KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF HORTICULTURE

EFFECT OF DIFFERENT CONCENTRATIONS OF GA_3 AND POLYETHYLENE FILM LININGS ON THE PHYSICOCHEMICAL PROPERTIES AND SHELF- LIFE OF BANANA (CAVENDISH) STORED UNDER DIFFERENT ENVIRONMENTS

BY

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SEPTEMBER, 2016

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A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF

MASTER OF PHILOSOPHY (POSTHARVEST TECNOLOGY)

SEPTEMBER, 2016

DECLARATION

I hereby declare that, except for specific references which have been duly

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acknowledged, this work is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

DEDICATION

This dissertation is dedicated to my mum and my entire family for their love, prayers and support.

ACKNOWLEGEMENT

I am very thankful to God Almighty for His mercies, grace and protection for me throughout this storm.

My sincere gratitude goes to my family for standing by me, supporting, encouraging and believing in me throughout these years.

My most sincere thanks go to my able supervisors, Mr Patrick Kumah, whose insightful criticisms, advice, guidance, corrections and suggestions have contributed immensely to my success.

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Finally, I wish to acknowledge all friends for their support in every aspect of my life which contributed in making this work a success.

ABSTRACT

Fresh bananas have a short shelf-life owing to rough handling, unprotected storage conditions and poor packaging methods leading to postproduction losses of 30-40 %. This study therefore, was to determine the effect of different concentrations of GA_3 and polyethylene film linings on the physicochemical properties and shelf life of Cavendish banana stored under different environments. A 4 x 4 x 2 factorial was employed, arranged in a completely randomized design. Dwarf Cavendish was obtained from a private farm orchard at Ninting, Ashanti Mampong, for the experiment. Three months old matured green banana (starting from flowering) were dipped in 150, 250 and 350 ppm of GA_3 for

2 minutes and control (0 ppm) were immersed in distilled water the same way. Data were collected according to banana ripening stages as contained in banana ripening chart except fruit weight that was recorded daily. Weight loss, firmness, TSS, TTA and pH were defined at different ripening stages throughout the storage period. The study revealed significant difference in weight loss (30 %) at 350 ppm in perforated low density lining under cold storage as best results. It also showed firmness of 4.57 kg cm^{-2} at 350 ppm and 4.53 kg cm^{-2} in perforated film lining, significantly different from the rest. TSS showed best results of 8.51 % at 350 ppm and 8.55 % in cold storage while TTA reduced to 1.31 % at 350 ppm which also revealed significant difference. Similarly, pulp pH dropped to 5.30 % at 0 ppm whereas shelf life was 13.75 % at 350 ppm, 11.06 % in perforated film lining and 14.13 % translating to 21 days being the best results under cold storage condition. Therefore, postharvest application of gibberellic acid at a concentration of 350 ppm and the use of perforated low density polyethylene lining in cold storage was an efficient method and can be employed by farmers and traders to reduce losses, maintain quality attributes of banana and prolong shelf life.

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CHAPTER ONE

1.0 INTRODUCTION

Banana with origins in Asia is currently one of the most common cultivated staple crops worldwide. It is both a tropical and a temperate crop and a major source of energy for all consumers (Vargas and Lopez, 2011). Ghana is seen as a commercial producer of tropical fruits, with a lot of the fruits cultivated in Ashanti Region. It is also reported that the United Kingdom alone imports over 2,000 tons of fruits from Ghana yearly. Banana is also used to produce various food types, principally energy rich food in numerous foods processing throughout the world. Banana is usually harvested at a very high moisture content to maintain its freshness (Mayer *et al.*, 2012).

According to Nartey (2011), banana is one of the extremely fresh agricultural crops in Ghana, next to pineapple as a foreign exchange earner. Ghana exported 2,972 tonnes of banana to the European market in 2007, representing an increase of 41 % over the 2000 export figure of 1,753 tons. The banana fruit is also produced locally by many smallholder farmers in the Kwahu area in the Eastern Region and the Ashanti Akim and Mampong areas in the Ashanti Region for the local markets in Kumasi, Accra and Tema.

Fresh produce especially fruits and vegetables are considered an important part of our daily diet because they are a major source of vitamins, minerals, organic acids, dietary fibres and also antioxidants. Food guide indicated that, a good meal should consider at least 2-4 servings of fruit daily. The intake of horticultural produce is on the increase with a lot of consumer awareness about the health benefits of fresh and processed horticultural crops. Fruits and vegetables are extremely delicate foods and good handling after harvest is required to prevent them from going bad and to retain freshness and quality (Josh *et al.*, 2013).

Akpabio *et al*. (2012) reported that postharvest loss of fresh produce is a major challenge in the postharvest sector resulting in short shelf life under tropical climate (less than 7 days). Commercial growth is usually supplemented by advance in a country's diet resource and progressive elimination or reduction in the problem of food insecurity and nutrient deficiency. Fresh bananas have a short shelf-life owing to rough handling, unprotected storage conditions and poor packaging methods leading to postproduction losses of 30-40 % which contributes hugely to food insecurity, hunger, malnutrition and poverty (Josh *et al.*, 2013).

Despite the fact that Ghana is experiencing huge losses in the post-harvest chain of banana produce, less attention or no emphasis is given to postharvest management of perishables such as banana. Proper postharvest treatment and techniques are therefore required to maintain good physical and chemical properties as well as prolong shelf life of banana.

The main objective of the research therefore, was to determine the effect of different concentrations of GA_3 and polyethylene film linings on the physicochemical properties and shelf life of Cavendish banana variety stored under ambient and cold environments.

The specific objectives were to determine the effect of different:

1. Concentrations of GA_3 on the physicochemical properties and shelf life of banana (Cavendish) under different storage conditions;
2. Polyethylene film linings on the physicochemical properties and shelf life of banana (Cavendish) under different storage conditions; and
3. Concentrations of GA_3, packaging and storage conditions on the physicochemical properties and shelf life of banana (Cavendish).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN OF BANANA

Banana (*Musa spp.)* belongs to the genus Musa of the family Musaceae. The scientific names of banana are Musa acuminate and Musa balbisiana. The main focus of the origin of bananas is said to be Malaysia and advanced to the tropical world. It is known to be the “first fruit crop" because its cultivation came to being at a time when hunting and gathering was still the main means of acquiring food. Banana, a nutritious gold mine is a large perpetual plant with leaf sheaths which form the stem like pseudostem and was initially grown in the humid areas of South East Asia. It is the most popular perishable crop all around the globe and derives its name from the

Arabic word “banan”, meaning finger. Bananas are rich sources of several nutrients required for good health of every individual. And some elements of these are the first choice of athletes due to their high energy potential. Bananas are now cultivated throughout the tropics and in selected areas in the subtropics (Osman, 2006).

Bananas are said to be cultivated in Africa during the ancient periods. Information available proposes that bananas came into the New World by Southeast Asians around 2000 B.C. and later by Portuguese and Spanish travellers in the early 16th century. The Portuguese introduced bananas into the Canary Islands and the Spanish to the Island of Hispaniola during the 1500s (Danso *et al.*, 2006).

2.2 AN OVERVIEW OF BANANA PRODUCTION AND DISTRIBUTION

Even though Ghana has grown bananas for home and international consumption, the fruits talked about here are international-grade banana produced on a huge scale for trade, nearly completely to the European Market. For profit-making purpose, such cultivation needs large size of plantation land, a structured, dedicated working force, and an official link with a foreign fruit corporation to offer technical and marketing support, as well as funds (Agness, 2009).

According to Kilimo (2012), banana (*Musa sapientum L.*) remains a single most essential tropical fruit, with a world-wide yearly output of nearly 102 million metric tonnes in which Asia supplies 63 million tons. Bangladish contributes 4.22 million of banana per annum from 0.15 million hectares of land. Among these, mango, banana, jackfruit pineapple, papaya, litchi and guava are the main produce. Among the fruits, banana occupies the highest position in terms of acreage (0.06 million hectare) and second in terms of output (0.82 million tonnes). Banana is widely grown and a key commodity for 13 million people and a significant source of food, nutrition and income security for smallholder producers. Consumption of bananas in Ghana and West Africa as a whole has increased sharply recently, from 5.7 million mt in 1990 to 12.5 million mt in 2009. According to FAOSTAT (2009), about 86 to 91 % of that amount is consumed in the domestic food supply, with the remainder either used for processing or wasted during production, storage, or transportation (Josh *et al*., 2013).

It has been reported by Sharrock and Lusty (2000) that the global cultivation of banana has improved by 175 % over the last three decades to 102 million metric tonnes in 2010. India is considered the major producer turning out 32 million metric tonnes. Some essential production areas include China, the Philippines, Ecuador, Brazil, Indonesia and Tanzania. Banana cultivation in Africa has increased in the last three decades to 10 million metric tons whereas production in Asia has quadrupled to 62 million metric tons. However, universal plantain output which is a close relation of banana has risen by almost 60 % over the three decades to 37 million metric tons.

Uganda is by far the main producer with 9.6 million metric tons with Ghana being second, 3.6 million metric tons. Plantain cultivation in Africa has almost doubled over the last 30 years to 27 million metric tons (Agness, 2009).

FAOSTAT (2007) stated that the world's and Africa's production of banana stood at 73,175,419 and 7,848,906 metric tons respectively. It again reported that banana requires a tropical climate where the temperature is between 10 ^{o}C and 45 ^{o}C and a good rainfall throughout the year but is however grown in regions where irrigation is available to compensate for rainfall shortages. Also, in an altered environment, banana can be successfully grown at temperature range of 40 ^{o}C – 45 ^{o}C and 1 ^{o}C – 8 ^{o}C especially in Western Australia and Israel (Nartey, 2011).

Banana being one of the principal fruit crops in the world that is widely grown is the first traded commodity with respect to value and ranks second after citrus. The total banana production of the world has been estimated to be 71.3 million metric tons per year, next to grape. The leading producing countries include India, Equador, Brazil, Philippines, China, Indonesia, Costa Rica, Mexico, Thailand and Colombia. However, in Sudan, banana is cultivated successfully in all the states, with total yearly output of 74 thousand metric tons (FAOSTAT, 2009).

According to Jain (2004), bananas are grown in almost all humid areas throughout the globe. Of specific significance to Africa is East Africa Highland Banana (EAHB) which is a main energy given food for eighty million individuals and an essential avenue for revenue. There are 120 EAHB cultivars for just Uganda that is grown nowhere else in the world. Several 100 million tonnes of banana and plantain were produced around the globe in 2007 according to FAO estimates. Uganda is the major producer of banana and plantain in the sub-Sahara Africa (SSA), trailed by Rwanda, Ghana, Nigeria and Cameroon. Banana and plantain are produced in diversified environments. The plants produce fruit throughout the year, capable of producing for several years and are suitable for intercropping. Asexual spread is needed because they seldom produce seeds and even those are not true to type varieties. Banana as stated earlier can be cultivated under different climatic conditions varying from the wet tropical to the subtropical regions. The banana plant is one of the largest herbaceous flowering monoecious plants. It is stated that the stems of the banana plants are called pseudostems and each one produces a single bunch of banana. After fruiting, the pseudostem dies, but the suckers may grow from the base of the plant with spiral arrangement of the leaves that can grow up to about 2.7 m long and 0.6 m wide when cultivated on fertile soil (Nartey, 2011).

According to FAOSTAT (2011), about 2.47 million mt of bananas was produced in Ghana, representing 2.3 % of worldwide production. One of the highest banana producers in Africa, Cameroon, ranks seventeenth worldwide and fourth in SubSaharan Africa, far ahead of the other West African countries. The area harvested of bananas increases overall from approximately 91,000 ha in 1990 to 199,000 ha in 2005, actually fell to 157,000 ha in 2007 and has been slowly increasing since. Yields of bananas vary widely while the average yield for bananas in West Africa as a whole was 15.8 mt/ha in 2011. Mali and Côte d'Ivoire both reported significantly higher yields, averaging around 40 mt/ha. However, the available data do not provide any explanation for the high yields in Mali and Côte d'Ivoire or the increasing yields in Ghana and Cameroon (Tijani *et al.*, 2009).

In Ghana, banana grows naturally in the forest and the transitional zones of Brong Ahafo, Western, Ashanti, Volta and Central. A few farmers also interplant it in plantain farms around these areas. The Volta River Estate Limited (VREL) is the largest producer and exporter of banana in Ghana. VREL farms are located along the Volta Lake in the Asuogyaman District of the Eastern Region (FAO, 2011).

The levels of output and area under cultivation with banana and plantain in Ghana have generally risen since 2000, with the Eastern Region having the largest area volume of production. Other high production regions include the Ashanti, Western, Brong Ahafo, Central and Volta with varying yield levels. It is possible that the increasing production indicates the growing relevance of the crop in those areas and the nation at large, or perhaps as a result of the increase in cocoa cultivation, as banana and plantain frequently serve as shade trees for young cocoa plants (Dzomeku *et al.*, 2011).

Bananas and plantains cultivation is done at the beginning of the rainy season. This coincides with the planting period of several other major crops such as rice and maize among others in most parts of West Africa. The fruits are seasonally produced from different environments, but the major harvesting time is at a time when there are no rains from November to February. At this time, several other starchy staples are usually inaccessible or hard to harvest and so it serves as a major food security crop in foodscarce months (Akinyemi *et al.,* 2008). Labour scarcities, often results from the simultaneous planting and harvesting with other crops, making establishment of large farms difficult, leading to delayed farming activities and reduced yields (Akinyemi *et al.,* 2008). However, despite the possible limitations posed by labour, banana cultivation is attractive to farmers due to their relatively lower inputs supplies for production as compared to other crops (Kayode *et al.*, 2013). In banana and plantain, they grow on a single "spike" or raceme, set on the central stalk of the spike in about 5-20 clusters or "hands" with each hand containing about 20 fruits or "fingers" (Davey *et al.,* 2007). Bananas and plantains follow similar growth patterns, taking up to about three months after suckers emerge before banana is ready for harvesting, or a total of approximately one year after planting. The produce maintains a persistent weight at development in around three days and then the weight begins to diminish with changes in the peel shading from green to yellow and then to dark. Banana development/availability can be evaluated by measuring the tissue, fragility of the blossom closes and also roundness of the fingers (Dzomeku *et al.,* 2011). Smallholder banana and plantain cultivation is carried out using a variety of techniques, including several intercropping methods which are preferred in West Africa due to the potential for improved profit margins from the cultivation of multiple crops (Fonsah and Chidebelu, 2011).

However, it is really not clear whether intercropping addresses production constraints caused by labour shortages. Banana also plays a secondary role as a ground shade and nurse crop for other food crop species (Olorunda, 2000).

2.3 BANANA VARIETIES

Smale *et al.* (2005) stated that Cavendish variety is the most extensively cultivated variety globally. It is a triploid AAA cultivar of Musa acuminate or scientifically known as Musa acuminate Colla cv. Dwarf Cavendish'. In the Asia, banana is the second principal produced commodity, up to about 16 % of the overall fruit output areas with Cavendish cultivar primarily cultivated and for international trade. Cavendish AAA banana cultivar (supermarket banana) has a fruit size of 6-8" long ×

1.5 2" in diameter. The bananas are to some extent sausage shaped but with a curve and the ends not completely rounded, with floret remains attached. It is a characteristic desert-type banana that grows comparatively tall (as compared to the Dwarf Brazilian or the Dwarf Apple banana). The stems (pseudostem) differ from green to greenish yellow to quite dark with a knobby stalk below the fruit (rachis). It is less "untidy" as compared to Dwarf Chines. They are "untidy" as the floret bracts tend to stay on the rachis right above the male flower bud and not fall off (Dita *et al.*, 2010).

According to Plainsirichai and Turner (2010), Cavendish banana are harvested at mature green stage (ripeness index 2) and can be kept in chilled state for up to one month while in shipment. Suitable weather conditions, maturity and ethylene gas are needed for ripening of banana. As they ripen, the peel colour modifies from green to yellow as taste increases and pulp relaxes. As banana is a typical organic product having a climacteric rise, the maturing treatment of banana could be artificially induced utilizing controlled ethylene gas. The industrial ripening offices for banana natural products included computerization and automatic ethylene gas control by technical hands (Liew and Lau, 2012).

2.4 IMPORTANCE OF BANANA

As a perennial crop with a short gestation period, bananas play an important role in West African domestic food production, and all stages of the fruit are used as a source of food. Sub-Sahara Africa's yearly intake is 21 kg of banana and plantain per capita, but Uganda consumes 191 kg per year or more than half of one kg in a day. In fact, Ugandans use the same word for food as the name of the local banana dish matooke. Four countries in Africa have the highest per capita consumption of banana/plantain all over the world, with Uganda being the highest. Bananas and plantains in West Africa are popular across a range of ages, genders and socio-economic groups due to their convenience and ease of preparation. They are eaten both alone and as part of a larger meal that may include stew, vegetable sauces, fried kidney beans, roasted meat or other dishes (Honfo and Coulibaly, 2011).

Fresh fruits in Africa supply not less than 25 % of foodstuff food vitality supplies to about 70 million consumers. The flesh/ tissue of the ripe fruit is basically high in sugar and can be readily assimilated. Boiled fruit is like that of potato in terms of nutrition. The composition is almost 70 % water, 27 % carbohydrate, 1.2 % protein, and 0.3 % fat. Banana is known to be a worth of vitamins A, B1, B2, and C. Plantain however has less moisture than banana. Subsequently carbohydrate is changed to sugars faster in bananas than in plantains. In some varieties, the substances of the carotenoids which can be converted into vitamin A is said to reach those in the best-performing sweet potato and carrot cultivars (FAO, 2014).

Zhang *et al.* (2005) stated that, banana cultivation and ingestion in the prehistoric and initial contemporary world was mostly geared towards small-scale operations. Nonetheless individual bananas are more than likely accessible for the market through marketable exchanges, most fruit cultivation happened as a small-scale operation for local consumption. The banana's prominence as a main commodity is soundly recognised, and its main usage is probable as either the key starch eaten, or due to its non-seasonal nature, as an essential buffer food between other major harvests. Though, large farm operations are undoubtedly evident, as China's plantation complex and the presence of bananas in colonial New World attests. Banana is a single inexpensive nutrition plant grown in the world over as the cost of production is very minimal as compared to most other staples. Apart from the fact that bananas are mainly used as dessert, they can be turned to juice, canned slice, deep-fried chips, toffees, fruit bars and brandy among others. Besides, the non-edible parts including leaves, fibres and pseudostem extract are as useful as the fruits. It has been reported that some materials of trade worth including foods, drugs and crafts are derived from these by-products (Chong, 2007).

Uncooked fruit thickener is resilient to α- amylase and glucoamylase due to its high degree of crystalline intrinsic structure. Hence, isolated banana starch is suitable to be used to produce starchy food. Green banana has been noted for high complete nutritional fibre content especially in hemicellulose which is higher than most horticultural crops. Bananas are useful for persons with peptic ulcer, for treatment of infant diarrhoea, in celiac disease and in colitis. The fruits can be used by and geriatric patients due to the less fat level as against high caloric rate. The soluble fibre is known to have positive effects on glycaemic, insulin and cholesterol responses to foods. Soluble fibre has prompted interest among researchers and food manufacturers for the health effect rather than the insoluble fibre (Jiang and Joyce, 2003)

Bananas are essential basis of food calories for humans in many parts of the world. Currently, bananas rank fourth as a very significant primary produce for tropical people, providing a significant source of carbohydrates and vitamins, in a readily absorbed, easily digested package. The great majority of the exported bananas consumed in the developed world belong to the Cavendish subgroup (AAA), which became popular in the mid-20th century due to its resistance to Panama disease, which had devastated the previously dominant Gros Michel subgroup (Dita *et al.*, 2010). However, this export crop accounts for less than 15 % of global banana production and there is a great deal of regional variation in locally consumed bananas. True banana/plantains (AAB), which are cooked before eating, are dominant not only in West Africa, but also in Central and South America as well. In East Africa, the most common varieties are highland bananas (AAA) which are steamed or used for making beer. In Southeast Asia and the Americas, cooking bananas (ABB) and dessert bananas (AAB) are the most common, while another type of cooking banana (AAB) is popular in the Pacific (Danso *et al.*, 2006).

According to Ekunwe and Ajayi (2010), bananas and plantains can be prepared through a number of methods including boiling, steaming, mashing, baking, drying and pounding into fufu (a popular West African staple made with boiled cassava, yams or plantains that are pounded into dough). In Cameroon, bananas/plantains are generally consumed between the green and yellow stages of ripeness after being boiled, pounded and then fried, roasted or made into flour (Yomeni *et al.,* 2004).

Dzomeku *et al.* (2011) reported that, the European Union (EU) has been a possibly huge trade for bananas produced in Ghana. Before 2006, banana trades were limited by the EU bananas Regime, which retained limiting proportions on the quantity of bananas that can be imported from African-Caribbean-Pacific (ACP) nations without being subject to an unreasonable tariff, while exports from non-ACP Latin American countries enjoyed a much larger quota and constituted more than 80 per cent of EU imports. Therefore, the major international banana companies selling in the EU — Chiquita, Dole, Del Monte, and Fyffes did not develop Africa as a main source for their banana supplies. Ghana has shown the ability to compete in the European market through exports from the country's two existing banana-export companies, Volta River Estates Ltd and Golden Exotics. Ghana continues to be a minor actor in the EU market, but that its locus visa- vie other traders proposes a major margin for competitive growth. Ghana traded up to 34 thousand metric tons of bananas to the

European Union in 2007, with export quantities continuing to increase (Agness, 2009).

Notwithstanding this proven export ability, a thorough valuation of Ghana's banana-export prospective came to a conclusion that Ghana meets all the vital requirements necessary to produce an international-grade banana. This economical capability is a requirement to producing constant commercial profits. Essentially, the valuation delivered crucial data regarding acres which can be suitable for banana production. As a starting point, bananas for export must be grown within 150 kilometres of a port to achieve cost-competitiveness for transport (USAID, 2009)

According to Dzomeku *et al.* (2011), Ghana enjoys several fundamental qualities that point in the direction of a large potential for Ghanaian banana sector. This prospective is expected to become conscious in a definite form of production in organisation where there will be a separation of duty and rewards between foreign banana companies and domestic Ghanaian interests. Tariffs in the EU banana Regime, which placed a €176 tariff per metric ton on most bananas from Latin America and eliminates preceding restrictions on importations from Africa, is the main strength behind Ghana's prospective as a main banana exporter. Moreover, there could be some shipping cost advantages vis-a-vis shipment from Latin America to the EU (though this may depend on improvement in Ghana's own post cost) and, in some cases, a more unwavering and accountable socio-political atmosphere within the country than in the typical bananatrading nations. It is imperative to note that Ghana has two important physical structures, from the viewpoint of multinational banana companies, are striking relative to the traditional banana export countries of Latin America. According to USAID report (2009), banana production in Latin America is inundated with black sigatoka disease, which is far less prevalent in Ghana. This implies a substantial cost reduction for the producers.

Additionally, Ghana does not suffer from certain severe weather conditions such as the shocking storms as do in other regions of Western farms. Unusually bad weather over the past decade in those regions is believed to be a temporary phenomenon forcing multinational banana companies to curtail production in many areas as a result. Although the October 2002 wind storm that devastated Volta Real Estate (VREL's) crop looms much in the experience of Ghana's small banana industry, the incident was (typical of Ghana's wind storms) highly localised and did not even reach all the five VREL's five plantations, located in closed proximity. This stands in sharp contrast to the vast areas vulnerable to a single hurricane in Latin America. Moreover, the 2002 storm experience resulted in the development of several countermeasures now being deployed by Ghana's industry, and scientist interviewed at the University of Ghana said more could be done in this regard as research continues (Lemchi *et al.,* 2004).

In comparison with both firms presently turn out bananas in Ghana, substantial expansionary investment and trade engagements could come from one of the four main multinational banana establishments. For Ghana, the crucial lost element is know-how; nonetheless Ghana is supporting its banana knowledge base annually using current production and can influence upcoming events in the country by key banana multinationals to advance the original understanding. The advantages of the existence of international companies in the country's banana production sector cannot be overemphasised: these corporations could bring about differences in knowledge, can expand the country's individual wealth through services and can make available an all market in developed world for the country's production (FAO, 2011).

Processed diets, for example, chips, banana puree, jam, squeeze and wine can be produced using the organic product. The delicate stem, which bears the inflorescence is extricated by evacuating the leaf sheaths of the collected pseudostem and utilized as vegetable. Plantains or cooking bananas are rich in starch and have a compound piece like that of potato. Banana fibre is utilized to make things like packs, pots and divider holders. Ropes and great quality papers can be produced using banana waste. Banana leaves are additionally utilized as solid and hygienic eating plates (Tapre and Jain, 2012).

In some parts of Africa, operational men eat 5 pounds of banana flesh in a day, which is equivalent to almost 3600 calories. In contrast with white potatoes, bananas have the similar quantity of caloric value but less fat and almost no protein. Yearly global production of Musa fruit go beyond 40 million metric tons. Banana may be eaten fresh, baked, mashed and chilled in pies and also in pudding. However in Ghana, banana is mainly consumed at the fresh ripened stage. The ripe banana fruit contains about 22%

carbohydrate, mostly as sugar and the fruit is also rich in potassium but low in protein and fat and contains vitamins A and C and about 75 % water (FAOSTAT, 2009).

Banana is one of the Foods and Drugs Authority's topmost horticultural produce. An exceptional basis of vitamin A, vitamin C, vitamin B-6, and potassium, provide fibre, cholesterol-free and low in sodium. A normal sized fruit contains nearly 95 calories. Certain medicines for regulating blood stress diminish the body's storage of potassium and one banana consumed daily reinstates the balance of potassium. Accepted as an essential portion of a meal and to reduce the risks of cancer, at least five servings every day of produce are recommended. A current study revealed that consuming nine or ten a day servings of fruits and vegetables, together with three servings of low-fat dairy products are effective in lowering blood pressure (Honfo and Coulibaly, 2011).

Overripe banana are processed into beverage or spiced with beans stew powder, broiled with palm oil and eaten as a nibble. The dried leaves, sheath and petioles (the stalk joining the leaf cutting edge to the stem) are utilized as tying materials, wipes and roofing material. Banana leaves are likewise utilized for the wrapping, bundling, advertising and serving of nourishment. The peels are utilized as food for domesticated animals, while the dried peels can be utilized as a part of cleanser processing (Akinyemi *et al.*, 2008).

2.5 INCOME GENERATION AND NUTRITION

FAOSTAT (2011) reported that as an income generation avenue, each acre of Ghanaian banana production was projected to generate huge sums of money yearly after the primary start-up investment is accomplished, including other subsidiary profits. Assuming a mean harvest of about 16 metric tons per acre, the entire commercial value potential for a range of prospective productivity levels by the Ghanaian banana sector can be massive. Bananas are an important source of income for smallholder farmers in West Africa, partly because of their low labour requirements for production compared to crops like cassava, rice, maize, and yams (Lemchi *et al.,* 2004). According to Ekunwe and Ajayi (2010), several banana farmers were interviewed in Edo State Nigeria about profitability and constraints to banana production. It was found out that banana production was profitable in the area, with a 37.7 % rate of returns for the original investment in planting materials, intercrops, fertilizer, chemicals, and labour. United Republic of Tanzania (2003) reported that banana has greater potential commercially through export to other regions and towns, particularly where demand for banana is very high for food consumption. In this regard, banana plays an important role in food security and income generation and thus contributes greatly to the livelihood of smallholder farmers. Since the crop is harvested throughout the year, it ensures food and income security particularly at the household level. Its contribution to household income has been increasing significantly (MOAC, 2001).

In addition to the income opportunities for farmers, processed bananas provide employment for the vendors who sell them. In many areas, roadside women sell the banana and plantain dish known as dodo, and plantain chips and other snacks are also sold by vendors. Bananas/plantains are an important part of the diet in Africa and other regions, accounting for up to 25% of the carbohydrates for approximately 70 million people in Sub-Saharan Africa's humid zone. According to FAOSTAT 2009 data, West Africans consumed an average of 39 kg per capita per year of plantains, compared to 76 kg of cassava and 71 kg of rice (and only 9 kg of bananas). In Southwest Cameroon and other high plantain-consuming areas, plantains can account for as much as 150 kg of consumption per capita per year (Ekunwe and Ajayi, 2010).

Bananas and plantains are a rich source of carbohydrates, which account for approximately 22 % of the dry weight for bananas and 32 % of the dry weight for plantains (Honfo and Coulibaly, 2011). Bananas and plantains are low in fat and sodium and contain compounds that reduce blood pressure (Sharrock and Lusty, 2000). They are also a good source of vitamins, including C, B, and A, and minerals such as potassium (K), calcium (Ca), and phosphorus (P) (Kayode *et al.*, 2013). Darkyellow or orange-fleshed banana and especially plantain cultivars are a good source of provitamin A carotenoids, which are the primary source of vitamin A for rural farming populations affected by vitamin A deficiency (Fungo and Pillay, 2011).

As bananas and plantains ripen, their compositions change. The dry weight of unripe plantains is more than 80 % starch and only 1.3 % sugars, but the sugar content increases to about 17 % in ripe plantains. Unripe bananas are about 20 % starch, which declines to 1-2 % in the ripe fruit, while the sugar content increases from less than 1% to 20% (Zhang *et al.*, 2005). The nutritional content of bananas and plantains also varies significantly across genotypes and preparation methods (Davey *et al.*, 2007).

One of the general differences between banana varieties and plantain varieties is the moisture content: plantains are about 65 % moisture on average, compared to 83 % for bananas. Because moisture enhances hydrolysis, the process that converts starches to sugars, starches become sugars more quickly in bananas, which also cause the peel to turn yellow. The sugar content of ripe bananas is unusually high in a fresh fruit, providing almost double the energy of an apple and close to three times the energy of citrus fruits. The energy value of bananas and plantains is comparable to other starchy staples such as yams and cassava, but only about a third as high as dry rice, wheat flour, and maize (Sharrock and Lusty, 2000).

As stated by Arias (2003), the primary import markets for bananas worldwide are North America, Europe and Japan while several West African countries import bananas on a small scale. In 2010, the top importers in West Africa were Senegal with 16,450 mt, Mali with 7,939 mt, and Liberia with 3,929 mt. It is likely that the import numbers reflect regional trade within West Africa, but the FAOSTAT data did not specify whether that is the case.

Although banana production may not be so high in some areas in Ghana, yet bananas are a significant source of imports and exports. The proportion of bananas grown in West Africa that are exported improved from 22 % in 1990 to 53 % in 2003, but steadily declined to 34 % in 2010. Banana exports are primarily from some African countries including Côte d'Ivoire 335,593 mt, Cameroon 237,942 mt and Ghana 11,030 mt all in 2010. Banana as a perennial crop has a short gestation period and plays an important role in West African domestic food production. All stages of the fruit are used as a source of food at different places making it an essential food security crop. Bananas in West Africa are popular across a range of ages, genders and socio-economic groups because of their convenience and ease of preparation. They are eaten both alone as a main meal and as part of a larger meal that may include stew, vegetable sauces, fried kidney beans, roasted meat or other dishes (Honfo and Coulibaly, 2011).

An improvement in the nutritional fibre level in the meals of people must be stimulated and sustained. This is due to the crucial role dietary fibre plays in influencing the wellbeing and illness situations of people by averting colon cancer, coronary heart disease, obesity, diabetes and gastrointestinal disorder. The American Dietetic Association (ADA) reported that, the present recommended fibre consumption required by adults falls within 20- 35 g/day or 10 -30 g/1000 kcal (FAO, 2014).

According to Hailu *et al.* (2012), banana is a main foodstuff for several individuals of the humid nations. The ripe banana comprises several of the components that are vital for a secured diet. It has fat, natural sugars, protein, potassium and vitamin A, B complex and C. The ripe fruit is simply assimilated and it provides rapid calories and can also be used as medicinal fruit. Banana aids in recovering from anaemia, blood pressure, brain power, constipation, depression, hangover, ulcer etc. Malnourishment and undernutrition have now developed to worrying problem of the people of the emerging nations upsetting their financial as well as physical growth. Protein-energy, nutrition and vitamin deficits are the most severe dietary conditions in the developing world. As a result of these deficits, under-weight and high death are predominant in pre-school children and babies. The least nutritional need of the fruit per day per person is 115 g, whereas our availability is only 30-35 g. Per capita obtainability of commodities is more reduced occasionally owing to great level of postproduction losses. Postharvest losses can be reduced substantially by improving storage technology and prolonging shelf life of fruits (Kader, 2002).

2.6 POSTHARVEST LOSSES OF BANANA

In long distance conveyance and delivery, the risk of postharvest losses may increase and therefore proper care and handling are being emphasized in recent years for postharvest commodities. There are several causes of post-harvest losses, including increased respiration rate, hormone production (i.e. ethylene), physiological disorders, general senescence, compositional and morphological changes. But the excess of ethylene (plant growth hormone) production is mainly responsible for higher postharvest losses, especially for climacteric fruits (Mansi, 2012).

There are several causes of post-harvest losses in banana including rough handling, harvesting at maturity just before the fruit ripens, nonexistence of processing options, infection from spoiled fruits and insufficient or inappropriate storage, packaging and transportation facilities (Zhang *et al.,* 2005). Poor organization and transport cause splitting, abrasion and other types of injury on the banana. Extreme high heat and humidity coupled with poor storage options shortens the usable period of banana, leading to increased spoilage and waste (Akinyemi *et al.,* 2008). Projected postharvest losses of banana are as high as 40% in some parts of West Africa or roughly 35% for emerging nations in general. In Cameroon, studies confirm that about 30 % of post-harvest losses of bananas are incurred during wholesale and about 70 % during retailing (Adeniji *et al.,* 2010).

Bananas in West Africa are generally stored simply by piling them on the ground. Some precautions are sometimes taken to maintain freshness and reduce damage, such as storing bananas under shade or covering the piles with banana leaves or bags that are frequently moistened with water. To extend shelf life, it is recommended that banana is packaged in plastic bags to reduce air circulation and storing them at 12 to 14 degrees Celsius, based on studies of the shelf life of banana harvested at maturity. However, traditional banana producers and traders generally do not use plastic bags or any form of refrigeration due to lack of the ideas as well as the cost associated (Odemero, 2013).

The worth of produce declines and significant quantity is lost, from harvesting to the ultimate consumption. This loss could be reduced to the minimum by modifying postproduction management practices especially during storage using appropriate packaging techniques or improved packaging practices. Even in the advance countries such as USA, postproduction injuries of produce are substantial and can be up to 20 %. These losses not merely consist of the food losses but also acreage cultivation, energy (fuel, machinery), soil stimulants, biochemical, irrigation water and work force losses. The upturn in yield and output is lagging considerably behind the rise in global populace, as well as the dietary requirement globally. Hence, decrease in postproduction losses must be seen as an intentional necessity throughout the world, particularly in emerging nations. The growth in harvest and efficiency, devoid of decreasing postharvest losses will not be adequate in securing the accessibility of food in the world (Amin and Hossain, 2012).

2.7 STORAGE AND EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON THE QUALITY OF FRUITS

Saeed *et al.*, (2006) defines storage as holding of produce for a period of time whether under controlled or ambient conditions. For storage purposes, it is essential to start with produce of high quality. These produce must be free from damage or diseased, and containers or structures and or materials should be properly aired and resilient enough to resist piling. Appropriate packaging procedure includes temperature regulation, relative humidity control, proper ventilation and preservation of space between containers for sufficient air circulation, and escaping unsuitable product mixes be carried out. Produces kept together should be able to withstand similar temperature, relative humidity and level of ethylene in the storage environment. Produce of high ethylene content including ripe fruits and banana could trigger both physical and biological changes in ethylene sensitive commodities resulting in undesirable colour, flavour and texture changes (Appiah and Kumah, 2009). Temperature control at the storage period is important and could be supported by making four-sided rather than oblong structures. Rectangular structures have more wall area per square feet of storage space; hence much warmth is directed through the walls, making them more expensive to cool. Temperature regulation could as well be supported by sheltering structures, painting warehouses white to aid redirect the sun's waves, or by using sprinkler systems on the top of a structure for expensive cooling (Thompson, 2003).

Bananas in West Africa are generally stored simply by piling them on the ground. Certain precautions are sometimes taken to maintain freshness and reduce damage, such as storing bananas in the shade or covering the piles with banana leaves or bags that are frequently moistened with water. To improve shelf life, researchers have suggested packaging bananas in plastic bags to reduce air circulation and storing them at around 14 degrees Celsius, based on studies of the shelf life of banana and plantains harvested at maturity. Banana/plantains covered with film linings mixed with dry cocoa leaf powder or rice husk had a shelf life of 14 to 27 days depending on the temperature. However, traditional plantain producers and traders generally do not use plastic bags or any form of refrigeration due to the cost (Kader, 2005).

According to Fernanda *et al*. (2013), banana is a characteristic ethylene producing crop, and essential physicochemical reactions occur when undergoing ripening. Therefore, as the produce has a short shelf life i.e, the elapse time between harvest and the beginning of ethylene production, management of the surrounding atmosphere, primarily relative humidity and temperature, is used to increase the usable period. Low temperature storage is a direction in the holding and management procedure, from the harvest till it is sold, to prolong the storage life of the commodity. Usually, this situation can considerably decrease the level of several metabolic pathways which can result in produce senescence, dying and degeneration. Low temperatures briefly weaken maturation and ripening by sustaining the least probable ethylene concentrations but most humid produce go through biological conditions and reduction in value when subjected to low temperatures. The external pitting at temperature lower than 10 °C is a classic indication of chilling injury and in that of bananas, though the tissue would not be damaged for some few days, the peel might look black, which undesirably reduces the quality (Osman, 2006).

According to Kader (2002), temperature and relatively humidity (RH) have a direct effect on the postharvest respiration of fruits and vegetables. It is also reported that elevated temperature increases respiration, resulting in increased ethylene production and high carbon dioxide level leading to changes in certain quality parameters such as flavour, taste, colour, texture, appearance and nutrients of the produce. Jobling (2000) reported that, extreme temperatures damage products especially those of perishable nature. There are certain products that suffer chilling injury while others suffer damage due to high temperatures. Exposing horticultural produce to too high or low temperatures also cause a marked decrease in shelf life and loss of quality. Therefore, appropriate and careful temperature management of produce (banana) throughout harvest, storage, transportation and marketing chain is critical if quality of the product is to be assured as well as extending the usable period. Sharma and Singh (2000) indicated that appropriate postharvest handling operations that should be applied must include controlling temperature (cooling) and RH, atmosphere (O_2 and CO_2 levels). These conditions are very important factors affecting fruit quality at delaying ripening by modified or controlled atmospheres but cannot substitute for keeping banana at the optimum level of environmental conditions. Universally, the shorter the periods between harvest and intake of the produce, the better the consumption value as postharvest-life created by taste feature is generally about 70 % of postharvest life based on exterior characteristics of produce. This is as a result of damages and reduction in sugars levels and organic acids utilised during respiration, reduction of the produce ability to create the typical aroma owing to lessening of precursors, and/or development of off-flavours (Sharma and Singh, 2000). Temperature of horticultural commodities can be lowered as early enough after harvesting and regulated precisely beyond the level chilling injury might occur. Thompson (2003) reported that tropical horticultural crops often are predisposed to chilling injury when temperature is reduced below 13°C which decreases the value of the commodity and curtails

storability of produce.

Kader (2002) indicated that modified atmospheric (MA) environments with reduced O_2 and increased CO_2 levels up to 10 % have shown reduced ascorbic acid loss and extended postharvest life of many different varieties of fruits and vegetables. However, the responses to MA environment vary greatly among plant species, maturity stage, duration and temperature of exposure.

2.8 PACKAGING OF FRUITS AND VEGETABLES

According to Nartey (2011), packaging is seen as the art, science and technology of enclosing or protecting product for distribution, sale, storage and use. Packaging is a way of making the product easy to carry or handle by placing the produce in any appropriate containers to improve mobility, prevent contaminants such as pathogens, dirt and undesirable reaction with the environment. It increases the quality and the shelflife of the product making it presentable to the consumer. The product can be packed manually to make it attractive, normally by a permanent amount of evenly sized elements. Packaging materials such as trays, wraps and liners may also be used to help prevent the products from movement. Machine-driven bagging structures can be used for volume-fill method or tight-fill process, where organised commodity is distributed into the containers and then vibration settled. Several machine driven systems use weight as an approximation of volume, and ultimately changes are manually (Appiah and Kumah, 2009).

It is also reported that ethylene stimulates the colour change development of the produce. Introduction of the commodity to undesirable ethylene should be eluded by sorting out ethylene-producing products from ethylene-sensitive fruits, by way of making use of ethylene scrubbers, or by allowing fresh air into storage rooms. Again, ethylene absorber envelopes put into packages with ethylene sensitive commodities will lessen the ripening process of the produce and chlorophyll degradation of produce. Bagging in polyethylene linings can change the air composition around the product known as modified atmosphere packaging or MAP (Kader, 2002).

2.9 RIPENING, GREEN RIPENING AND SOFTENING

According to Plainsirichai and Turner (2010), ripening is a complex occurrence in fresh fruits that comprises several physiological and metabolic changes. Vital substances that determine fruit quality such as sugars, pigments and aromas accumulate during the ripening stages, and usually fruits change their dimension and texture. Ripening has a great influence on the absolute quality of the fruit and its economic value. However, studies investigating the softening process in several fruit crops especially perishable produce demonstrate that softening begins much earlier than formerly known, during the early stages of ripening, prior to rapid sugar accumulation and colour development (Du *et al.*, 2014). Whereas softening is presumed to result from destruction of cell wall arrangement, firmness is intensely linked with the turgor force (P) of the mesocarp cells. Similar observations of P decrease during softening in other fruits indicate that decreases in P may serve as a primary mechanism of softening. In fact changes of cell wall structure by degrading enzymes and the starch degradation in fruits are the two main reasons of fruit softening (Archana and Sivachandira, 2015).

In bananas, associated to other ripening related events, there is a decrease in starch content and the decline in fruit firmness within the first 3- 4 days during storage at 20

^oC. Chlorophyll degradation is relatively evident in early ripening events which are linked to temperature. This situation could explain the reason that the first 3 days are usually serious for temperature result on the colour modification of the produce.

Specifically, on day three, chlorophyll ruin increases at 20^oC, but suppressed at 30^oC, resulting in whole or partial chlorophyll destruction, respectively. Plainsirichai and Turner (2010) also detected that environmental condition at the initial phase of the commodities ripening determined whether or not the peel reaches full yellow colour.

At usual chlorophyll degradation of bananas at 20 ^oC, numerous crucial transcription chlorophyll degradation genes such as MaSGR, MaNYC and MaPaO are usually activated when the transcript points rise as the ripening progresses. The gene expression forms display a maturing habit like some ripening associated inheritable factor in fruits (fruits), such as MaACO and many banana softening related genes; MAPG3, MAPG4, MaEXPA2, MaEXPA3, MaEXPA4 and MaEXPA5 (Asha *et al.*, 2007). Whereas in the fruit ripening at 30 ^oC, the expression of the above chlorophyll degradation genes temporarily increase and then decrease to low levels, not reacting to faster ripening (Asif and Nath, 2005).

Softening without ripening in banana seems to be unusual, as related to several fruits, and some kinds of the Musaceae family. For instance, plantain (Musa, ABB group) loses greenness more rapidly as temperatures rise in the range of 20–35 ^oC. It is obvious that green-ripening of banana results from the inhibition of chlorophyll destruction by high temperature, resulting in high levels of chlorophyll retained in their peel (Yang *et al.*, 2011). The retention of chlorophyll mainly found at the surface of the peel of bananas, leads to the greenish yellow outlook of the commodity. Studies of the mechanisms by which temperature disturbs chlorophyll destruction during banana fruit ripening might add to our appreciation of chlorophyll degradation regulation during climatic fruit ripening (Plainsirichai *et al.*, 2003).

2.10 PROCESSING

Banana chips in West Africa are made by frying of unripe or slightly ripe banana tissue in vegetable oil, and are packaged in plastic or aluminium sachets. Banana chips are the most popular banana foods in Nigeria, and are sold either by vendors on the street or by small companies which supply them to supermarkets (Ekunwe and Ajayi, 2010). Bananas are also made into flour by peeling the banana, cutting the pulp into smaller size and dry by air, and then grinding the dried pulp in a wooden mortar or corn grinder. Banana flour can be used to make fufu, bread, biscuits, baby food and/ or cakes. The quality and characteristics of the banana/plantain chips or flour are affected by the stage of ripeness of the bananas (Yomeni *et al.,* 2004). One advantage of banana/plantains chips or flour is that it has a longer shelf life and easier to transport (Adeniji *et al.,* 2010).

In Ghana, chips are primarily for domestic usage with little export, while banana and plantain flour has been marketed at the African diaspora. The False Horn and True Horn plantains are the ideal varieties for food processing due to their large sizes and higher dry matter content (Dzomeku *et al.,* 2011).

2.11 MARKETING OF BANANA

Bananas and plantains are highly perishable and the nonexistence of modern technology and advanced harvesting practices in most parts of banana producing areas in Ghana and Africa means that the produce must be consumed in a short time during post-harvest, requiring quick delivery and marketing. Banana distribution in West Africa is done through different interactions between farmers, collectors, wholesalers, and vendors. Since banana production is far more focused on export than other crops, large wholesalers and vendors, and even multinational corporations often play a larger role in banana marketing (Fonsah and Chidebelu, 2011).

Banana distribution in Ghana is so complex that farmers whose land lies nearer to main roads harvest the produce at the mature green stage and display it at the roadside or convey the commodities to the nearest markets, allowing small-scale wholesalers, retailers and consumers to buy directly. In other cases however, trade collectors move around farms, collect the produce from farmers and convey it to the well areas where they delivered to wholesalers, who also pass the produce on to retailers or sellers for sale to consumers. Transportation and distribution to the main cities and other areas where they are not is normally by wholesalers (Akinyemi *et al.*, 2008). Similarly in Ghana, the sale of bananas consists of a good number of growers and few wholesales who deliver banana to consumers in a large scale. A nationwide survey of some banana farmers and sellers conducted in Ghana identified four main channels through which bananas get to consumers (Dzomeku *et al.*, 2011) thus producer to wholesaler to retailer, producer to retailer, wholesaler to agri-industry and producer to agriindustry.

Banana marketing becomes very difficult due the distribution of the production zones, the absence of environments of the lines of interaction with city consumption areas as well as unbalanced supply in the market by wholesalers and middlemen who set the prices. However, banana marketing in other places like Cameroon appears to be more centralized, with wholesalers and large production firms coordinating acquisition of bananas from smallholders, as well as the packaging, transportation and marketing of the produce (Fonsah and Chidebelu, 2011). Bananas have the marketing characteristics specific to all other perishable foodstuffs whose production is complex and distribution difficult to organise. The process involves a large number of producers and a few wholesalers who distribute bananas to consumers on a large scale (Asha *et al.*, 2007).

According to Dzomeku *et al.* (2011), women play a significant role in the marketing and sale of bananas in West Africa. In many locations female market supervisors, often known locally as ‘market queens,’ manage each market and regulate the quantity and price, and usually new entrants are not allowed to sell their commodities if they do not belong to that market. As for smallholders who do not have market access through wholesalers or direct participation on local markets, marketing options are primarily limited to sale at the farm gate. This marketing method largely limits sales to local consumption and, in the absence of village trade collectors or larger-scale buyers, puts more isolated smallholders at a greater disadvantage. Traders that will sell their fruits when they are ripe usually facilitate the ripening process by piling them in baskets, drums and or other containers covered with plastic films or jute sacks to maintain heat within the produce (Akinyemi *et al.*, 2008).

The banana trade is done by persons or producer groups at farm gate or the bulking site, anywhere producers prearranged in groups, direct relationships with traders and /or brokers occur although every farmer collecting minor amounts supply straight to the bulking centre. There are efforts by the public and private sectors to assist farmers increase on worth and marketing of desert bananas. Africa harvest has played a significant role in advancing the course of tissue culture bananas as well as providing knowledge and technology transfer services to improve farmers’ management practices in some African countries. Advance, an NGO, has collaborated with farmers to increase produce marketability through connecting farmers directly to purchasers and instituting fruit management services such that buyers and farmers would transact.

Effort is being made to advance producers’ entrepreneurial skills and stimulate banana value addition technologies, in terms of acceptability and change towards commercialisation of these enterprises is not enough (FAO, 2014).

According to Dzomeku *et al.* (2011), the presence of agents in the banana market line principally at the farm gate is as a result of the absence of collaboration on the part of farmers to cumulate the commodity at one point where merchants can buy. Agents move from farm to farm to gather harvested produce heaped by the roadside. Marketing agents usually live in the same area as the farmers and are contracted to buy produce prior to the day earmarked for collection. Traders get there a day before market days allocated for each of the sides where banana is sold to purchase from and get in touch with their brokers and farmers to make arrangement for advance purchases. Some traders that deal directly with producers organise for vehicle to move around farms to gather banana that have been bulked at the road sides in rural areas. The traders who do not have direct appointment with the farmers will have to wait for brokers or farmers at the road sides to buy products. Wholesalers make transport and loading arrangements from the bulking sites to the wholesale market where the ripening process is done. Mostly groups of wholesalers come together to organise transport hence sharing the cost of transport and municipal levies for their commodities (Akinyemi *et al.*, 2008).

Sellers comprising superstores, kiosk owners, vendors and green grocers purchase bananas at several phases of ripening (turn fully yellow) from traders. These constitute 5 % of the entire sweet fruits eaten, mostly grade A and preserve a cold chain from storage to display in the supermarkets and stores. Hawkers, estate dealers and kiosk owners on the other hand sell to the low end of the market subdivision that accounts for 95 %. Banana traded up to this point of the market are ready for consumption regardless of hygienic situations and are of mixed grades. Marketers at some urban areas on the other hand are found selling full yellow banana at lorry stations and when traffic is heavy on major roads (Dzomeku *et al.*, 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 SOURCE OF MATERIALS

Both Cavendish banana bunches were obtained from a private farmer's orchard fields at Ninting, Ashanti Mampong, a banana farming community and a suburb of Kumasi. The three months old fruits (starting from flowering) were harvested at optimum stage of maturity and bunch gently cut off from the stems to ensure that the fruits were not damaged. They were transported immediately after harvesting to the experimental site at KNUST.

3.2 EXPERIMENTAL DESIGN

The experiment was laid out in a 4 x 4 x 2 factorial arrangement in a Completely Randomised Design (CRD) with three replicates and was carried out at the laboratory of Horticulture Department of the Faculty of Agriculture, KNUST.

3.3 PREPARATION AND TREATMENT OF SAMPLE MATERIALS

3.3.1 Sample preparation

Banana were harvested when the fruits of the first hand on the bunch indicated signs of ripening or yellowing and the fingers changed to circular in shape but those that showed sign of yellowing were not used in the experiment. Harvesting was carried out early and manually in the morning between the hours of 6:00-7:00 am with great care to avoid mechanical damaged. Harvested banana were de-handed and arranged in a paper box lined with a soft material to provide cushioning and transported to the laboratory by a vehicle.

Transportation was done in the early hours of the morning to reduce heat damage. Individual fingers were separated and similar size rounded fruits were selected. Fruits were selected as samples with no serious defects such as cuts, bruises, deep wounds or insect damage. The samples were then graded by size and colour and fruits with defects were discarded. Then unblemished uniform fruits were cleaned using a wet soft material in order to clean them of dirt/soil particles on the fruits.

3.3.2 Treatment of samples

0.15 g, 0.25 g, and 0.35 g, each of powdered GA_3 was dissolved in three drops of ethanol using dropper pipette before adding clean tap water to prepare the solution in plastic buckets. Each was added to 1000 ml, 1500 ml, 2500 ml and 3500 ml of water respectively and stirred to ensure that it was thoroughly mixed as recommended by AOAC (2005).

The different concentrations of GA_3 solution (0 ppm, 150 ppm, 250 ppm, and 35 ppm) were applied to the individual fingers of banana as T_o, T1, T2 and T3 respectively by dipping a whole fruit for 2 minutes and then air-drying. The control (T_o-0 ppm) was dipped in distilled water and air dried. In each variety GA_3 treated fruits were put into four packaging methods; perforated low density polyethylene film lining, nonperforated low density polyethylene film lining and vacuum polyethylene bag and also left in the open as control as (perf, unp, vac and NP) respectively and stored under cold and ambient storage conditions in three replications and monitored.

3.4 PARAMETERS

3.4.1 Colour

Green banana fruits were considered fully ripened when their peel colour completely changed from green to yellow colour. Peel colour of banana fruit was determined using a banana colour chart and was observed daily. Changes in colour of peel and pulp were also determined and recorded during the storage period. Seven stages of colour changes were characterized in banana colour chart; green, green-trace of yellow, green, green -trace of yellow, more green than yellow, more yellow than green, green tip, all yellow and yellow-flecked with brown colour.

3.4.2 Weight loss

The initial weights of the banana fingers were also taken using a digital balance. The physiological loss in weight (PLW) was measured as the loss of weight in grams in relation to initial weight and expressed as percentage. During storage, the fruits were weighed every day sample by sample and their weight recorded in order that weight loss can be estimated. The difference between initial and final weight was considered as total weight loss (%) during the storage interval.

Both temperature and relative humidity of the both storage environments (cold and ambient environments) were also recorded throughout the period with a portable data logger model EL-USB 110674 manufactured in the USA.

3.4.3 Firmness

A mechanical property such as firmness of the whole fruit was determined. The samples were placed on a lateral surface of a fixed table and the puncture test was carried out by puncturing the fruit at the middle, stem end and the end of the fruit and the readings recorded and averaged. Firmness values were expressed when the maximum force needed till tissue failure evaluating the penetrometric hardness of the whole fruit. The firmness of the fruit was determined using a hand held penetrometer (model 65104, China) and values were expressed in kg cm^{-2}.

3.4.4 Total soluble solids (TSS)

The total soluble solids (TSS) were determined using a Refractometer (model HI 96801, China). The fruit was peeled and sliced into an electric blender made in Japan. After weighing the pulp, distilled water was added to top up to 100 g before it was blended. Distilled water was used to clean the Refractrometer before standardising to zero. Three drops of the sample pulp juices was dropped on a table top Refractrometer and the readings recorded three times, and then mean values calculated. This process was carried out thrice for each sample and readings recorded.

3.4.5 Titratable acidity (TTA) and pH

Assessment of pH and titratable acidity (TTA) of banana was used mainly to estimate consumption quality and hidden qualities. They are considered as indicators of fruit maturity and or ripeness. The pH values from the filtrate of the pulp samples already obtained were determined using a pH electrode (metre) model A131509092 manufactured in the USA at a temperature of 25°C. The filtrate was put in a small plastic bottle and the rod of the pH metre dipped into the filtrate until the reading became stable. The process was done three times for each sample and mean pH values calculated. Total titratable acidity of the filtrate from the fruit samples was determined by titrating the sample with sodium hydroxide to the phenolphthalein end point and calculating acid present as malic acid, which was obtained by titrating 10 ml of the juice in 0.1N NaOH three times till the pink end point persisted for 15 s (Hailu, *et al.*, 2012). 10 ml the banana filtrate was measured into three separate conical flask and three drops of phenolphthalein were added to each flask. A titrating burette was filled with sodium hydroxide and initial reading recorded as initial titre value. The mixture was gently titrated into the flask which was gently and simultaneously shaken until the mixture in the flask turned pink. The titration was then stopped then the reading taken as final titre value then the difference between the two values found and the process was repeated for the remaining two flasks until all samples were done.

3.4.6 Shelf life

The shelf life of the banana fruits was calculated by counting the days required for them to attain the last stage of ripening, but up to the stage when they still remained acceptable for marketing. The fruit shelf life was determined at the completely yellow ripened stage using banana colour chart as a guide. Changing of the peel colour to yellow is an indication of banana ripening. In the colour chart, it is represented by stage 6 (all yellow) however; stage seven marked the end of the shelf life of the banana fruits (see appendix 2).

3.5 DATA COLLECTION AND STATISTICAL ANALYSIS

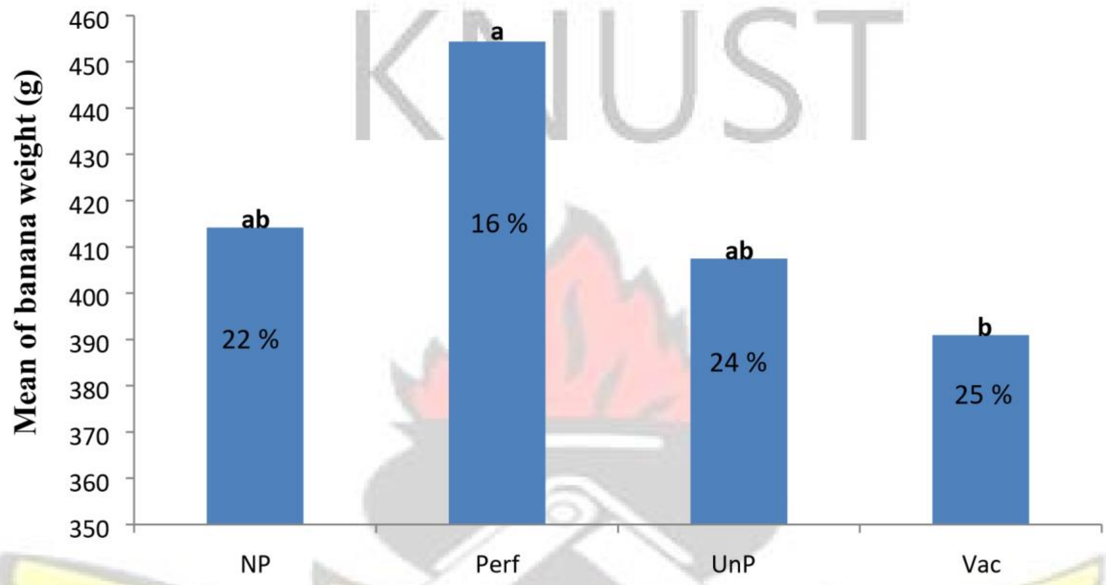
All data were collected according to the ripening stages of banana for the determination of physical and chemical qualities of the fruits except fruit weight, temperature and relative humidity that were recorded on daily basis. Data on the chemical properties as well as firmness of banana were taken from sample banana fruits meant for destructive analysis during the storage period. The data were processed using analysis of variances (ANOVA) techniques based on completely randomised design (CRD) with the aid of statistix software version 9.1. The probability value P = 0.01 was used to test for significant differences of the results and mean separated using Tukey's Honest Significant Difference (HSD).

CHAPTER FOUR

4.0 RESULTS

4.1 WEIGHT LOSS

There were significant differences (p = 0.01) among the various packaging methods for fruit weight as banana in perforated low density polyethylene lining retained more weight. Banana packaged in vacuum bags lost the most weight (Figure 4.1). Similarly, bananas that were subjected to cold storage retained significantly more weight while banana in ambient condition lost more weight. There were also significant differences (p = 0.01) in weight loss as well as GA_3 x packaging x storage interaction (Table 4.1).



Packaging Figure 4.1: Effect of packaging on the weight loss of banana NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 4.1: Effect of GA_3 and packaging on the weight loss of Cavendish banana stored under different environments (%).

Pre -treatment		**Storage**	**Condition**	
GA_3	**Package**	**Cold**	**Ambient**	**Mean**
0 ppm	No package	334.67bc	417.45ab	
	Perforated	425.86ab	418.33ab	
	Unperforated	473.81ab	417.71ab	
	Vacuum	381.66bc	417.37ab	20.99bc
150 ppm	No package	449.39ab	425.66ab	
	Perforated	419.59ab	408.72ab	
	Unperforated	456.46ab	423.06ab	
	Vacuum	399.01ab	411.22ab	18.95ab
250 ppm	No package	453.69ab	364.13abc	
	Perforated	450.01ab	351.79bc	
	Unperforated	365.54bc	368.75bc	
	Vacuum	372.07bc	346.33bc	
350 ppm	No package	392.41bc	422.23ab	
	Perforated	574.66a	414.79ab	
	Unperforated	424.27ab	415.09ab	15.99ab

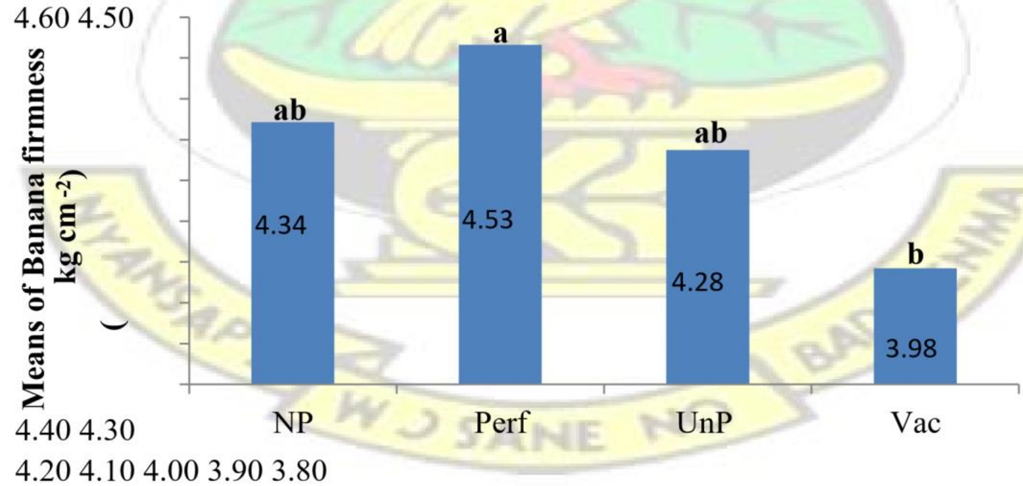
	Vacuum	406.07ab	393.59bc	7.89a
Mean		5.79a	20.74b	
CV		27.99		

HSD 1% GA_3 = 73.07; Packaging = 73.07; Storage = 42.59; GA_3x Packaging x Storage = 273.82

HSD.

4.2 FRUIT FIRMNESS

There were significant differences among the various packaging methods for firmness of banana fruits (Figure 4.2). Fruit firmness varied from 3.98 kg cm^{-2} to 4.34 kg cm^{-2}. There were also significant differences in firmness among GA_3 treated banana fruit firmness. Banana fruit firmness varied from 4.01kg cm^{-2} to 4.57 kg cm^{-2}. In the same way, banana stored in cold condition were significantly firmer than banana stored in ambient environment. There were no significant differences for GA_3 x packaging x storage interaction for firmness of banana fruits (Table 4.2).



HSD = Honest significant difference, ppm = part per million CV = Co-efficient of variation

Means with different letters within a column are significantly different at 1 % using

3.70

Packaging Figure 4.2: Effect of packaging on the firmness of banana

NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 4.2: Effect of GA_3 and packaging on the firmness of Cavendish banana stored under different environments (kg cm^{-2})

Pre-treatment		**Storage**	**Condition**	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	4.24a	4.23a	
	Perforated	4.96a	4.42a	
	Unperforated	4.03a	4.79a	
	Vacuum	4.43a	4.00a	4.01b
150 ppm	No Pack	4.37a	4.46a	
	Perforated	4.26a	4.52a	
	Unperforated	4.95a	4.63a	
	Vacuum	4.02a	4.25a	4.12ab
250 ppm	No Pack	4.73a	4.36a	
	Perforated	3.96a	3.93a	
	Unperforated	4.22a	4.06a	
	Vacuum	3.91a	3.79a	4.43ab
350 ppm	No Pack	3.93a	4.43a	
	Perforated	5.52a	4.10a	
	Unperforated	4.06a	4.07a	
	Vacuum	3.72a	3.76a	4.57a
Mean		4.53a	3.24b	
CV		9.06		

HSD 1% GA_3 = 0.46; Packaging = 0.46; Storage = 0.26; GA_3 x Packaging x Storage = 1.85

HSD = Honest significant difference, ppm = part per million

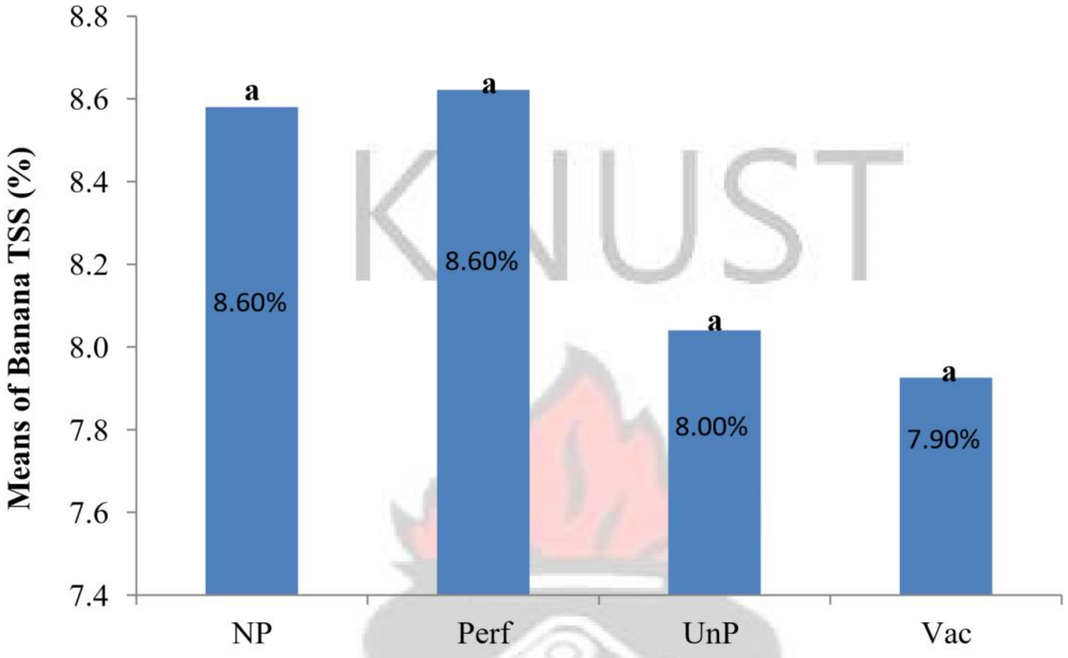
CV = Co-efficient of variation

Means with different letters within a column are significantly different at 1 % using HSD.

4.3 TSS OF BANANA

There were no significant differences among the various packaging methods for TSS of banana fruits (Figure 4.2). Banana fruit TSS ranged from 7.90 % to 8.60 %. There were significant differences among treatments for banana TSS as high concentration of GA_3 application revealed high TSS (8.51 %). There were also significant differences between storage conditions with banana in cold storage performing better. Cold storage had a higher TSS level (8.55 %), significantly greater than ambient storage condition.

However, there were no significant differences for GA_3 x packaging x storage interaction for TSS of banana fruits.



Packaging Figure 4.3: Effect of packaging on the TSS of banana

NP- No pack; Perf- Perforated film lining; Unp- Unperforated; Vac = Vacuum

Table 4.3: Effect of GA_3 and packaging on the TSS of Cavendish banana stored under different environments (%).

Pre-treatment		**Storage**	**Condition**	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	9.16a	8.79a	
	Perforated	7.80a	7.89a	
	Unperforated	8.53a	8.48a	
	Vacuum	7.94a	7.55a	8.27abc
150 ppm	No Pack	8.57a	8.29a	
	Perforated	8.75a	8.29a	
	Unperforated	9.70a	8.85a	
	Vacuum	9.09a	8.35a	8.73ab
250 ppm	No Pack	9.21a	8.75a	
	Perforated	8.13a	7.44a	
	Unperforated	8.67a	8.00a	
	Vacuum	7.83a	7.18a	
	No Pack	8.26a	7.59a	
	Perforated	8.26a	7.80a	
				8.15ab
350 ppm				
	Unperforated	8.64a	8.12a	

	Vacuum	8.24a	7.23a	8.51a
Mean		8.55a	8.04b	
CV		8.19		

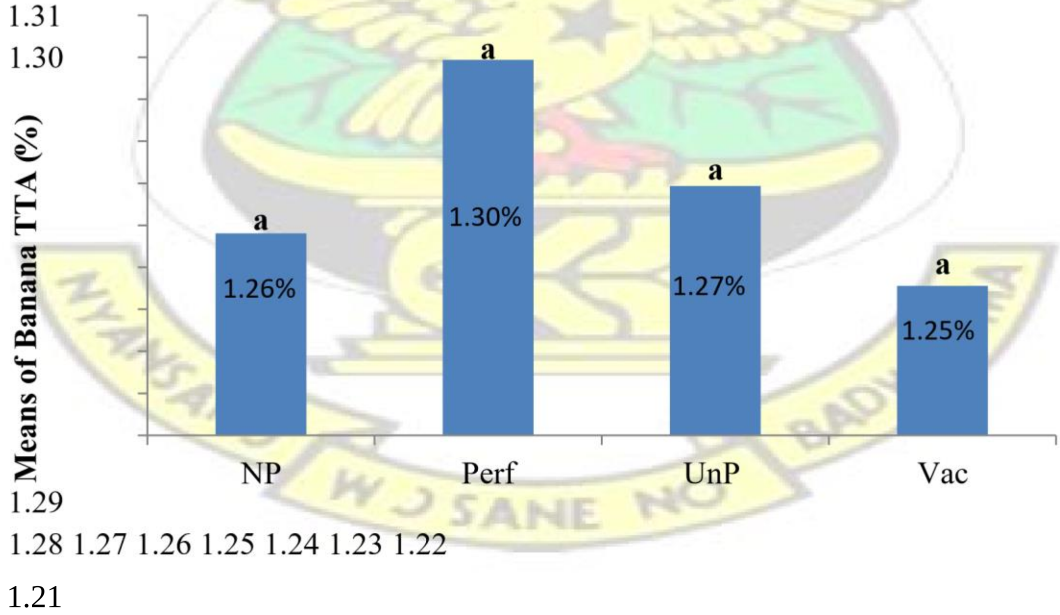
HSD 1% GA_3 = 0.81; Packaging = 0.81; Storage = 0.46; GA_3 x Packaging x Storage = 3.24

HSD = Honest significant difference, ppm = part per million CV = Co-efficient of variation.

Means with same letters within a column are not significantly different at 1 % using HSD.

4.4 TTA OF BANANA

There were no significant differences among the various packaging methods for TTA of banana fruits (Figure 4.4). Banana fruit TTA ranged from 1.25 % to 1.30 %. There were significant differences among treatments for banana TTA with 150 ppm and 350 ppm (1.32 %) and (1.31 %) respectively showing significantly higher TTA values. However, there were no significant differences between storage conditions. There were no significant differences for GA_3 x packaging x storage interaction for TTA of banana.



Packaging Figure 4.4: Effect of packaging on the TTA of banana

NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 4.4: Effect of GA_3 and packaging on the TTA of Cavendish banana stored under different environments (%).

Pre-treatment		Storage	Conditions	
GA₃	Package	Cold	Ambient	Mean
0 ppm	No Pack	1.22a	1.27a	
	Perforated	1.20a	1.21a	
	Unperforated	1.19a	1.20a	
	Vacuum	1.04a	1.05a	1.17b
150 ppm	No Pack	1.29a	1.23a	
	Perforated	1.45a	1.45a	
	Unperforated	1.26a	1.23a	
	Vacuum	1.32a	1.34a	1.32a
250 ppm	No Pack	1.20a	1.19a	
	Perforated	1.32a	1.29a	
	Unperforated	1.28a	1.28a	
	Vacuum	1.31a	1.34a	1.27ab
350 ppm	No Pack	1.34a	1.35a	
	Perforated	1.22a	1.28a	
	Unperforated	1.33a	1.40a	
	Vacuum	1.31a	1.28a	1.31a
Mean		1.26a	1.27a	
CV		8.22		

HSD 1% GA_3 = 0.12; Packaging = 0.12; Storage = 0.07; GA_3 x Packaging x Storage = 0.5

HSD = Honest significant difference, ppm = part per million CV = Co-efficient of variation.

Means with different letters within a column are significantly different at 1 % HSD.

4.5 PULP PH

There were no significant differences among the various packaging methods for pH of banana fruits (Figure 4.5). Banana pH ranged from 4.90 % to 5.11 %. There were significant differences among treatments for banana pH with GA_3 0 ppm fruits recording a significantly high value (5.30 %). There were no significant GA_3 x packaging x storage interaction for pulp pH of banana being significantly different.

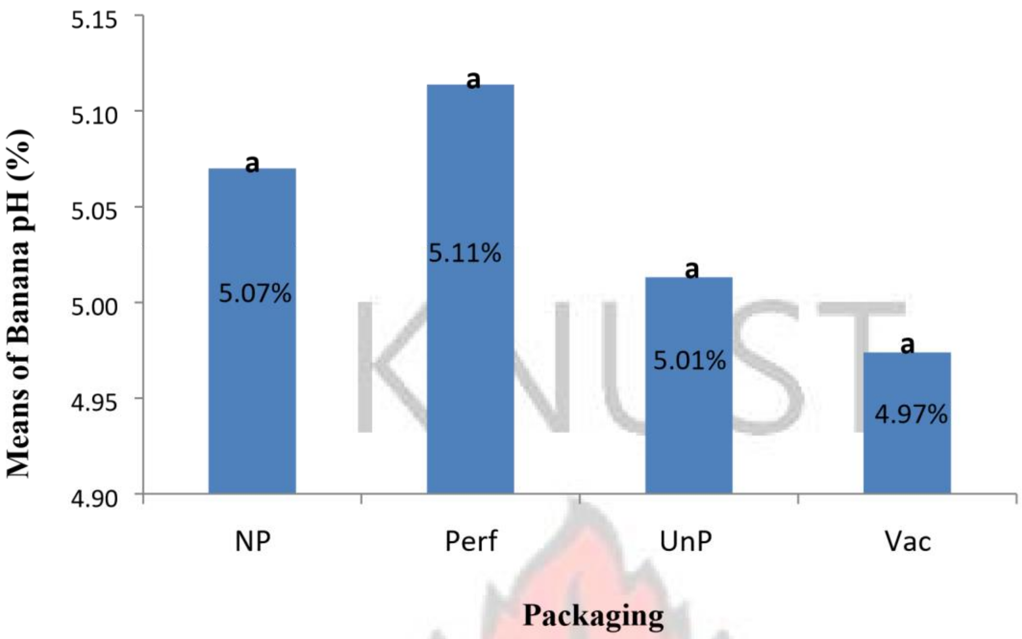


Figure 4.5: Effect of packaging on the pH of banana (%)

NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 4.5: Effect of GA_3 and packaging on the pulp pH of Cavendish banana stored under different environments (%).

Pre-treatment		**Storage**	**Condition**	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	5.28abc	5.31ab	
	Perforated	5.45a	5.30ab	
	Unperforated	5.33ab	5.33ab	
	Vacuum	5.22abc	5.23abc	5.30a
150 ppm	No Pack	5.16abc	5.16abc	
	Perforated	5.06abc	5.05abc	
	Unperforated	4.95abc	4.95abc	
	Vacuum	4.84abc	4.83abc	5.02b
250 ppm	No Pack	5.05abc	5.06abc	
	Perforated	4.86abc	4.85abc	
	Unperforated	4.83abc	4.81bc	
	Vacuum	4.66c	4.66c	4.99bc
350 ppm	No Pack	4.77bc	4.75bc	
	Perforated	5.22abc	5.37ab	
	Unperforated	4.77bc	4.84abc	
	Vacuum	5.22abc	5.23abc	4.85c
Mean		5.04a	5.04a	
CV		2.6		

HSD 1% GA_3 = 0.16; Packaging = 0.16; Storage = 0.09, GA_3 x Packaging x Storage= 0.63

HSD = Honest significant difference, ppm = part per million CV = Co-efficient of variation.
Means with different letters within a column are significantly different at 1 % using HSD.

4.6 BANANA SHELF LIFE

Shelf life of banana fruits varied from 5 days to 21 days in which significant differences among the various packaging methods for shelf life were shown (Figure 4.5). There were also significant differences among treatments for shelf life with concentration at 350 ppm significantly showing longer shelf life (21 days). Significant differences for GA_3 x packaging x storage interaction for shelf life of banana were also revealed. Banana stored in cold environment also showed significant shelf life lasting up to 21 days in storage as compared to 11 days in ambient storage.

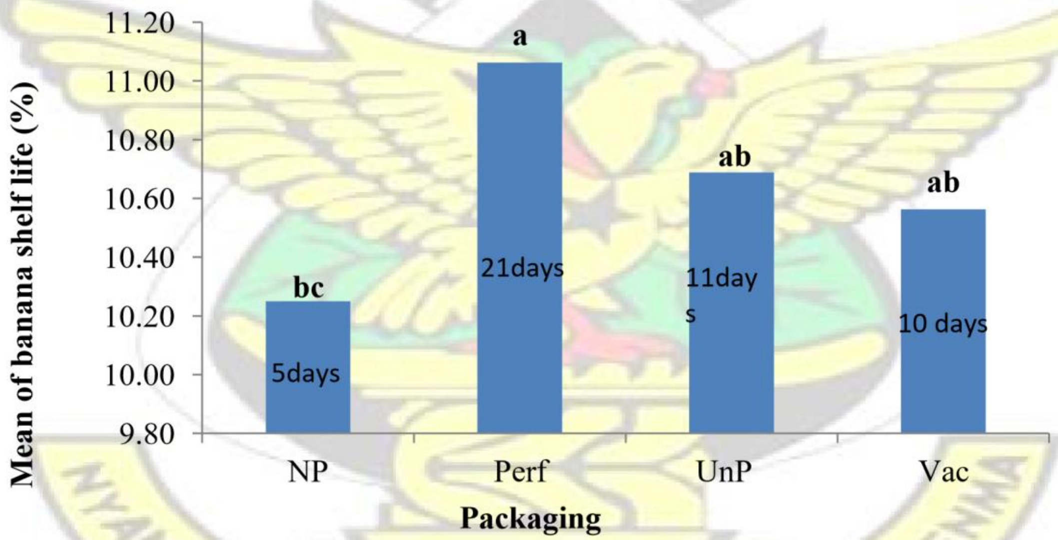


Figure 4.6: Effect of packaging on the shelf life of banana (days)
NP = No packing; Perf = Perforated film lining; Unp = Unperforated; Vac= Vacuum

Table 4.6: Effect of GA_3 and packaging on the shelf life of Cavendish banana stored under different environments (days).

Pre-treatment		Storage	Condition	
GA_3	**Package**	**Cold**	**Ambient**	**Mean**
0 ppm	No package	10.00cdef	5.50f	
	Perforated	7.50def	7.00ef	
	Unperforated	7.50def	5.50f	

	Vacuum	8.00def	5.50f	5c

250 ppm	No package			
	Perforated			
	Unperforated			
	Vacuum			
350 ppm	No package			
	Perforated			
	Unperforated			
	Vacuum			
150 ppm	No package	14.50abcd	5.50f	
	Perforated	13.50abcde	7.50def	
	Unperforated	12.50bcdef	6.00f	
	Vacuum	14.50abcd	6.50ef	15b
		17.50ab	7.00ef	
		14.50abcd	14.50abcd	
		14.50abcd	14.50abcd	
		17.00abc	7.50def	19b
19.00ab 8.50def 20.00a 9.00def 18.50ab 9.50def				
		17.00abc	8.50def	21a
Mean		21a	9b	
CV		14.72		

HSD 1% GA_3 =1.87; Packaging = 1.87; Storage = 1.07; GA_3 x Packaging x Storage = 7.48

HSD = Honest significant difference, ppm = part per million CV = Co-efficient of variation.

Means with different letters within a column are significantly different at 1 % using HSD.

CHAPTER FIVE

5.0 DISCUSSIONS 5.1 EFFECT OF GA_3 AND PACKAGING ON THE COLOUR OF BANANA

STORED UNDER DIFFERENT CONDITIONS

The chlorophyll degradation changes in the peel colour from green to yellow was the most obvious change, which occurred during the ripening of bananas. This was as a result of loss of chlorophyll which served as a rough guide to the stage of ripeness.

Appearance or the peel colour is used as a guide of shelf life for retail distribution and texture is an important part of eating quality. External skin colour changed during ripening that reflected changes in pulp colour. Yellowing begun at or shortly after the climacteric peak and the fruit that were not put in any packaging material became fully yellow in less than seven days at the ambient storage similar to that observed by (Plainsirichai *et al.,* 2003). The disappearance of the green colour was due to the degradation of the chlorophyll structure. The main agents accountable for this degradation are pH changes (principally owing due the leakage of organic acids from the vacuole), oxidation systems and chlorophyllase activity. According to Yang *et al.* (2011), the loss of green colour depended on some of these factors that acted in sequence to destroy the chlorophyll structure. Colour changes in ripening fruits have been linked by consumer with the conversion of starch to sugar (i.e. sweetening) and the development of the appropriate characteristics, so that the right peel colour is usually all that is necessary for a choice to purchase the commodity (Salvador *et al*., 2006). Bananas that were dipped into 350 ppm of GA_3 showed the best ripening probably due to the longer time as ripening was gradual resulting in a complete yellowing. Also, perforated low density polyethylene linings showed the best performance in terms of ripening because the perforations allowed exchange of gases thus modified the environment surrounding the fruits. The cold storage condition was a better environment for desirable colour of banana.

5.2 EFFECT OF GA_3 AND PACKAGING ON THE PHYSICAL PROPERTIES OF BANANA STORED UNDER DIFFERENT CONDITIONS

5.2.1 Weight loss (%)

Weight loss of fruits is an unconditional requirement that occurs during ripening process. GA_3 retarded ripening of banana fruits but the effect of it differed based on the different concentrations. It was revealed that GA_3 concentration at 350 ppm had the highest significant effect on the fruit weight due to the relative delay in ripening. Because weight loss is linked to fruit ripening, the faster fruits ripen, the faster they lose weight. Bananas that were treated with GA_3 concentration (0 ppm) lost weight rapidly (the most weight lost, 20.99 %) as a result of rapid ripening. GA_3 concentration of (350 ppm) gave the best results (7.89 %) in losing less weight due to delayed ripening. This is so because, the faster the ripening process, the faster the weight loss of the fruit.

Packaging reduced ripening of banana fruits but the effect of it varied because of different packaging methods. Packaging also significantly affected banana weight as banana packaged in perforated low density polyethylene film lining recorded heavier weights (losing the least weight, 16 %) thus the best results. This was as a result of the fact that the perforations served as media through which exchange of gases occurred thus providing a modified surrounding to the fruits and diffusing ethylene gas that would have built up. However, bananas that were stored in vacuum bags had more accumulation of heat and ethylene resulting in rapid ripening. Therefore, temperature and relative humidity play very key roles in determining the amount of weight loss at storage and during ripening. Packaging banana in intact or perforated polyethylene packages or use of package film lining, result in high relative humidity inside the package and hence may reduce weight loss in the produce. Polymeric film packaging has been extensively used to reduce water loss and to enhance fruit quality (Osman, 2006).

The average temperature and relative humidity at ambient storage were 30^{o}C and 60 % respectively while it was 18^{o}C and 80 % respectively at cold storage. Cold storage environment played a major role in reducing weight loss. Fruits and vegetables are living, respiring tissues separated from their parent plant. Keeping product at their low temperature increased storage life by reducing respiration rate, reducing sensitivity to ethylene gas and limiting water loss. Hence banana in the cold storage performed best (5.79 %), resulting in significantly heavier fruits than bananas stored in ambient condition because the cold storage slowed down the rate of water loss as temperature was relatively low. Similarly, GA_3 x packaging x storage interaction also showed significant results as banana in 350 ppm in perforated lining stored under cold condition lost the least weight due to higher concentration of GA_3, improved condition around the fruits as well a relatively low temperature within the cold storage environment.

5.2.2 Banana firmness

As shelf life period progressed, firmness decreased from 4.53 kg cm^{-2} to 3.98 kg cm^{-2} across all treatments as texture of banana fruits is being softened by ripening. Application of GA_3 (350 ppm) contributed to the retention of fruit firmness for GA_3 (350 ppm) showed the best performance resulted in highest firmness 4.57 kg cm^{-2} which could be attributed to the fact that GA_3 delayed ripening in fruits which also affected softening during the ripening process resulting in firmer fruits. Similarly, banana in perforated low density polyethylene film lining had relatively firmer fruits at the end of the shelf life hence showed the best results 4.53 kg cm^{-2}. This was due to the perforations which altered the immediate surroundings of the fruits by allowing easy exchange of gases. After harvesting and during storage, the fruit continues to respire as physiological processes continue to occur. The perforations enabled carbon dioxide and ethylene to escape and that reduced the rate of respiration and metabolism within the fruit thereby reducing softening of fruits. Cold storage also showed positive effect (better storage environment) with firmness of 4.53 kg cm^{-2} as it decreased the pulp permeability and so reduced the rate of water loss resulting in delayed fruit ripening and reduced softening as compared to fruits that were in ambient conditions and this was also observed by Plainsirichai *et al*. (2003).

5.3 EFFECT OF GA_3 AND PACKAGING ON THE CHEMICAL PROPERTIES OF BANANA STORED UNDER DIFFERENT CONDITIONS

5.3.1 Total soluble solids (TSS)

TSS content of the banana in the study varied between 8.01 % and 8.01 % °Brix throughout the storage period. According to Haliu (2012), fruits such as banana, cooking banana and plantain, contain many compounds which are soluble in water including sugars acids, vitamin C, amino acids and some pectin. The conversion of starch into sugars is the most important change in ripening bananas and these soluble substances form the soluble content of banana. For many commodities such as banana, cooking banana and plantain, sugar constitutes the key element of soluble solids. Even though GA_3 application on bananas affected the TSS level, GA_3 350 ppm concentration revealed most significant and best results in TSS up to 8.51 %, probably due to longer storability which led to more sugar build up in the fruits. Fruits that were subjected to 0 ppm concentration of GA_3 however showed low TSS levels due to the short storability.

Similarly, banana in polyethylene film linings showed differences in TSS, banana in perforated low density polyethylene film lining showed the best results of 8.60 %. This was due to the perforations which improved the immediate surroundings of the fruits by allowing easy exchange of gases. Also, bananas that were exposed to the different storage conditions exhibited differences in TSS levels, banana that were subjected to cold storage showed better performance as they recorded significantly higher TSS of 8.55 % than ambient condition of 8.04 % due to the prolong stay of the fruits in the storage environment as longer shelf life could result in more sugar accumulation even though there were no significant effects. During the ripening process, starch content of bananas is hydrolysed into soluble sugars such as glucose, sucrose and fructose which also increase the total soluble solids content of fruits. This suggests that the TSS levels could increase further given a much longer storage period in low temperature (Yang *et al.,* 2009a).

5.3.2 Titratable acidity (TTA)

The study revealed that TTA varied from 1.17 to 1.31 % among fruits treated with GA_3 during the storage period. Although the use of GA_3 showed diverse effects, significant effects can be seen with GA_3 (350 ppm) and GA_3 (150 ppm) showing best results 1.31 % and 1.32 % respectively because as pulp pH reduced, TTA increased. Again, TTA of banana increased during the period of ripening and decreased later during the senescence period as some fruits, like banana, have the maximum amount of organic acids at their complete ripeness. Zomo *et al.* (2014) reported that decrease in titratable acidity during the period of ripening may be attributed to the utilization of organic acids in various bio-degradable reactions. The increase in metabolic activities and formation of sugars during the senescence period led to decrease in the acid concentrations. However, packaging and storage conditions did not significantly affect the TTA in this study (see appendix 1). Similarly, there were no significant GA_3 x packaging x storage interaction for TTA.

5.3.3 Banana pulp pH

From the study, it was revealed that the use of GA_3 affected the pH levels of banana. GA_3 concentration of (0 ppm) recorded the highest pH level of 5.30 % hence showing significant variation among them. This may be due to changes in fruit malic acid content that is a dominant acid especially in Cavendish banana. This result was similar to findings made by Hailu *et al.* (2012) that pH of banana tissue got accelerated when put in 0.2 % GA_3 solution. The pH could be related to titratable acidity where higher pH results in lower titratable acidity. Significantly low pH was recorded in treatment GA_3 350 ppm due to the reverse effect of GA_3 (see appendix 1).

Packaging on the other hand did not affect banana, hence there were no significant effects among packaging methods even though pH varied from 4.97 to 5.11 %. GA_3 0 ppm packaged in perforated low density polyethylene film lining stored at cold environment showed the best performance though not significant. This was due to the absence of GA_3 in the fruits as stated earlier. However, there were significant difference for 0 ppm GA_3 x perforated low density lining interaction effect recorded for pH revealing best performance of 5.45 % during the study due to the combined effect of the absence of GA_3 and the improved condition around the fruits.

5.4 SHELF LIFE

Use of GA_3 prolonged shelf life of fruits as it delayed ripening as indicated earlier. The research revealed that significant GA_3 effect was observed for the shelf life of banana with concentration of 350 ppm showing the longest shelf life of 13.75 %. GA_3 is known to reduce tissue permeability of banana; coupled with the lower temperature and higher relative humidity might have slowed down the physiological activities such as respiration in the fruit and thus reduced the rate of water loss resulting in delayed fruit ripening as reported by Ahmed *et al.* (2006).

Shelf life exhibited the best significant results to packaging methods with perforated film lining recording the longest shelf life 11.06 %. This was because ethylene gas was not trapped in the package unlike the vacuum bag or unperforated film lining where there was a high build-up of ethylene which negatively affected the life of the fruits by accelerating rapid ripening of banana. Similarly, highly significant difference was observed for banana in cold storage lasting up to 21 days in the cold storage environment translating to 14.13 % thus proving better performance as compared to a maximum of 11 days or 7.16 % in ambient storage. Fruits and vegetables are living and respiring tissues separated from the parent plants. Keeping these produce in low temperature extends the shelf life by reducing respiration rate, lessening sensitivity to ethylene gas and lowering water loss and this occurred in the cold storage condition.

The results (Table 4.6) also showed highly significant GA_3 (350 ppm) x packaging x storage interaction resulting in the best and longest storability as GA_3 (350 ppm) x packaging x cold storage (20.0 %) proved to be the best in extending usable period of banana under this study in the cold storage environment (see appendix 1). This was attributed to the combined effects of high concentration of GA_3, perforations in the linings that altered the condition on the surface of the fruits and the low temperature in the cold storage environment that reduced the various physiological activities of the fruits.

5.5 SOFTENING AND GREEN RIPENING

Softening of fruits is related to a change in the cell well component and starch conversion. The starch granules, packed in the tissue of banana pulp gives rise to the toughness of the unripe fruit, and are hydrolysed to sugar while an increase in the cell wall solubility allows water and nutrients to pass in and out of the cells. Banana firmness reduced steadily during the full ripening stage. It may occur during that period all the starch will be absolutely hydrolysed to sugars (Osman, 2006).

Reduced green-life period of stored bananas as a result of low relative humidity has been described by some other researchers. Generally, water deficit triggers ethylene production which causes earlier climacteric respiring rise (Du *et al.,* 2014). In this experiment, the bananas were stored in ambient condition at a temperature of 32^{o}C and

60 % and while in cold storage temperature and relative humidity of 18^oC and 73 % respectively. These conditions (temperatures and humidity) adversely impacted on the storability of the banana because the optimal temperature and relative humidity for successful banana ripening are 14^oC and 98 % respectively. High temperatures result in green ripening as was observed in this study. The chlorophyll degradation patterns in green-ripening of banana represent an anomaly in the context of normal fruit ripening but not under agreeable temperature (30^oC). In addition, it is also reported that the conversion of chlorophyll occurred prior to degradation and enzyme responsible for the conversion has been identified as non-yellow colouring (NYC) or chlorophyll reductasee (Yang *et al*., 2009a).

The loss of green colour is also due to the degradation of the chlorophyll structure. The major agents responsible for this degradation are pH changes (principally due to leakage of organic acids from the vacuole), oxidation systems and chlorophyllase activity. Loss of green colour depends on one or more of these factors acting in sequence to destroy the chlorophyll structure. Yang *et al*. (2009a) reported that chlorophyllase activity in banana peel increases sharply at the onset of the climacteric peak, and then falls to near zero in the post-climacteric period. Fruits such as bananas are ripened at higher than optimum temperature, full loss of green colour does not occur even though the flesh is ripened. Banana ripening during storage is often linked to the enzymatic breakdown of cell wall materials (Osman, 2006).

However, it is still not clear how chlorophyll breakdown is measured in other progressive phases or when plants react to environmental and non-environmental stresses. Green-ripening in fruit seems to be unusual, as associated with several different produce, including some species in the Musaceae family. And the retention of chlorophyll mainly located on top of the peel of banana, resulting in greenish yellow exterior of the fruit (Plainsirichai *et al.*, 2003).

However, storage in controlled atmospheric conditions increased storability of bananas compared to storage in normal air. Ideally, at temperatures of 13°C and 15°C reduced respiration occurs resulting in higher firmness, lower weight loss and delayed yellowing compared to fruits under storage in normal air. In this study, the temperature in the controlled storage was between 18 ^{o}C and 22 ^{o}C and relative humidity of 68 -80 % as shown in table 11 below. These conditions resulted in a much better performance in terms of storability lasting up to 21 days as well as better quality of ripening and firmness among others. But green ripening still occurred in some few samples as compared to those stored in the ambient condition that had relatively more green-ripened fruits.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

It was concluded from the study that;

- GA_3 concentration at 350 ppm and perforated polyethylene lining improved the physicochemical properties as well as prolonged shelf- life of banana up to 21 days in cold storage.
- GA_3 concentration at 350 ppm proved to be the best in enhancing firmness, fruit weight and prolonging shelf- life of banana up to 21 days in cold storage.
- Use of perforated low density film lining also proved to be the best in enhancing physicochemical properties and extending shelf life of banana up to 21 days for cold storage.
- Use of perforated low density film lining at 350 ppm of GA_3 under cold storage was the best in enhancing the physicochemical properties and prolonging shelf life banana up to 21 days.

6.1 RECOMMENDATIONS

At the end of the study, it was recommended that;

- Producers, traders or consumers may use the technology in order to enhance the shelf life of banana while maintaining good chemical qualities of the fruits for safe consumption.
- Further research work could be done using much lower temperature to determine the extent to which shelf life can be prolonged further in order that losses can be drastically reduced so as to ensure food security thus improving the livelihood of farmers and consumers. This could also limit green ripening of banana which is an undesirable quality with respect to marketability.

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APPENDICES

APPENDIX 1

Statistix 9.1 29/04/2016, 02:58:30

Analysis of Variance Table for Weight

Source	**DF**	**SS**	**MS**	**F**	**P**
GA3	3	44860	14953.3	1.14	0.0049
Packaging	3	28446	9482.1	0.72	0.0009
Storage	1	12967	12966.6	0.99	0.0017
GA3*Packaging	9	50065	5562.8	0.42	0.9209
GA3*Storage	3	26805	8934.9	0.68	0.5650
Packaging*Storage	3	14988	4995.9	0.38	0.0247
GA3*Packaging*Storage	9	54145	6016.1	0.46	0.0004
Error	160	2099576	13122.4		
Total	191	2331852			

Grand Mean 409.23 CV 27.99

Statistix 9.1 04/05/2016, 17:50:53

Analysis of Variance Table for Firmness

Source **DF** **SS** **MS** **F** **P** GA3

3 3.3215 1.10718 7.35 0.0007 packaging

3 2.4817 0.82722 5.49 0.0037 storage

1 0.1388 0.13876 0.92 0.0042 GA3*packaging 9

2.3342 0.25935 1.72 0.1243 GA3*storage 3

0.8133 0.27109 1.80 0.1669 packaging*storage 3

0.2463 0.08211 0.55 0.6548

GA3*packaging*storage 9 0.4645 0.05161 0.34 0.9532

Error 32 4.8175 0.15055

Total 63 14.6177

Grand Mean 4.2837 CV 9.06

Statistix 9.1 04/05/2016, 12:56:55

Analysis of Variance Table for TSS **Source** **DF** **SS** **MS** **F** **P** GA3

3 4.6986 1.56619 3.40 0.0095 packaging

3 6.1761 2.05871 4.47 0.0299 storage

1 4.1820 4.18202 9.08 0.0050 GA3*packaging 9

5.5731 0.61923 1.34 0.2542 GA3*storage 3

0.5991 0.19970 0.43 0.7305 packaging*storage 3

0.2225 0.07415 0.16 0.9218

GA3*packaging*storage 9 0.3675 0.04083 0.09 0.9997

Error 32 14.7435 0.46073

Total 63 36.5623

Grand Mean 8.2909 CV 8.19

Statistix 9.1 04/05/2016, 12:58:05

Analysis of Variance Table for TTA

Source DF SS MS F P GA3

3 0.22156 0.07385 6.80 0.0011 packaging

3 0.02535 0.00845 0.78 0.5151 storage

1 0.00090 0.00090 0.08 0.7754 GA3*packaging

9 0.24926 0.02770 2.55 0.0247 GA3*storage

3 0.00516 0.00172 0.16 0.9235 packaging*storage

3 0.00073 0.00024 0.02 0.9954

GA3*packaging*storage 9 0.01211 0.00135 0.12 0.9988

Error 32 0.34770 0.01087

Total 63 0.86278

Grand Mean 1.2681 CV 8.22

Statistix 9.1 04/05/2016, 12:14:11

Analysis of Variance Table for Mean of pH

Source DF SS MS F P GA3

3 1.75613 0.58538 34.02 0.0000 packaging

3 0.17916 0.05972 3.47 0.0274 storage 1

0.00010 0.00010 0.01 0.9397 GA3*packaging 9

1.30631 0.14515 8.43 0.0000 GA3*storage 3

0.01426 0.00475 0.28 0.8421 packaging*storage 3

0.02324 0.00775 0.45 0.7190

GA3*packaging*storage 9 0.04815 0.00535 0.31 0.9656

Error 32 0.55070 0.01721

Total 63 3.87804

Grand Mean 5.0416 CV 2.60

Statistix 9.1 30/04/2016, 23:28:16

Analysis of Variance Table for Shelf Life

Source DF SS MS F PGA3

3 382.42 127.474 51.96 0.0000 packaging 3

5.42 1.807 0.74 0.0009 storage 1 777.02

777.016 316.75 0.0000 GA3*packaging 9 13.14

1.460 0.60 0.7912 GA3*stor age 3 123.92

41.307 16.84 0.0000 packaging*storage 3 23.17

7.724 3.15 0.0384

GA3*packaging*storage 9 7.14 0.793 0.32 0.9610

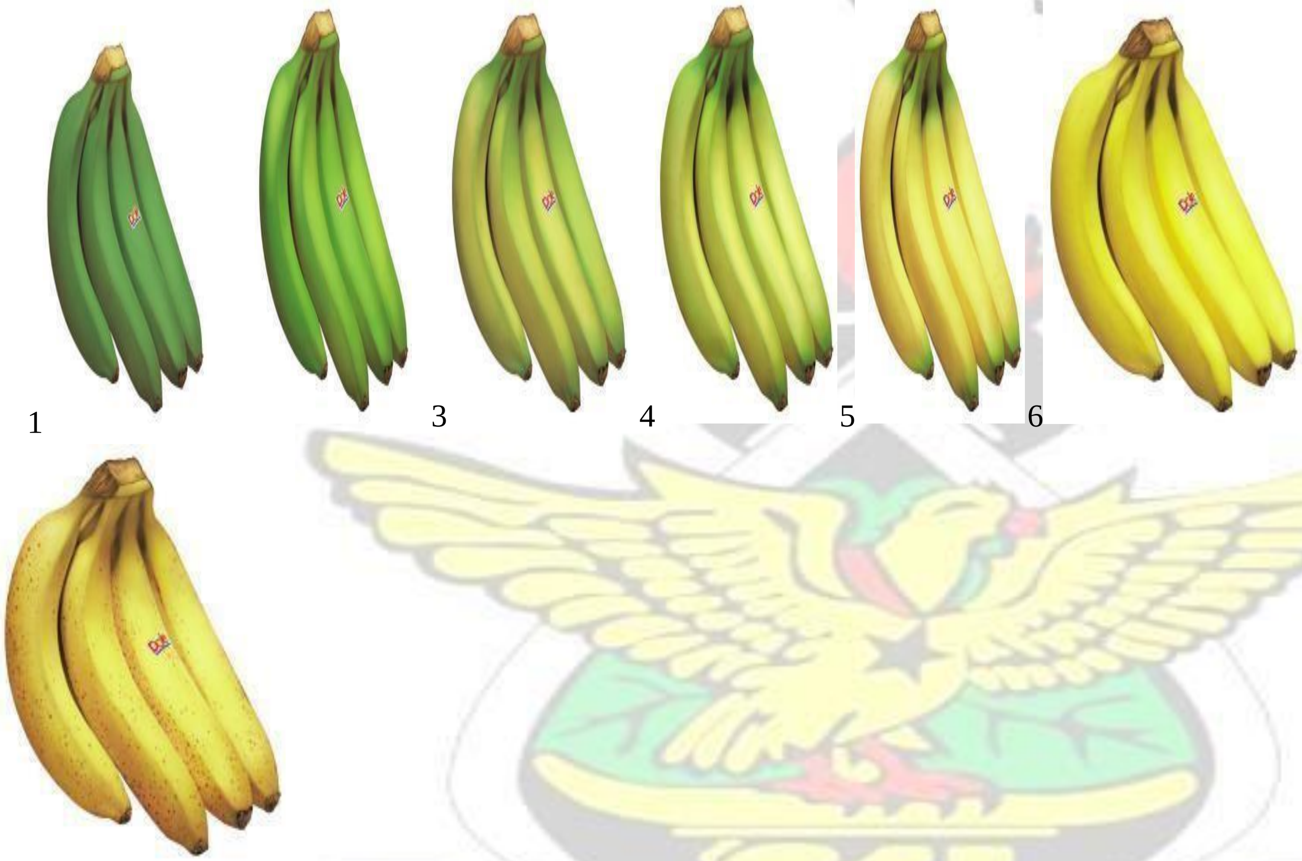
Error 32 78.50 2.453

Total 63 1410.73

Grand Mean 10.641 CV 14.72

APPENDIX 2

Banana Colour Chart



ALL GREEN LIGHT GREEN 50% GREEN, MORE YELLOW YELLOW WITH FULL YELLOW YELLOW FLECKED

50% YELLOW THAN GREEN GREEN TIPS WITH BROWN

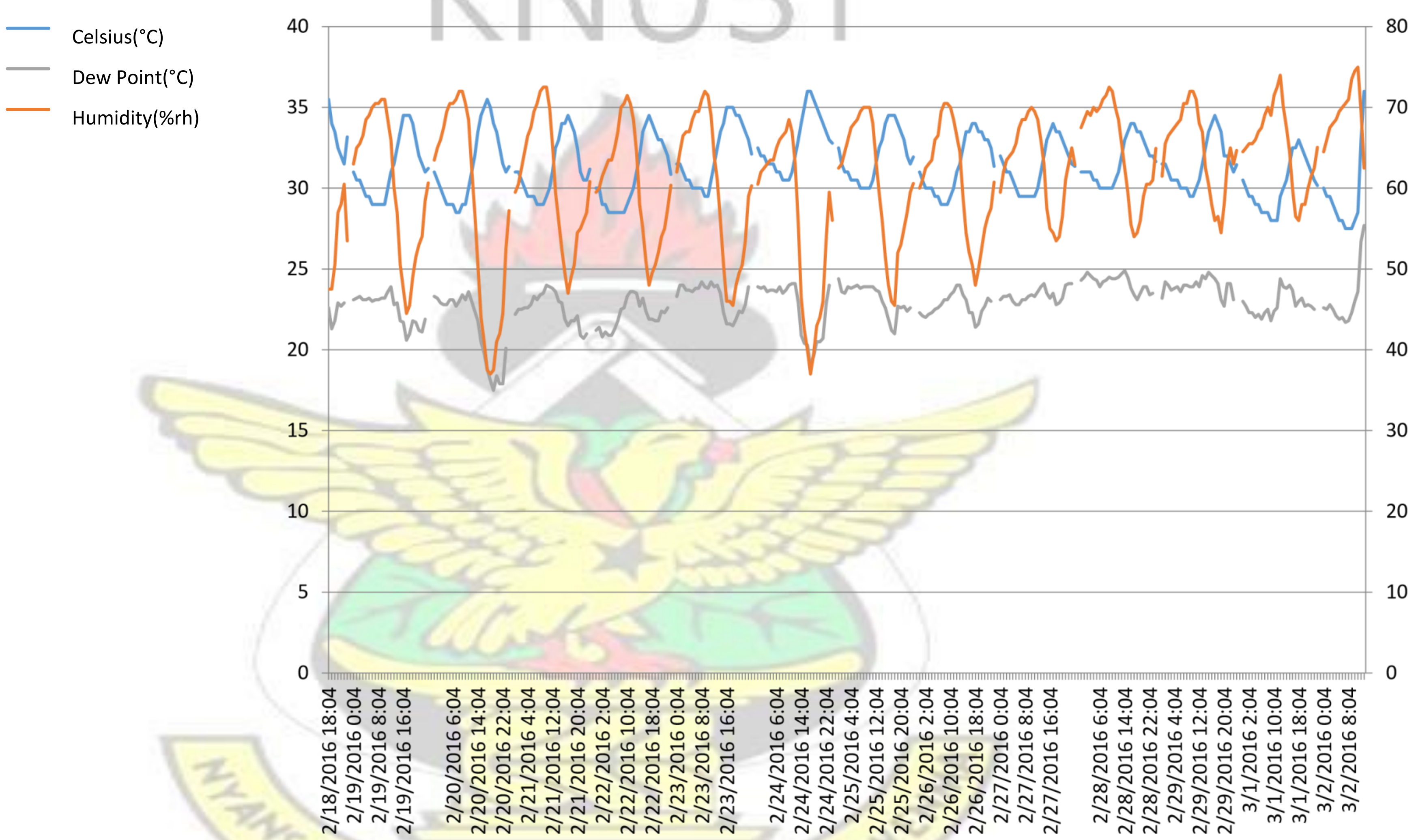
Table 4.7: Effect of temperature and relative humidity on shelf life during ambient storage of banana varieties

Temperature and relative humidity in days after storage											
Temp(^{O}C)	33.17	31.23	31.33	31.19	30.85	32.79	31.94	31.35	31.35	31.65	31.46
RH (%rh)	53.5	60.67	57.23	60.83	60.35	56.04	60.58	60.75	62.92	64.92	64.69

Table 4.8: Effect of temperature and relative humidity on shelf life during cold storage of Cavendish banana.

Temperature and relative humidity in days after storage

Temp(^{O}C)	19.4	18.9	19.4	20	20.3	20	19.1	22.3	20.4	19.7	21.1	22.2	20	21.3	23.5	21.6	20	20.2	21.1	22
RH (% rh)	75.7	80.1	76.9	74.5	74.7	70.1	76.8	70	73.9	75.9	72	70.7	74	73.6	67.5	68.9	71.2	72.2	71.9	68.8



Celsius(°C)
Dew Point(°C)
Humidity(%rh)
40
35
30
25
20
15
10
5
0
80
70
60
50
40
30
20
10
0
2/18/2016 18:04
2/19/2016 0:04
2/19/2016 8:04
2/19/2016 16:04
2/20/2016 6:04
2/20/2016 14:04
2/20/2016 22:04
2/21/2016 4:04
2/21/2016 12:04
2/21/2016 20:04
2/22/2016 2:04
2/22/2016 10:04
2/22/2016 18:04
2/23/2016 0:04
2/23/2016 8:04
2/23/2016 16:04
2/24/2016 6:04
2/24/2016 14:04
2/24/2016 22:04
2/25/2016 4:04
2/25/2016 12:04
2/25/2016 20:04
2/26/2016 2:04
2/26/2016 10:04
2/26/2016 18:04
2/27/2016 0:04
2/27/2016 8:04
2/27/2016 16:04
2/28/2016 6:04
2/28/2016 14:04
2/28/2016 22:04
2/29/2016 4:04
2/29/2016 12:04
2/29/2016 20:04
3/1/2016 2:04
3/1/2016 10:04
3/1/2016 18:04
3/2/2016 0:04
3/2/2016 8:04