750mg/lit, the unlined fruits (figure 4.6) ripened on day 17 but lined fruits, perforated and unperforated (figures 4.7 & 4.8) remained green on the same day.

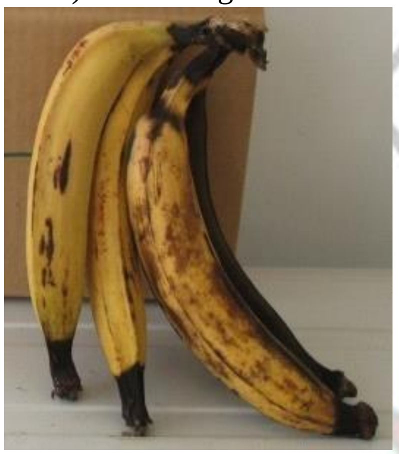

Figure 4.6: Unlined *Apem* ripened still green on day 17

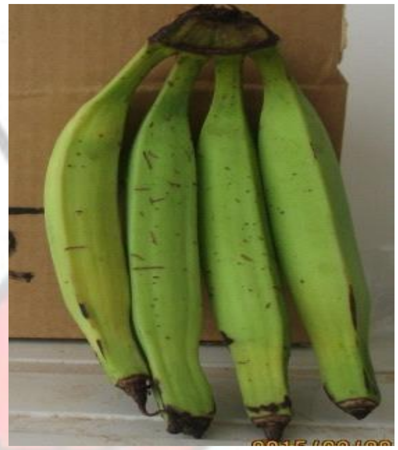

Figure 4.7: *Apem* with perforated lining on day 17

Figure 4.8: *Apem* with unperforated lining still green on day 17

4.4 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE AND CONCENTRATION OF GA_3 ON QUALITY CHARACTERISTICS OF FRUITS

Table 4.4 shows the effect of interaction between plantain type and GA_3 concentration on some quality characteristics of plantain fruits. Combinations between plantain type and concentration of GA_3 produced different effects ($P<0.01$) on the quality characteristics of fruits.

Table 4.4: Effect of interaction between plantain type and GA_3 concentration on quality characteristics of fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
AxC1	37d	10.60d	0.99f	5.85a	0.68h	5.12abc	3.17c	0.24h
AxC2	55a	18.40a	0.98f	5.23c	1.06e	5.47ab	2.06e	0.46e
AxC3	50c	12.80c	1.00f	5.87a	0.87f	5.50a	2.17	0.41f
AxC4	53b	14.80b	1.03e	5.70b	0.77g	5.29abc	2.20e	0.33g
BxC1	20g	8.00e	1.70c	3.58e	4.79b	5.07bc	4.71a	0.95c
BxC2	17h	6.33g	2.06a	5.18c	5.12a	5.36abc	3.05cd	1.2b
BxC3	25f	10.33d	1.82b	4.19d	3.69c	5.03c	4.26b	1.31a
BxC4	30e	7.67f	1.28d	5.86a	1.30d	5.11abc	2.73d	0.55d
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

A= *Apem*, B= *Apentu*, C1= 0mg/lit GA_3, C2=375mg/lit GA_3, C3=750mg/lit GA_3, C4=1000mg/lit GA_3

Means with the same letter(s) are not significantly different ($P < 0.01$)

Mean separation by Highest Significant Difference

Apem still stored longer than *Apentu* when combined with different concentrations of GA_3 and treated fruits stored longer than those that were not treated with GA_3 for both types of plantain. The highest mean number of days (55) was recorded when *Apem* fruits were treated with GA_3 concentration of 375mg/lit with *Apentu* treated with same concentration of 375mg/lit recording the lowest mean number of days (17) to ripening. *Apem* lost more weight and was still firmer than *Apentu*. The highest weight loss (18.40%) was recorded for *Apem* fruits treated with GA_3 concentration of 375mg/lit while *Apentu* with the same GA_3 application recorded the lowest mean weight loss of 6.33%. In terms of firmness too, the highest mean value (5.87N) was observed from *Apem* fruits treated with GA_3 concentration of

750mg/lit that was statistically similar to the non-application of GA_3 (0mg/lit) to *Apem* that also produced a mean firmness value of 5.85N while treatment of *Apentu* with GA_3 concentration of 0mg/lit produced the lowest of 3.58N. Application of GA_3 concentration of 1000mg/lit to *Apentu* also recorded 5.86N statistically similar to the highest recorded firmness. On the other hand, *Apentu* had higher pulp to peel ratio, total soluble solids, total titratable acidity and sugar to acid ratio. The highest pulp to peel ratio of 2.06 was recorded for *Apentu* treated with GA_3 concentration of 375mg/lit with *Apem* treated with GA_3 concentration of 375mg/lit recording the lowest of 0.98, statistically similar to 0.99 recorded by GA_3 treatment of 0.0mg/lit to *Apem*. The highest total soluble solids (5.12) was observed for *Apentu* fruits treated with 375mg/lit, whereas, the lowest value of 0.68 came from untreated *Apem* fruits. For total titratable acidity, the highest value of 4.71mEq was observed for untreated *Apentu* fruits with the lowest (2.06mEq) recorded for *Apem* fruits treated with GA_3 concentration of 375mg/lit. With respect to sugar to acid ratio, the higher of 1.31 came from *Apentu* treated with GA_3 concentration of 1000mg/lit while the lowest value of 0.24 came from untreated *Apem* fruits. The combinations did not have noticeable trend on pH.

4.5 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE AND PACKAGING TYPE ON QUALITY CHARACTERISTICS FRUITS

Table 4.5 shows the effect of different combinations of plantain type and packaging type on some characteristics of the plantain fruits under storage. Combining plantain type and packaging type resulted in significant differences ($P<0.01$) in all the parameters except pH.

Table 4.5: Effect of interaction between plantain type and packaging type on quality characteristics of fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
A × L1	30c	25.45a	1.22c	5.85a	0.85d	5.2258a	2.49d	0.39d

A ×L2	52b	12.40c	0.85e	5.57c	0.88d	5.4250a	2.32d	0.35e
A ×L3	64a	4.60e	0.933d	5.57c	0.80e	5.3850a	2.39d	0.35e
B × L1	14f	14.75b	2.34a	3.84e	6.59a	5.1775a	4.53a	0.87b
B×L2	29d	5.65d	1.41b	5.77b	1.29c	5.1475a	3.03c	0.59c
B×L3	25e	4.00f	1.40b	4.50d	3.30b	5.0850a	3.52b	1.57a
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

A= *Apem*, B = *Apentu*, L1= unlined card box, L2= card box with perforated lining, L3= card box with unperforated lining

Means with the same letter(s) are not significantly different ($P < 0.01$)

Mean separation by Highest Significant Difference

Apem stored longer, lost more weight and remained firmer than *Apentu*. The highest mean number of days (64) was recorded from *Apem* in boxes with unperforated lining. The lowest mean number of days (14) was recorded for *Apentu* in unlined boxes. In terms of firmness, the highest mean (5.85N) was observed for *Apem* in unlined boxes while the lowest of 3.84N was recorded for *Apentu* in unlined boxes. *Apentu* on the other hand recorded higher pulp to peel ratio, accumulated more soluble solids, and recorded higher total titratable acidity and sugar to acid ratio. The highest pulp to peel ratio (2.34) was observed for *Apentu* fruits in unlined boxes while *Apem* stored in boxes lined with perforated polyethylene recorded the lowest mean pulp to peel ratio of 0.85. The highest total soluble solids {6.59(°Brix)} was recorded for *Apentu* in unlined boxes with the lowest {0.80(°Brix)} recorded for *Apem* in unperforated lined boxes. In terms of total titratable acidity, the highest value (4.53mEq) was recorded for unlined *Apentu* with the lowest (2.32mEq) recorded for

Apem fruits stored in boxes with perforated lining. *Apentu* in boxes lined with unperforated polyethylene films recorded the highest sugar to acid ratio (1.57) while *Apem* in both types of lining recorded the lowest mean of 0.35.

Furthermore, fruits in lined packages stored longer, lost less weight and had lower pulp to peel ratio, higher firmness and lower total soluble solids for both types of plantain

4.6 EFFECT OF INTERACTION BETWEEN GA_3 CONCENTRATION AND PACKAGING TYPE ON QUALITY CHARACTERISTICS OF PLANTAIN FRUITS

Combining GA_3 Concentration and packaging type produced different effects on the number of days to ripening (P<0.01).

Table 4.6: Effect of interaction between GA_3 concentration and packaging type on quality characteristics of plantain fruits

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
C1 x L1	18j	16.50d	1.71c	4.82h	3.85c	4.95b	3.87c	0.85c
C1 x L2	32g	1.90h	1.16fg	4.92g	1.12g	5.20ab	2.53def	0.43g
C1 x L3	36f	4.50j	1.18ef	4.42i	3.24d	5.14ab	5.44a	0.51f
C2 x L1	21i	25.00a	1.24a	5.00f	5.54a	5.29ab	2.95d	0.63de
C2xL2	41e	7.700g	1.14g	5.42d	1.15g	5.54a	2.97d	0.36h

C2xL3	45c	4.400j	1.19ef	5.20e	2.59e	5.42ab	1.76g	1.57a
C3x L1	21i	18.70c	1.85b	3.92j	4.51b	5.26ab	4.73b	0.60e
C3 x L2	46b	11.50e	1.18ef	6.04b	0.95h	5.22ab	2.36ef	0.65d
C3 xL3	46b	4.80i	1.20e	5.13e	1.38f	5.29ab	2.57def	1.33b
C4x L1	29h	20.20b	1.31d	5.64c	0.98h	5.31ab	2.49def	0.44g
C4x L2	41d	10.00f	1.05i	6.30a	1.12g	5.19ab	2.84de	0.44g
C4x L3	53a	3.500k	1.11h	5.40d	1.00h	5.10ab	2.07fg	0.43g
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

C1=0.0mg/lit GA_3, C2=375mg/lit GA_3, C3=750mg/lit GA_3, C4=1000mg/lit GA_3, L1=unlined card box, L2=card box with perforated lining, L3=card box with unperforated lining.

Means with the same letter(s) are not significantly different ($P < 0.01$).

Mean separation by Highest Significant Difference.

Increasing the concentration of GA_3 successively increased mean number of days to ripening. The highest mean number of 53 days was recorded when GA_3 concentration of 1000mg/lit was combined with unperforated lining while the lowest number of 18 days was recorded from no lining in combination with no treatment with GA_3. The treated fruits became firmer than the untreated ones. The highest mean firmness of 6.30kg was recorded from GA_3 concentration of

1000mg/lit in combination with perforated lining whereas GA_3 concentration of 750mg/lit in combination with no lining offered the lowest value of 3.92kg. Mixed effects were observed for mean pulp to peel ratio, total soluble solids, pH, total titratable acidity and sugar to acid ratio.

It was also observed that plantain fruits in lined packages stored longer than those in unlined packages with those in unperforated packages lasting longest and becoming firmest. It was further observed that fruits in the unlined packages had higher weight loss, pulp to peel ratio, total soluble solids and total titratable acidity than fruits stored within lined boxes. For pH and sugar to acid ratios, no noticeable trends were observed

4.7 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE, GA_3 CONCENTRATION AND PACKAGING TYPE ON QUALITY CHARACTERISTICS OF FRUITS

Table 4.7 shows the effect of all factor combinations on some characteristics of the plantain fruits under storage. There was differences for all the parameters ($P<0.01$) except pH.

Table 4.7: Effect of interaction between plantain type, GA_3 concentration and packaging type on quality characteristics of fruits.

Source of variation	Days to ripening	Weight loss (%)	Pulp: peel	Firmness (N)	TSS (ºBrix)	pH	TTA (mEq)	TSS: TTA
AxC1xL1	23l	20.00d	1.19i	6.53b	0.84lm	4.71a	3.14cde	0.36jk
AxC1xL2	35g	10.80j	0.87lm	5.30k	0.57p	5.33a	2.53efghi	0.22m
AxC1xL3	52d	1.00p	0.91kl	5.73 f	0.63 op	5.32a	3.85bcd	0.13n
AxC2xL1	33h	34.00a	1.07j	5.53hi	0.77mn	5.33a	2.00ghij	0.36jk
AxC2xL2	60c	12.40h	0.82n	5.37jk	1.23 hi	5.52a	2.17fghij	0.45i
AxC2xL3	71a	8.80k	1.05j	4.80l	1.17ij	5.57a	2.02ghij	0.57g
AxC3xL1	31i	22.40c	1.22hi	5.67pg	1.04	5.52a	2.60efgh	0.46i
AxC3xL2	52d	11.40I	0.85mn	5.70 fg	0.83lm	5.52a	1.90hij	0.40j

AxC3xL3	67b	4.60m	0.92k	6.23 d	0.73mno	5.45a	2.00ghij	0.36jk
AxC4xL1	34h	25.40b	1.38f	5.67fg	0.73mno	5.34a	2.22fghij	0.36jk
AxC4xL2	59c	15.00f	0.86mn	5.90e	0.90 l	5.33a	2.67efgh	0.32k
AxC4xL3	67b	4.00n	0.85mn	5.53hi	0.67nop	5.20a	1.70ij	0.32k
BxC1xL1	13n	13.00g	2.22c	3.10 o	6.85 c	5.18a	4.59b	1.33c
BxC1xL2	28j	3.00o	1.45e	4.53m	1.67g	5.06a	2.53efghi	0.63f
AxC1xL3	19m	8.00L	1.44e	3.10 o	6.85c	4.96a	7.02a	0.88d
BxC2xL1	9p	16.00e	3.40a	4.47m	10.30a	5.52a	3.90bc	0.89d
BxC2xL2	22l	3.00 o	1.45e	5.47 ij	1.07jk	5.56a	3.77bcd	0.27l
BxC2xL3	19m	0.00q	1.32g	5.60gh	4.00e	5.26a	1.49j	2.57a
BxC3xL1	11 o	15.00f	2.48b	2.17p	7.97b	5.00a	6.85a	0.74e
BxC3xL2	40e	11.60 i	1.51d	6.37c	1.07jk	4.92a	2.81efg	0.89d
BxC3xL3	25k	5.00m	1.47ge	4.03n	2.03f	5.12a	3.13cde	2.29b
BxC4xL1	24k	15.00f	1.24h	5.67fg	1.23hi	5.28a	2.76efgh	0.53h
BxC4xL2	27j	5.00m	1.24hi	6.70a	1.33h	5.05a	2.67efgh	0.56gh
BxC4xL3	38f	3.00n	1.36fg	5.53hi	1.33hi	5.20a	1.70ij	0.55gh
CV (%)	1	1.14	0.93	0.69	1.34	4.55	8.02	1.68
Grand Mean	36	11.14	1.36	5.18	2.28	5.24	3.05	0.68

C1=0.0mg/lit GA_3, C2=375mg/lit GA_3, C3=750mg/lit GA_3, C4=1000mg/lit GA_3, L1=unlined card box, L2= card box with perforated lining, L3= card box with unperforated lining. Means with the same letter(s) are not significantly different ($P < 0.01$).Mean separation by Highest Significant Difference

Apem stored longer and lost more weight than *Apentu*. The highest mean number of 71 days was recorded when *Apem* was combined with GA_3 concentration of 375 mg/lit and unperforated lining. *Apentu* combined with the same GA_3 concentration of 375mg/lit recorded the lowest number of 9 days. The highest weight loss 34.00% also came from *Apem* in combination with GA_3 concentration of 375mg/lit while *Apentu* in combination with GA_3 concentration of 375mg/lit and unperforated lining recorded the lowest weight loss of 0 %. *Apentu* on the other hand had higher pulp to peel ratio, total soluble solids, and sugar to acid ratio. The highest pulp to peel ratio of 3.40 was recorded for *Apentu* in combination with GA_3 concentration of 375mg/lit and no lining while *Apem* in combination with 375mg/lit GA_3 and perforated lining, 750mg/lit GA_3 and perforated lining, 1000mg/lit GA_3 and perforated lining and 1000mg/lit GA_3 and unperforated lining recorded similar low values of 0.82, 0.85, 0.86 and 0.85, respectively. The highest mean total soluble solids of 10.30 (ºBrix) was recorded for *Apentu* in combination with GA_3 concentration of 375mg/lit and no lining while the lowest mean value of 0.57 was recorded for *Apem* in combination with no treatment with GA_3 and perforated lining. *Apem* in combination with 375mg/lit GA_3 and unperforated lining and 1000 mg/lit GA_3 with unperforated lining also recorded values of 0.63 and 0.67 respectively statistically similar to the lowest recorded value. The highest sugar to acid ratio of 2.57 was recorded for *Apentu* in combination with GA_3 concentration of 375mg/lit and unperforated lining while *Apem* in combination with 0mg/lit GA_3 and unperforated lining recorded the lowest value of 0.13. The pH for the two plantain types were not significantly different ($P>0.01$). Furthermore, fruits in lined packages stored longer than those in unlined packages, however, the untreated fruits recorded lower mean weight losses. It was also noticed that the mean total titratable acidity for the untreated fruits were higher than the treated ones.

5.0 DISCUSSION

5.1 EFFECT OF PLANTAIN TYPE ON QUALITY CHARACTERISTICS OF FRUITS.

The two types of plantain under different GA_3 concentrations and packaging had significant different responses with respect to all the eight quality characteristics that were studied in the experiment except sugar to acid ratio. From table 4.1, it took *Apem* for instance a mean of 48.76 days to ripen while *Apentu* took a mean of 23.03 days to ripen. *Apem* also lost a mean of 14.20 % weight while *Apentu* lost a mean of 8.13 % weight. These observations were in agreement with results obtained by other researchers. Tigist *et al.* (2013) observed that three processing and six fresh market tomato varieties harvested at "mature green" stage had different total soluble solids, titratable acidity, sugar-acid ratio, pH, ascorbic acid content, colour and firmness under storage. The differences in the characteristics between the two varieties could be due to differences in their natural physical and chemical properties. *Apem* naturally has smaller fruits with higher surface area to volume ratio compared to *Apentu*. The higher surface area to volume ratio may be the reason for *Apem* losing more weight in storage than *Apentu*. Furthermore, all the properties of *Apem* and *Apentu* were different at harvest and therefore it is not surprising that the differences continued even to the end of the experiment under different treatments of GA_3 and packaging.

5.2 EFFECT OF GA_3 CONCENTRATION ON QUALITY CHARACTERISTICS OF PLANTAIN FRUITS

It was noticed that GA_3 delayed the ripening of both types of plantain. René *et al.*. (2011) similarly soaked plantain fruits for 5 minutes in gibberellic acid solution of 100 μM and noticed that the growth regulator could be used to delay the ripening of plantain. Osman and Abu-Goukh (2008) also observed that gibberellic acid could significantly delay the ripening of banana. Furthermore Alfonso *et al.* (2011) working on banana under cold storage observed that GA_3 formulations could significantly cause delay in number of days to ripening.

It was further observed that higher GA_3 concentrations were able to cause more delay in ripening of plantain fruits. Although Alfonso *et al*. (2011) working on banana under cold storage observed neither linear nor quadratic relationship between gibberellic acid concentration and number of days from harvest to ripening, they observed that higher GA_3 formulations could significantly cause more delay in number of days to ripening. This was because, perhaps, with higher concentrations the fruits absorbed more of the growth regulator and therefore effectively suppressed the production of ethylene.

The results also showed that fruits treated with GA_3 were firmer than those that were not. This could be explained by the fact that as ripening was delayed by the growth regulator, the breakdown of starch to soluble sugars was also delayed. As a result, osmotic movement of water into the pulp that account for loss of firmness was also delayed. Increased sugar in the pulp leads to a change in osmotic pressure. The peel then loses water both by transpiration to the atmosphere and also to the pulp by osmosis (Stover and Simmonds, 1987) leading to softening of the pulp as the fruit ripens. Other processes responsible for firmness that were perhaps delayed were the breakdown of cell wall or reduction in the cohesion of the middle lamella (Palmer, 1971; Smith *et al*, 1989).

Total titratable acidity for fruits treated with GA_3 were observed to be lower than fruits that were not treated with the growth regulator. The decline in total titratable acidity is due to the breakdown of organic acids as they are respired or converted to sugar (Wills *et al.,* 1989). GA_3 perhaps influenced the breakdown of organic acids into other compounds.

5.3 EFFECT OF PACKAGING TYPE ON QUALITY CHARACTERISTICS OF PLANTAIN FRUITS.

The results showed that lined packages delayed ripening of fruits, reduced weight loss pulp to peel ratio as well as total soluble solids**.** The delay of ripening, the reduction in weight loss, pulp to peel ratio and total soluble solids might have been caused by the slowdown of physiological activity caused by the creation of modified atmosphere by the polyethylene materials. Similarly, Osman and AbuGoukh (2008) observed that polyethylene film liner, sealed or perforated, significantly delayed fruit ripening, maintained quality and extended shelf-life of bananas. Pulp to peel ratio reduction of treated fruits could be explained by the reduction in water movement from the peel into the pulp by osmosis as a result of slowdown in the breakdown of starch into sugars, thereby decreasing the weight of the pulp (Stover and Simmonds, 1987). The reduction in total soluble solids was due to the decline in the breakdown of starch into sugar as a result of the modified atmosphere. During ripening, hydrolysis of starch takes place leading to accumulation of sugar i.e. sucrose, glucose and fructose (Loesecke, 1950, Palmer, 1971).

It was also observed that fruits in lined boxes became firmer than those in unlined boxes. Smith *et al*. (1989) observed that as ripening progresses, pulp firmness declines but the lining slowed down the process that lead to the decline in firmness as a result of the modified atmosphere that was created by the lining of the packaging material.

It was also observed that unperforated lining caused more delay in ripening of the fruits than the perforated lining. This could be due to the fact that the unperforated lining created optimum levels of oxygen and carbon dioxide as well as relative humidity.

5.4 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE AND GA_3 CONCENTRATION ON QUALITY CHARACTERISTICS OF FRUITS

The results showed that the introduction of GA_3 did not change most quality characteristics of the two types of plantain except sugar to acid ratio. From table 4.1, the acid to sugar ratios for the two types of plantain were not significantly different. With the introduction of GA_3, as can be seen from table 4.4, significant differences in acid to sugar ratios were recorded between *Apem* and *Apentu*. Lower ratios of 0.24, 0.46, 0.41, and 0.33 were recorded for *Apem* while higher ratios of 0.95, 1.2, 1.31 and 0.55 were recorded for *Apentu*. The increase in the sugar to acid ratio of *Apem* might have been caused by GA_3. Sinnadurai and Amuti (1970) similarly observed an increase in total soluble solids in some cultivars of tomato fruits treated with gibberellic acid with varying effects on soluble solids of other cultivars with the same treatment.

The results also showed that *Apem* took more days (48.76) to ripen and had higher pulp firmness than *Apentu*. Perhaps *Apem* lost more weight as a result of losing more moisture because of its higher surface area to volume ratio. The higher loss of weight could also be explained by the fact that *Apem* stayed longer in storage than

Apentu.

The higher pulp to peel ratio and total soluble solids of the *Apentu* could be due to varietal difference. Again these observations confirmed observations made by Tigist *et al.* (2013) that three processing and six fresh market tomato varieties harvested at "mature green" stage had different total soluble solids, titratable acidity, sugar-acid ratio, pH, ascorbic acid content, colour and firmness under storage.

5.5 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE AND PACKAGING TYPE ON QUALITY CHARACTERISTICS OF FRUITS

The different packaging methods did not induce many changes in quality characteristics of the two varieties of plantain. Similarly Elamin and Abu-Goukh (2009) observed that polyethylene film liner, sealed or perforated, significantly delayed fruit ripening, maintained quality and extended shelf-life of bananas.

Higher sugar to acid ratios was observed for *Apentu* (0.87, 0.59, and 1.57) than *Apem* (0.39, 0.35 and 0.35) with the introduction of packaging. The reason for the higher sugar to acid ratio for *Apentu* could be that the introduction of the polyethylene lining that created a modified atmosphere was able to delay physiological activity more in *Apem* than *Apentu*.

5.6 EFFECT OF INTERACTION BETWEEN GA_3 CONCENTRATION AND

PACKAGING TYPE ON QUALITY CHARACTERISTICS PLANTAIN FRUITS

From the results, the interaction between packaging and GA_3 concentration did not induce changes except in sugar to acid ratio where a mixed result was obtained.

From the results it was observed that given the same GA_3 concentration (0mg/lit, 375mg/lit 750mg/lit or 1000mg/lit), ripening was delayed with the introduction of lined packages. For example, ripening was delayed from 21 days up to 44 days with no lining and unperforated lining respectively when fruits were treated with 375mg/lit GA_3. Pulp to peel ratio did not change as it decreased for example from 1.71 to 1.18 with no lining and unperforated lining respective treatments with GA_3 concentration of 0mg/lit. Furthermore, total soluble solids did not change except with GA_3 concentration of 1000mg/lit where the amount in the unlined package was observed to be smaller (0.98). The reason for that observation could be that growth regulators are effective at low concentrations and therefore could not slow down the ripening process effectively. pH did not change as different packaging methods were used i.e. no significant difference or statistically similar. Moreover, no changes were observed with respect to total titratable acidity and sugar to acid ratio when different combinations of GA_3 and packaging methods were used as no noticeable changes were observed.

Conversely, given the same type of lining the delay of ripening increased as the concentration of GA_3 was increased. For example, number of days to ripening increased from 31.67 days to 46.00days when the concentration of GA_3 was increased from 0mg/lit to 750mg/lit when the plantain fruits were put in boxes with perforated lining as shown in table 4.6. Similarly, Osman (2002) observed that polyethylene film liners sealed or perforated and gibberellic acid significantly delayed fruit ripening and maintained quality of bananas.

5.7 EFFECT OF INTERACTION BETWEEN PLANTAIN TYPE, GA_3 CONCENTRATION AND PACKAGING TYPE ON QUALITY CHARACTERISTICS OF FRUITS

Combining all the factors considered in the study did not induce observable changes in the trends of physicochemical properties of both types of plantain. The effect of plantain type, GA_3 concentration, and packaging types on their own were similar to the results from their interactions.

Combining polyethene lining and gibberellic acid resulted in a more delay in the ripening of plantain fruits. From table 4.7, combining GA_3 concentration of 750mg/lit with unperforated polyethylene lining on *Apem* recorded the longest mean number of days (71) to ripening. From tables 4.4 and 4.5 the longest mean number of days recorded by GA_3 concentration and polyethylene film lining alone were 55 days from 375mg/lit GA_3 and 64 days from unperforated polyethylene lining respectively. For *Apentu*, the longest mean number of days (38.days) to ripening was recorded by combining 750mg/lit GA_3 and unperforated polyethylene film lining. The longest mean number of days by GA_3 concentration and polyethylene lining were 30 days and 25 days, respectively. Osman and AbuGoukh (2008) similarly observed that combining GA_3 with polyethylene lining, sealed or perforated, further delayed ripening and maintained quality of banana

fruits.

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION 6.1 SUMMARY

The study was done to investigate the possibility of increasing the shelf life of two types of plantain, *Apem* and *Apentu* by delaying ripening under ambient temperature storage using GA_3 and polyethylene lined card boxes, perforated (20 perforations) and unperforated.

The study also sought to investigate the effects of the treatments on other postharvest characteristics of the fruits. Four concentrations of GA_3 (0mg/lit, 375mg/lit, 750mg/lit, 1000mg/lit) were used by dipping the plantain fruits for three minutes. Daily relative humidity and room temperatures were recorded. Average relative humidity was 59.92% and room temperature was 30.72 degrees Celsius.

6.2 CONCLUSION

It was observed that

- *Apem* stored longer than *Apentu*. *Apem* stored for a mean of 48.76 days while *Apentu* stored for 23 days.

- GA_3 delayed ripening of plantain fruits and was able to increase the shelf life of fruits from a mean of 28 days to 42 days. Increasing GA_3 concentration caused more delay to the ripening of the fruits.

- Lining delayed ripening and increased shelf life of plantain fruits with unperforated lining causing more delay of ripening. The unperforated lined packages delayed ripening from a mean of 22 days up to 45 days while perforated lining delayed ripening up to 41 days.

- Unperforated lining was more effective in delaying ripening in *Apem* while the perforated type appeared to be effective for *Apentu*. Whereas perforated lining delayed ripening in *Apem* up to 52 days, the unperforated lining delayed ripening in *Apem* up to 64 days and whereas perforated lining delayed ripening in *Apentu* up to 29 days, the unperforated lining delayed ripening in *Apentu* up to 25 days

- Combining both GA_3 and lined packaging methods caused longer delay in the ripening of plantain fruits. The combination delayed the ripening of *Apem* from 23 days (AxC1xL1) up to 71days (AxC2xL3) while *Apentu* was delayed from 13 days up to 40 days.

- Treatments with GA_3 and lining did not induce many changes to the postharvest characteristics of the two types of plantain. *Apem* maintained higher number of days to ripening, pulp firmness and weight loss while *Apentu* maintained higher pulp to peel ratio, total soluble solids and total titratable acidity.

- GA_3 treatment alone, lining packaging alone or their combinations could be used to delay significantly the ripening of *Apem* and *Apentu* at normal room temperature.

6.3 RECOMMENDATIONS

It is recommended that

- In future approaches matured fruits should be obtained by selecting plantain plants that flower at the same time rather than using other subjective maturity indices.

- Future research work could also study the effect of different rates of application of the growth regulator in order to obtain the optimum economic level for the delay of fruits.

- Furthermore, efforts should be made to study different perforations that could possibly improve the storage of the fruit.

- Research may further be extended to other types or varieties of plantain.

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APPENDICES Appendix 1.0 ANOVA Appendix 1.1: Analysis of Variance Table for wgtLRip

Source	DF	SS	MS	F	P
reps	2	0.01	0.01		
Var	1	651.61	651.61	40143.5	0.0000
Conc	3	93.18	31.06	1913.42	0.0000
Lining	2	3156.97	1578.48	97246.0	0.0000
Var x Conc	3	286.13	95.38	5875.99	0.0000
Var x Lining	2	310.87	155.44	9575.91	0.0000
Conc x Lining	6	226.19	37.70	2322.49	0.0000

Var x Conc x Lining	6	120.53	20.09	1237.58	0.0000
Error	46	0.75	0.02		
Total	71	4846.24			

Appendix 1.2: Analysis of Variance Table for PPR

Source	**DF**	**SS**	**MS**	**F**	**P**
reps	2	0.0001	0.00004		
Var	1	9.2235	9.22351	57922.4	0.0000
Conc	3	1.2523	0.41745	2621.50	0.0000
Lining	2	6.3012	3.15061	19785.4	0.0000
Var x Conc	3	1.6144	0.53815	3379.48	0.0000
Var x Lining	2	1.4987	0.74934	4705.74	0.0000
Conc x Lining	6	1.4667	0.24445	1535.09	0.0000
Var x Conc x Lining	6	3.1534	0.52557	3300.51	0.0000
Error	46	0.0073	0.00016		
Total	71	24.5177			

F P

Appendix 1.3: Analysis of Variance Table for PF

Source	DF	SS	MS		
reps	2	0.0016	0.0008		
Var	1	16.6753	16.6753	12964.5	0.0000
Conc	3	10.7626	3.5875	2789.19	0.0000
Lining	2	8.9331	4.4666	3472.60	0.0000
Var x Conc	3	19.4228	6.4743	5033.52	0.0000
Var x Lining	2	14.8276	7.4138	5763.96	0.0000
Conc x Lining	6	8.5641	1.4273	1109.71	0.0000
Var x Conc x Lining	6	8.0238	1.3373	1039.71	0.0000
Error	46	0.0592	0.0013		
Total	71	87.2702			

Appendix 1.4: Analysis of Variance Table for TSS

Source	DF	SS	MS	F	P
reps	2	7.778E-05	3.889E-05		
Var	1	149.559	149.559	159048	0.0000
Conc	3	43.5851	14.5284	15450.2	0.0000
Lining	2	85.0587	42.5294	45227.7	0.0000
Var x Conc	3	38.0104	12.6701	13474.0	0.0000
Var x Lining	2	86.8464	43.4232	46178.3	0.0000
Conc x Lining	6	44.6810	7.44683	7919.31	0.0000

				F	P
Var x Conc x Lining	6	46.7000	7.78333	8277.16	0.0000
Error	46	0.04326	9.403E-04		
Total	71	494.484			

Appendix 1.5: Analysis of Variance Table for pH

Source	DF	SS	MS		
reps	2	0.09537	0.04768		
Var	1	0.78333	0.78333	13.76	0.0006
Conc	3	0.96830	0.32277	5.67	0.0022
Lining	2	0.08714	0.04357	0.77	0.4709
Var x Conc	3	0.48830	0.16277	2.86	0.0470
Var x Lining	2	0.23272	0.11636	2.04	0.1411
Conc x Lining	6	0.45061	0.07510	1.32	0.2678
Var x Concx Lining	6	0.57416	0.09569	1.68	0.1471
Error	46	2.61810	0.05692		
Total	71	6.29803			

Appendix 1.6: Analysis of Variance Table for TTA

Source	DF	SS	MS	F	P
reps	2	0.201	0.1005		
Var	1	29.954	29.9538	502.01	0.0000

				F	P
Conc	3	25.435	8.4785	142.09	0.0000
Lining	2	8.660	4.3301	72.57	0.0000
Var x Conc	3	6.191	2.0636	34.59	0.0000
Var x Lining	2	5.499	2.7493	46.08	0.0000
Conc x Lining	6	44.930	7.4883	125.50	0.0000
Var x Conc x Lining	6	17.897	2.9828	49.99	0.0000
Error	46	2.745	0.0597		
Total	71	141.512			

Appendix 1.7: Analysis of Variance Table for SAR

Source	DF	SS	MS		
reps	2	0.0002	0.00011		
Var	1	7.6375	7.63753	58017.2	0.0000
Conc	3	2.2726	0.75753	5754.48	0.0000
Lining	2	3.0110	1.50548	11436.1	0.0000
Var x Conc	3	1.2398	0.41328	3139.41	0.0000
Var x Lining	2	3.1697	1.58483	12038.9	0.0000
Conc x Lining	6	4.4209	0.73681	5597.05	0.0000
Var x Conc x Lining	6	3.2027	0.53378	4054.76	0.0000
Error	46	0.0061	0.00013		

				F	P
Total	71	24.9604			

Appendix 1.8: Analysis of Variance Table for NDR

Source	DF	SS	MS	F	P
reps	2	0.2	0.1		
Var	1	11919.7	11919.7	93097.7	0.0000
Conc	3	1691.7	563.9	4404.20	0.0000
Lining	2	6874.1	3437.1	26844.8	0.0000
Var x Conc	3	1040.5	346.8	2708.98	0.0000
Var x Lining	2	1685.9	843.0	6583.87	0.0000
Conc x Lining	6	334.1	55.7	434.91	0.0000
Var x Conc x Lining	6	678.3	113.0	882.91	0.0000
Error	46	5.9	0.1		
Total	71	24230.4			