EFFICACY OF WAXING INNOVATIONS TO EXTEND SHELF LIFE AND PRESERVE POSTHARVEST QUALITY OF MANGO FRUITS

BY

MAINA BENSON

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Department of Plant Science and Crop Protection

Faculty of Agriculture

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other University.

Maina Benson

Signature…….…… Date…….

This Thesis has been submitted with our approval as University supervisors

SUPERVISORS

Prof. Jane Ambuko

Department of Plant Science and Crop Protection

University of Nairobi

Signature……. Date……

Prof. Margaret Hutchinson

Department of Plant Science and Crop Protection

University of Nairobi

Signature ……. Date ……

Prof Willis Owino

Department of Food Science and Technology

Jomo Kenyatta University of Agriculture and Technology

Signature…… Date …….

DEDICATION

I dedicate this work to my parents Mr. John Kipanga and Mrs. Susana Mukundi for their love and support in my academics.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEZ Agro-ecological Zones

ANOVA Analysis of Variance

AOAC Association of Official Analytical Chemists

CA Controlled Atmosphere

FAO Food Agricultural Organization

GAP Good Agricultural Practice

GDP Gross Domestic Product

Ha Hectares

HCDA Horticultural Crop Development Authority

HPLC High Performance Liquid Chromatography

Ksh Kenya Shillings

LSD Least Significance Difference

MAP Modified Atmosphere Packaging

1-MCP Methylclyclopropene

SSA Sub Saharan Africa

TSS Total Soluble Solids

TTA Total Titratable Acidity

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ABSTRACT

Mango *(Mangifera Indica* L.) is one of the major fruits produced in Kenya mostly for the domestic market, and to a small extend for export markets. Mango is widely adapted to different Agro-Ecological Zones and its production is mainly by smallholder farmers who depend on it for their livelihoods. However, there are many challenges which have inhibited realization of the full potential of mango in Kenya. High postharvest losses estimated to be 40 – 50% is one of the challenges facing mango value chain actors. The high losses result from various factors including poor harvesting practices, pest and diseases, lack of postharvest technologies, among others. Various postharvest technologies such as controlled atmosphere storage, refrigeration, modified atmospheric packaging, among others have been used with great success, but are out of reach for small holder farmers who are resource constrained. Waxing of fruits is an old practice which has been demonstrated to have benefits on various fresh commodities such as avocados, mangos, citrus, apples, loquats, among others. However, application of waxing technologies in mango fruit has not been tried commercially in Kenya. This study was conducted to evaluate the efficacy of two waxing options on prolonging the shelf life of two popular mango varieties in Kenya under different storage conditions. Fruits for the study were harvested from 6 – 10-year-old trees on commercial farms in Machakos County. In the first experiment, 'ngowe' and 'apple' mango fruits were harvested at mature green stage and transported in padded crates to the postharvest laboratory where they were sorted for uniformity, washed with disinfected water, brushed gently with Decco Clear (food brush sanitizer), dipped in hot water (45-55°C) and placed on wire shelves for air drying. Each variety was then batched into five groups for different treatments. The treatments included Shellac wax (3% and 5%, w/w), Mango wax, Mango wax+prochloraz (fungicide) and

untreated (control). The fruits were then packed in open carton boxes and stored in different storage conditions including ambient (25°C) and simulated commercial cold storage (12°C). A random sample of three fruits was taken from the different treatments and storage environment for analysis of attributes associated with ripening. The ripening attributes measured included physiological (respiration and weight loss) and physical (peel/flesh firmness and peel/pulp color).

In the second experiment, the best performing treatment(s) from each storage option in experiment 1 was selected and applied on the mango fruits ('ngowe' and 'apple') to establish their effect on postharvest quality attributes. The parameters measured included total titratable acidity (TTA), total soluble solids (TSS), total sugars, beta carotene and vitamin C. Completely Randomized Design with factorial arrangement was used as the study design. Results from the study showed waxing to have a significant ($p<0.05$) effect on shelf life of mango fruits. Waxed fruits had an extended shelf life of 3 and 4 days at ambient storage conditions for 'ngowe' and 'apple' mango fruits respectively and for 6 days under cold storage (12°C) for both varieties. Waxing suppressed the rate of respiration for both mango varieties in the different storage conditions compared to the control. Under ambient storage conditions, untreated 'apple' mango fruits had a high respiratory peak of 85.09ml/kg hr (day 10) compared to a low average peak of 51.55ml/kg hr (day 14) for the treated fruits. Weight loss was significantly reduced by waxing. Control 'apple' mango fruits under ambient storage conditions lost 12.4% of the initial weight compared to an average of 7.75% weight loss for the treated fruits by end of the storage period. Similarly, in the case of cold-stored fruits, untreated 'apple' mango lost 5.5% compared to an average of 3.7% for the treated fruits by end of storage period. Other ripening related physiological and physical changes followed a trend that correlated positively with water loss and respiratory activity. Wax treated fruits maintained

relatively higher hue angles (peel and pulp) and higher firmness (peel and pulp) throughout the storage period compared to control fruits.

In the second experiment, results showed waxing to be effective in delaying the rate of loss of the fruit's quality attributes for both 'ngowe' and 'apple' mango fruits. Brix levels for the treated fruits remained relatively low especially for the fruits in the cold storage. Control 'apple' mango fruits had a high brix level of 20.88 ºbrix by day 15 compared to a lower average level of 19.05ºbrix for the treated fruits, by end of storage period (day 28). The other parameters (total titratable acidity, vitamin C, beta carotene and sugars) for the waxed fruits were also retained longer, showing a positive correlation with water loss and respiration. The results from this study show that waxing is an effective postharvest technology which can be used as an alternative technology to extend shelf life and maintain postharvest quality of mango fruits during storage, transportation or marketing.

Key words: Cold storage, Ambient, Mango wax, Shellac wax, Shelf life, Postharvest quality.

CHAPTER ONE

1.0 INTRODUCTION

Agriculture is the mainstay of the Kenyan economy contributing to about 24% of the Gross Domestic Product (GDP), with an estimated 75% of the population depending on it directly or indirectly (Nnadi *et al*., 2012). The horticulture sub-sector has continued to experience significant growth and has become a major source of employment and a source of government revenue (HCD, 2016). The livelihoods of many people are significantly impacted by this sector when compared with other sectors in the country. In 2016, the industry generated a total of Kshs. 216.37 billion compared to Kshs. 207.73 billion in 2015, realizing a growth of 4% in a year. Approximately 619,114 hectares of land is under horticulture with a production of 8.127 million tons, compared to 7.983 million tons in 2015. The key produce for export in the industry include vegetables, fruits, flowers, nuts, herbs and spices (HCD, 2016).

Mango is an important fruit ranked first among the export fruits (HCD, 2016). It is adapted to wide agro-ecological zones (AEZs) and this makes it an important crop in Kenya. In the last decade, mango production in Kenya expanded considerably in acreage and geographical spread. The growth in the industry has been stimulated by a continuous increase in demand in the domestic, regional and international markets (HCD, 2016), becoming a major income earner for many smallholder farmers living in dry areas (Arid and Semi-Arid lands). However, mango fruit is highly perishable with a short shelf life of about 4 to 5 days under room temperature and about 3weeks in cold storage (13°C) (Emongor, 2010).

Over the years, different postharvest technologies have been developed to increase shelf life and preserve postharvest quality of perishable commodities such as antioxidants like ascorbic acid, firming agents like calcium derivatives, 1-Methylcyclopropene (1-MCP), Controlled

Atmospheres (CAs), Modified Atmosphere Packaging (MAPs), among others. Kader (1999), reported that CA is effective in extending shelf life of mango, however, the technique is not commercially viable especially for the small holder farmers. Also, produce stored under CA has been found to have CO_2 injury and with off flavor (Bender *et al*., 1997; Kader 2008). The use of Active bag® (MAP) has been shown to be effective in extending shelf life of mango fruits (Githiga *et al*, 2012), however, the packaging is not yet commercialized and there is fear of environmental pollution (Lorevice *et al*., 2014). Kader (2008), noted that poor balancing of oxygen and carbon dioxide in the film packaging leads to skin discoloration, grayish pulp color and formation of off flavor especially in mangos.

Coating fresh produce, fruits in particular, has been demonstrated to have beneficial effects as the coating helps to stimulate the fruit's epidermal structure and wax layer of different fruits with improved performance (Abassi *et al*, 2009). It is also used to replace the natural wax that is lost during washing. Appropriate amounts of the coating when applied forms a thin porous membrane on the surface of fruits reducing transpiration rates, respiration and prevents invasion by micro-organisms (Krochta *et al*., 1994). Coatings are useful in delaying dehydration, inhibits volatilization of aromatic substances and helps to improve texture of most fruits (Mladenoska, 2012). The use of food coating technology is environmentally friendly (Dhall, 2013) and reduces reliance on synthetic packaging. Other than giving a modified environment like MAP, food coating works to give an additional protective cover on the produce and allows the addition of other active ingredients such as fungicide, antioxidants, spices, among others into the polymer matrix which improves its performance (Mladenoska, 2012).

In pursuit to realize the commercial potential of mango fruit through loss minimization, researchers have developed various postharvest technologies which are affordable, accessible and

easy to use. Among these are waxing technologies whose effectiveness and cost benefit can only be realized through research. Hoa *et al*., (2002), reported positive results on the effect of four wax coating (shellac, carnauba, zein and cellulose) on shelf life of Kent, Lirfa and Tommy Atkins. All coatings reduced rate of CO_2 production, development of skin and pulp color and retarded loss of firmness. Banana and tomato fruits which were coated by gum Arabic were reported to have delayed ripening and maintained postharvest quality (Maqbool *et al*., 2011).

1.2 PROBLEM STATEMENT AND JUSTIFICATION

1.2.1 Problem statement

Mango is a climacteric fruit with a short shelf life of 4-7days depending on harvest maturity and storage conditions (Slaughter, 2009). High perishability and seasonality contribute to high postharvest losses (40-50%) reported in the mango value chain. Postharvest deterioration in climacteric fruits like mango results from various factors including ethylene effects, water loss and respiration. Ethylene is a gaseous plant hormone which is known to trigger ripening and senescence processes leading to a quicker deterioration of perishable commodities. Water is lost from perishables through transpiration process. Cuticle, a waxy layer that prevents water loss to the environment is usually broken or lost during harvesting, handling and washing and this predisposes the fruit to a faster water loss causing withering and senescence (Hagenmaier and Baker, 1997). On the other hand, respiration becomes a dominant process after harvest. Oxygen taken in through lenticelss is used to break down carbohydrates in fruits releasing the energy required for other biochemical processes to occur.

To achieve prolonged shelf life and maintain quality of perishable commodities like mango fruits, various postharvest technologies including cold storage, Controlled Atmosphere (CA),

Modified Atmospheric Packaging (MAP), 1-Methylcylopropene (1-MCP), edible coatings, among others have been shown to delay ripening and preserve postharvest quality. However, many of them have not been adopted due to high cost of acquisition and operation and some of them unsuitable for different category of fruit due to CO_2 injury (Lorevice *et al*., 2014). This challenges therefore requires development of alternative affordable postharvest technologies.

Advances in food coating has led to the development of coatings with a wide range of gas permeability characteristics to suit the metabolic characteristics of different produce. Positive results on the use of these coatings include mango coated with pectin and chitosan (Medeiros *et al*., 2012), tomato and banana coated with gum Arabic (Ali *et al*., 2010), citrus and apples coated with shellac and carnauba wax, tangerines coated with bees' wax (Abassi *et al*., 2009; Bashir *et al*., 2004; Sabir *et al*., 2003), among others. There are various waxing technologies whose application requires extensive research to establish their effectiveness on shelf life extension and quality preservation of fresh commodities. Such is shellac wax and mango wax.

Although waxing has been used successfully in various commodities in different countries, its use and registration on Kenyan mango has not been done. Therefore, the current study focused on establishing the effect of different waxing technologies (mango wax and shellac wax) on shelf life and postharvest quality of mango fruits under different storage conditions.

1.2.2 Justification

Various processes that occur after harvest such as water loss, respiration, pathological breakdown, decay and high rates of bruises subjects the fruits to a quick deterioration (Ray and Ravi, 2005). To realize longer shelf life and quality preservation, various postharvest techniques and postharvest technologies must be employed along the value chain. Cuticle, a natural waxy

layer on fruit's surface has a general low permeability to water vapor. Harvesting, packaging and handling of mango fruits along the value chain, causes this natural barrier to be broken or lost and this subjects the fruit to a high-water loss and respiration. Artificial application of wax enhances or replaces the lost cuticle thus providing a partial barrier to moisture loss and gas exchange. Also, the thin layer of wax improves the mechanical handling property by maintaining structural integrity, retention of volatile flavor compounds and addition of functional compounds helps deter pathological breakdown (Mladenoska, 2012).

Successful application of wax delays ripening and retain postharvest quality longer. This can contribute to reduction of the losses and wastage in the mango value chain. The quick deteriorative nature of mango fruits leaves the exporters with the option of air freight in shipping their produce to distant markets. Air freight is very expensive, and this renders the produce uncompetitive in the overseas market. Delayed ripening of mango fruits coated with wax and cold storage gives an opportunity for sea shipping which would help cut down on costs and improve the competitive ability of mango fruits from Kenya.

Evidence of the effectiveness of waxing on shelf life extension and preservation of postharvest quality of mango fruits could lead to its adoption by various actors, especially the mango exporters.

1.3 OBJECTIVES

1.3.1 General objective

To reduce postharvest losses in mango fruits through application of waxing technologies.

1.3.2 Specific objectives

1. To compare the effectiveness of different waxing technologies to extend shelf life of 'apple' and 'ngowe' mango fruits stored under different storage conditions.

2. To determine the effect of waxing on postharvest quality attributes of ‘apple’ and ‘ngowe’ mango fruits under different storage conditions.

1.4. Hypothesis

(i) The different waxing options on ‘apple’ and ‘ngowe’ mango fruits will have the same effect on shelf life in the different storage conditions.

(ii) The effect of waxing on postharvest quality of ‘apple’ and ‘ngowe’ mangos will be the same in the different storage conditions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background information

Mango (*Mangifera indica* L.) is an exotic fruit tree in Kenya, but it has been grown in the Kenyan Coast for over centuries. It is said to have originated from India, Myanmar, Malaysia and Bangladesh, and it is now grown in over 90 countries worldwide (Salim *et al*., 2002). Mango is thought to have been introduced into the Kenyan Coast by the slave traders during the 14th century who brought the seeds with them. In the coastal region there are old mango trees of different varieties that have existed in decades and the names are mostly known in the local language for a detailed scientific description is non-existence. It was thereafter distributed all over the region and adapted giving formation of landraces that are highly variable. Some of the populations have been identified as drought, pest and disease tolerant and they have gained the potential of being used as rootstocks by the horticulture industry (Kehlenbeck, 2010).

2.2 Production statistics

Mango is produced by over 90 countries around the world. Globally, Asian countries contribute more than 77%, followed by the Americas 13% and Africa 10% (FAOSTAT, 2011). Kenya contributes about 1.7% of the global production and is ranked at number 15 after Vietnam, but it is second to Nigeria in Africa (Match Maker Associates, 2011). In Kenya, mango production is done by both small- and large-scale holders for the domestic and export market. The main varieties grown include Sabine, Ngowe, Tommy Atkins, Dodo, Van Dyke, Boribo, Apple, Kent and Haden.

Mango harvesting season in Kenya is able to compete with that of other producing countries of the world like Mexico, Brazil, South Africa, Pakistan and Israel and this is promising to many small-scale farmers. Interestingly though, Kenya has a very small tonnage (3000 t/year) of export in comparison to the worlds (580,000t/year) (FAOSTAT, 2011). The introduction of newly imported cultivars has tremendously boosted commercial production of mangoes in the last three decades and due to its wide Agro-ecological adaptation, it is now grown in many parts of the country becoming a major income earning crop.

In 2016, mango production volume decreased to 779.147 metric tons compared to 806.575metric tons that was realized in 2015. The drop-in production volume is attributed to the poor rains received in 2016 as mangos are mainly produced under rain fed conditions (HCD, 2016). Currently, mango is the leading export fruit crop from Kenya, earning about 6% of the total export value of horticultural crops, but its potential has not been fully unlocked. Export to Europe and to the Middle East has been on the decline because of the production and postharvest challenges experienced including pests and diseases, unreliable supplies, climate change, harvesting at wrong the maturity stage and poor postharvest technologies being the major constraints (Gomathi *et al*, 2009). Various mechanisms have been exploited to curb the losses incurred, but most of them remain un-adopted because of price constraints especially to the poor resource farmers.

2.3 Physiological and Biochemical changes during mango ripening

2.3.1 Color change

As the fruit ripens, color change occurs which is used as a prerequisite by consumers in making decision to purchase. Color development is as a result of enzymatic breakdown of chlorophyll and synthesis of color pigments like carotenoids and anthocyanin (Valero and

Serranno, 2010). All mango cultivars pulp color changes from white or cream to yellow or orange as the fruit matures and ripens, but the skin color cannot be correlated with ripeness or maturity or the internal eating quality. Skin color of mango fruits may change from green to yellow or orange or remain green depending on the cultivar. Color changes in mango is as a result of chlorophyll degradation or change to chromoplast (John *et al*., 1970) or emergent of other pigments. Ambuko *et al*., (2017) reported pulp color reduction (hue) from 91.5°to 58.53° for apple mango fruits that were stored in ambient room conditions. The high carotenoid content of the mango fruits results in the development of an intense yellow to deep orange color, although this is cultivar dependent. The all-trans- β-carotene is the most abundant, however, violaxanthin carotene and its isomers are the most important (Chien *et al.*, 2009).

2.3.2 Flavor, Aroma and TTA

Flavor and aroma produced is usually specific to a fruit and this is what attracts consumers. Flavor is a complex perception of taste, smell, texture and mouth feel. The fruit's aromatic characteristics results from a number of volatile compounds and their qualitative and quantitative composition determines the fruits aromatic characteristics (Valero and Serrano, 2010). The production of individual volatile components gives a fruit its characteristic aroma. Taste continues to develop as the fruit ripens due to the hydrolysis of polysaccharides especially starch into simple sugars with decreased acidity that results in an excellent sugar: acid blend. The acidity in fruit as it develops is as a result of accumulation of many organic acids, but as the fruit matures acidity reduces due to large amounts of accumulated sugars (Valero and Serranno, 2010). Glucose levels of apple mango under room storage condition was reported to increase from 1.7mg/100ml to 4.8mg/100ml by end of storage period (Ambuko *et al*., 2017). The decrease in Total Titrable

Acidity (TTA) with fruit ripening is associated with organic acids being used as respiratory substrates.

2.3.3 Firmness

This is the most relied indicator of maturity and ripeness and has been an important tool used by the different players in the value chain (growers, wholesalers, retailers, importers and consumers). Flesh and skin firmness in fruit is related to their resistance to shearing and deformation due to the characteristics of the cell walls and to the resistance of inter-cell joints, mostly dependent on maturity level. When the fruit is young and immature it is hard, but it softens over time as it ripens to being very soft as the fruit become fully ripe (Mahajan and Dhatt, 2007). Ambuko *et al*., (2017) reported reduction in peel and pulp firmness of apple mango fruits which were packaged in MAP and stored in ambient room conditions to have reduced from 56.8N to 28.1N and 40.9N to 17.6N by end of marketable quality (day 12).

2.3.4 Total Soluble Solids (TSS)

The ratio of sugars to acidity is an important component of the mango flavor. As the fruit undergoes growth and development, it accumulates starch that is later converted to soluble sugars as the fruit ripens. TSS content of fruits can be measured using a refractometer especially under commercial conditions. Juice from the mango is squeezed out onto a refractometer and the readings are obtained. TSS content of the mango fruit has been correlated with the fruit taste, and sucrose is usually the predominant sugar (Silva *et al*., 2008). Titratable acidity of the mango fruit results from citric and malic acids, and this decreases over as the fruit ripens giving the fruit its desirable aroma (Kader, 1999).

2.4 Challenges of mango farming in Kenya

Mango farmers in Africa and Kenya in particular face a lot of challenges along the value chain among them being poor infrastructure, price fluctuation, pests and diseases, poor storage, maturity determination, limited knowledge in marketing among others (Serem, 2010).

2.4.1 Lack of quality Seedlings

Most farmers have a limited access to good quality planting materials which would give higher yields. Farmers often use inferior seedlings obtained from germinating mango seeds from indigenous varieties which give low yields and come to bearing after a long time. The kind of varieties that farmers use too are easily attacked by pest and diseases like fruit fly, seed weevil and mealy bugs (Gomathi *et al*, 2009).

2.4.2 Poor prices and lack of market information

Many small holder farmers depend on income from the sale of their fruits for their livelihoods, but this potential has not been realized due to poor prices of the fruits at the farm gate. Prices of mango fruits fluctuates from Ksh. 5 to Ksh. 25 per piece, limiting farmers from making projections and reliable planning from mango fruit income (AgriBusiness Development, 2011). Often, farmers earn very low income from the sale of their mango fruits in spite of this fruit fetching very high prices at the final consumer (Mutoto, 2011). Mango farmers are not involved directly in the sale of mangoes and they are manipulated by brokers who end up with super normal profits. Furthermore, the limited access to information by mango farmers on technology in husbandry limits the potential of production, and when it comes to postharvest management they lack or are unaware of existing technologies which could be used to extend the shelf life of their produce. This challenge is further compounded by the lack of information on existing ways of

adding value to mangoes like juicing, mango drying, etc which can fetch higher prices as well as reducing losses. This discourages farmers and makes them abandon mango farming thus affecting their economic status as well as that of their region.

2.4.3 Poor road network and lack of postharvest handling technology

Poor infrastructure and postharvest handling in the major producing zones pose a great challenge to the mango farmers (Kehlenbeck, 2010). The roads in the rural areas are usually rendered impassable especially during the wet seasons, and even when it is dry, the roads are very bumpy and this hampers movement of produce. Poor produce packaging and lack of cold chain management causes the fruits to senesce fast contributing to huge losses. Few existing technologies like CAs, MAPs, and refrigerators, among others are unaffordable to the poor resource farmers and some of them are unknown to the farmers. Many times, the farmers use jute bags to pack the produce and this type of bags do not prevent fruits from physical damage and over packing leads to an increased respiration. Also, over packing leads to heat generation that escalates respiration leading to a faster loss of the produce.

2.4.4 Lack of harvesting tools and techniques

The defects that arise right from harvesting, packing and transportation leads to postharvest decay (Madrid, 2011). More often, fruits are harvested and dropped on the ground which causes skin injuries. During packing and sorting, fruits are roughly handled and thrown in bins or bags inducing bruises on the skin and removing cuticle. Friction damage is a serious problem during harvest and handling, and it has been estimated to occur in over 78% of the fruits. Damaged tissues become oxidized which later inclines downward and turn brown. The damaged surfaces lead to accelerated loss of water and causes disruption of the superficial arrangement of cells and tissues

allowing a faster exchange of gas on the fruit surface. These sites also become entry points for disease causing microorganism such as fungus and bacteria (Madrid, 2011).

2.4.5 Wrong maturity indices

Maturity is an important determinant of the mango eating quality. Changes in the parameters used to quantify maturity differs with region, variety and consumer perception. There are various ways of measuring maturity including chronological, physical, physiological and biochemical, each or a combination being suitable for a particular produce (Yahia, 2006). When mangoes are harvested, it is important to discriminate over mature and immature fruits, for immature fruits never possess the full eating quality potential and the waxy layer that protects water loss which forms later as the fruits develops, is usually under developed and this leads to high water loss and a faster shrinking (Yahia, 2006). As the fruit mature, there is development of internal flesh color, which is an important indicator of maturity, as well as dry matter content which is correlated to the final total soluble solids attained by the fruit (Abassi *et al*., 2009). However, the fruits should not be harvested when they have started to ripen as this makes handling difficult and also respiration rates at this stage is higher which leads to high temperatures and leads to a faster deterioration of the fruits. Thus, farmers and traders need to be educated to ensure they harvest only those fruits that are mature enough and which can withstand handling process during transport and marketing period.

2.4.6 Postharvest diseases

Postharvest diseases reduce the quality and quantity of fruits significantly. Latent infections such as anthracnose (*Colletotrichum gloeosporiodes*), stem end rot (*Lasiodiplodia theobromae*) and Alternaria black spot (*Alternaria alternata),* are the most critical postharvest diseases that leads to high losses during the supply chain. During transport and storage of fruits,

stem-end rots has been reported to cause large losses. The disease develops as dark spots as the fruit ripens and then progresses at times forming large spots. The pathogen is known to infect the fruit during developmental stages, or during harvesting or de-sapping processes which then continues leading to severe losses (Serem, 2010). Anthracnose is reported to infect fruits during development on the tree or during postharvest operation like de-latexing, among others. Fruits with anthracnose disease appear to have dark lesions which are sunk on the surface, with pink spore masses that are slimy. Postharvest decay incidences in fruit results from spores that come into contact with the fruit. Susceptibility of mango fruits to decay goes up as the fruit ripens (physiological changes that occur) and colonization of the pathogen increases (Eckert *et al*., 1996).

2.4.7 Poor Relative Humidity and Temperature management

Most horticultural commodities require high relative humidity conditions during storage to lower the rate of water loss as this is often associated with loss of quality. It is therefore recommended that the relative humidity be increased to reduce the vapor pressure deficit, hence less water loss (Blakey *et al*., 2011). When the relative humidity in the storage environment is less than 100%, water is lost from the fruit to the surrounding environment (Yahia, 2009). Mango fruits lose water via lenticels and other sutures found on the fruit surface. The prevailing temperature conditions surrounding stored produce, skin thickness, and morphological structure, surface wax and epidermal cells influence the rate at which water is lost from the fruit. When temperature increases, transpiration rates go high and more moisture is lost. Mangos harvested when immature tend to lose more moisture because they lack a wax coating which forms at a later stage of the fruit development (Yahia, 2006). Various postharvest technologies such as CAs, MAPs, cold storage, among others have been used successfully, but most of them are out of reach to the small holder farmer.

2.5 Applicable technologies for shelf life extension and postharvest quality preservation of mango fruits

2.5.1 Cold storage

Mangoes stored under low temperature of up to 13°C and high relative humidity can be stored for up to 4-6weeks dependent on cultivar (Yahia, 1998). Low temperature is critical while storing fresh horticultural produce as this helps to lower metabolic activity, reduce water loss, delay ripening and senescence, disease and insect activity hence maintaining postharvest life and quality (Thompson, 2003). However, just like most tropical fruits, mango stored on sub-optimum temperature develops chilling injury that is manifested as brown discoloration on the skin and later there is formation of pitting. Low temperatures have also been realized to cause uneven ripening, poor color and flavor and susceptibility to disease (Emongor, 2010). This sensitivity of mangoes to chilling injury limits its storage life in temperatures below its optimum. Some factors which influence mango susceptibility to injury include growing conditions, cultivar, maturity when picked, postharvest handling techniques and duration of exposure to the chilling temperature (Emongor, 2010). Chilling injury in mangos develop due to prolonged exposure to temperature below 13°C (Gomez-Lim, 1997).

2.5.2 Controlled Atmosphere Storage (CAS) and Modified Atmosphere Packaging (MAP)

The use of CAS and MAPS to delay ripening is achieved by reducing O_2 and increasing CO_2 levels thus reducing respiration rate and preventing water loss (Yuen *et al*., 1997). These systems also help to control insect and pathogen attack. CA is sophisticated and is used to achieve a constant temperature, oxygen and carbon dioxide. The high CO_2 levels achieved by CA is able to keep ethylene at low concentration because CO_2 antagonizes ACC synthase enzyme which

converts S-adenosylmethionine (SAM) to ACC. Although CA storage has shown significant delay in the ripening process of mango, it is cost prohibitive and only used for high value crops. There is also tendency of CO_2 injury and formation of off-flavors due to anaerobic respiration (Bender *et al*., 1997). On the other hand, MAP is the practice of modifying the composition of the internal atmosphere of a package in order to improve the shelf life of a commodity. Unlike in the case of controlled atmosphere storage, the gas composition in MAP is not precisely controlled and depends on the interplay between the commodities respiration and the permeability characteristics of the package. MAP has been effective at the laboratory level and there are successful commercial applications that have been realized in fruits such as apples (Moodley *et al*., 2002), loquats (Amoros *et al*., 2008), mangos (Githiga *et al*, 2012), among others. However, mango has a short tolerance to elevated CO_2 and reduced O_2 which leads to off flavors and can cause non-uniform color development, making it an unfavorable option (Gonzalez-Aguilar *et al*., 1997).

2.5.3 1-Methylcyclopropene (1-MCP)

1-MCP is a gas (at standard atmospheric pressure and temperature) and is similar in structure to that of aminocyclopropene carboxylate oxidase making it competitive to the binding sites as those of ethylene (Hofman *et al*., 2001). It prevents the action of ethylene by binding on the receptors that would otherwise be occupied by ethylene and thus inhibiting ethylene from triggering ripening response to the fruit (Sisler and Serek, 1997). 1-MCP also inhibits the expression of 1-aminocyclopropene-1-carboxylic acid (ACC) and aminicyclopropene carboxylate oxidase (ACO) enzymes which are important in the biosynthesis of ethylene (Blankenship and Dole, 2003). 1-MCP has successfully been applied to delay ripening in mangos (Kemunto, 2013; Githiga *et al*, 2012), apples (Feng *et al*., 2000) and bananas (Harris *et al*., 2000).

2.5.4 Evaporative Cooling Technologies

Zero-energy brick cooler (ZEBC) and charcoal cooler function on the principle of evaporative cooling. The ZEBC is made up of a double wall filled with river sand in between, while the charcoal cooler is made by building a structure whose walls are filled with charcoal held up by wire netting (Das and Chandra, 2001). The pads are wetted by a constant supply of water and as warm dry air passes through the wetted pads, water evaporates taking with it heat from the environment within the storage chamber hence cooling the air around the product itself, (Basediya *et al*., 2013). Wayua *et al* (2012), reported that charcoal cooler has an efficiency of between 74.2 to 87% during the hottest time of the day, cooling the product to 10ºC below the ambient temperatures. ZEBC has been found to maintain relatively low temperatures and high humidity in comparison to external environment (Islam *et al*., 2012). The cooler has been used successfully in storing spinach, potatoes, tomatoes, mangos, bananas, among others, extending shelf life by 3 to 15 days compared to ambient stored produce (Kalpana *et al*., 2010).

2.5.5 Waxing and Edible Coatings

Waxes are a diverse class of organic compounds that are lipophilic, malleable solids near ambient temperatures. They include higher alkanes and lipids, typically with melting points above about 40 °C, when melted gives low viscosity liquids. Waxes are soluble in organic, nonpolar solvents but insoluble in water. Natural waxes are produced by plants and animals and also occur naturally in petroleum. Animal waxes consists of wax esters derived from a variety of fatty acids and carboxylic alcohols while plant waxes, characteristic mixtures of unesterified hydrocarbons may predominate over esters. The best known animal wax is beeswax used in constructing the honeycombs of honeybees, but other insects secrete waxes. Plants secrete waxes into and on

the surface of their cuticles as a way to control evaporation, wettability and hydration. These waxes are harvested and processed for different industrial use including furniture polish, glazing agents, candle, in confectionary and coating fruits and vegetables.

Coating of fresh produce has been a practice of over centuries, majorly used to protect food and reduce moisture loss. Baldwin (1994), reported that this was first recorded in China where citrus fruits were coated with wax. Wax, oils or fatty acids of either animal or plant origin are usually applied on the surface of fruits or vegetables by brushing or spraying. The film is thinly applied to lower the rate of water loss and gas diffusion on the surface of fruits (Baldwin, 1994). The film formed reduces the rate at which oxygen diffuses into the produce and this helps to lower the rate of respiration. The rate at which carbon dioxide resulting from respiration leaves the produce is lowered and this leads to buildup of Carbon dioxide in the fruit which helps to hinder the autocatalytic production of ethylene which causes fruit ripening (Wills *et al*., 1981).

2.5.5.1 Function of coating

Cuticle is the natural waxy layer on the surface of fruits and vegetables that has a general low permeability to water vapor. During handling of the produce; harvest or processing, this layer gets disrupted or removed. Applying an external coating enhances this natural barrier or replaces it in cases where it has been washed off completely thus providing a partial barrier to moisture and gas exchange, improving mechanical handling property through maintenance of structural integrity, retention of volatile flavor compounds and carrying other functional ingredients. Proteins, lipids, resins and polysaccharides are some of the common biopolymers coating- forming material which can either be used singly or in combinations.

The characteristics (physical and chemical) of these biopolymers greatly determines the functionality of the resulting coatings (Krochta, 2002). The most common biopolymers used in

developing coatings are lipids, proteins, resins and polysaccharides generally based on their water solubility, hydrophilic and hydrophobic nature, ease in forming coatings and sensory properties.

2.5.5.2 Advantages of coating

When the coating is thinly applied on the surface of produce, it is advantageous as it reduces the number of lenticels through which water transpires hence maintaining turgidity and reducing action of ethylene (Bai *et al*., 2002). It also helps to protect the produce against invasion of microorganisms because it camouflages the produce and the microorganisms are not able to recognize food molecules if any on produce's surface (Cuq *et al*., 1995). The coating contributes to both the physiological characteristic of fruits and in enhancing the exterior aesthetic appeal by imparting a sheen and gloss to the exterior of the fruit like avocado (Maftoonazad *et al*., 2008). Fruit coating also leads to formation of a layer that protects the produce against bruises. Also, waxing helps to manipulate the internal environment of each produce unlike CA and MAP that gives a modified atmosphere around the produce. Functional ingredients such as fungicides and other antimicrobials such as ant browning agents, preservatives, firming agents and antioxidants can be carried in the coating material and applied on produce to improve the coating's microbial stability, appearance and texture (Baldwin *et al*., 1996). Coatings also help to restrict exchange of volatile compounds between fresh produce and its immediate environment through providing gas barriers that prevents loss of natural volatiles compounds as well as restricting acquisition of foreign odors.

2.5.5.3 Successful application

Edible coatings have long been used on various fruits like citrus, apples (Sabir *et al*., 2004) tomatoes (mineral oil), and cucumbers (various waxes) (Bashir *et al*., 2003). Hassan *et al* (2014),

reported that tangerine treated with different wax ratios and stored in cold storage and ambient (25°C) retained most of the fruit quality attributes assessed through a sensory evaluation. His study showed that highest score of overall acceptability value was observed in 12% wax coated fruits stored at ambient (25°C). Other successful application of coating includes coating avocado with methylcellulose (Maftoonazad *et al*., 2008), mango with shellac (Hoa *et al*., 2002), citrus with chitosan (Fornes *et al*., 2005), among others.

2.5.5.4 Challenges in developing coatings

Coating application is intended to create a modified atmosphere inside the fruit that will delay ripening and senescence in manner similar to the cost prohibitive technology like CA or MAP storages. However, poor coating leads to modification of the internal atmosphere of produce which leads to formation of off-flavors due to anaerobic respiration associated with too high CO_2 or very low O_2 concentration (Wills *et al*., 1981; Bai *et al*., 2002). It is therefore critical to pick a coating material which will give desired permeability to gases leading to a modified internal environment of fresh produce for purpose of preserving food. Coat application on fruits and vegetables can be done by either brushing, dipping or spraying. Most of the time the challenge arises on adherence. Due to the different chemical nature between the coating material and the surface of fruits, adhesion becomes poor (Baldwin, 1997). To improve surface adhesion, surfactants are added into the coating formulations to improve wettability and adhesion (Lin and Krochta, 2005). Also, of great importance is controlling environmental temperature and relative humidity since coating permeability and produce respiration is highly depended on them.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental materials

3.1.1 Fruit samples

Two experiments were conducted between the month of January and April 2018. Two popular mango fruit varieties, ‘apple’ and ‘ngowe’ were selected for the study. A survey was conducted to identify trees that were between 6 and 10 years from commercial farms in Machakos County from where the fruits were harvested. Three hundred and fifty pieces of each variety at mature green stage (flesh color around seed starting to turn cream/yellow) were carefully handpicked, packed in plastic crates lined with wet paper (to reduce temperature and respiration) and transported to the postharvest laboratory, in the University of Nairobi.

A  B 

Plate 1: Mature green ‘ngowe’ (A) and ‘apple’ (B) mango fruits

3.1.2 Wax and sanitizing material

Two types of wax (Shellac and Mango wax) with different formulations were used for this study. Mango wax and Mango wax+prochloraz (fungicide), Decco clear (brush sanitizer) and Decco spark (Calcium chloride) were obtained from United Phosphorus Limited company, while Shellac wax (a resin obtained from secretion of insect *Laccifer lacca*) was obtained from a trader

in flakes form and the solution prepared in the laboratory by dissolving determined amounts in 0.1N Sodium hydroxide to make different concentrations (3% and 5%, w/w).

3.1.3 Experimental set up

On arrival to the postharvest laboratory, the fruits were sorted for uniformity and washed in tap water mixed with Calcium Chloride (0.18g/L). A fine brush dipped in Decco clear (food brush sanitizer diluted in water in the ratio 1:1) was used to clean the surface of fruits after which the fruits were dipped in hot water (45-55ºC) for 10 seconds, removed and placed on wire shelves for air drying. The fruits were then randomly batched into five groups for the different treatments. These included untreated (control), Shellac wax (3 and 5%), Mango wax and Mango wax+Prochloraz (fungicide). Waxing was applied by dipping the fruits in a bowl of wax, turning the fruits to ensure full coverage and placing them on wire shelves for air drying. Upon drying, the fruits were packed in open-carton boxes for storage in ambient (25ºC) and simulated commercial cold storage (12ºC) conditions.

3.2 Evaluation of the Effectiveness of Different Waxing Technologies on Shelf Life of 'Apple' and 'Ngowe' Mango Fruits Under Different Storage Conditions

For each variety and treatment, 3 fruits were sampled every 3 and 7 days (ambient and cold storage respectively) for analysis of physical and physiological attributes associated with ripening. These included color change (pulp and peel), cumulative weight loss, respiration and firmness (pulp and peel). A Completely Randomized Design (CRD) with factorial arrangement was used as the study design. The factors included storage (25°C) and treatment. The procedure used in the analysis of the attributes associated with mango fruit ripening are described below:

3.2.1 Evaluation of Physical and Physiological Attributes

3.2.1.1 Cumulative weight loss

Mass loss for five individual fruits was taken and recorded using a digital balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). The initial weight (W1) of each fruit (marked) at day 0 and the new weight of the same (W2) was taken for the subsequent days. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days. The formula:

$$\text{Cumulative weight loss (\%)} = 100 \times (W_1 - W_2)/W_1$$

3.2.1.2 Respiration rates

Mass loss for five individual fruits from each treatment and storage condition was taken and recorded using a digital balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). These fruits were then separately incubated for 2 hours in airtight jars fitted with a CO_2 gas sensor (Model CM-0187 Cozir AMB, UK). Gas sample from the headspace was read by the CO_2 sensor, and a graph drawn from which the slope was used to calculate the amount of CO_2 in ml per Kg hour. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days. The following formula was used to calculate CO_2 produced:

$$\text{Respiration } (CO_2) = (G \times \text{Volume of vessel})/ (\text{Time} \times M)$$

Where G-slope of the curve, M-mass of fruits in kilograms

3.2.1.3 Peel and pulp firmness

Three fruits were sampled, and peel firmness measured at two different spots of intact fruits, while pulp firmness was determined from peeled portions of the fruit. In each case, firmness was determined from two different spots of intact or peeled fruit using a penetrometer (Model CR-

100D, Sun Scientific Co. Ltd, Japan) fitted with a 5 mm probe. The probe was allowed to penetrate the peel and pulp up to 1.5mm and the corresponding force required to penetrate this depth was determined. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28days. Firmness was then expressed as Newton (N) (Jiang *et al.,* 1999).

3.2.1.4 Peel and Pulp color

The color change of the fruits was measured at 2 different spots along the equator using Minolta color difference meter (Model CR-200, Osaka, Osaka Japan) which had been calibrated on a white and black standard tile. To access the pulp, the fruits were cut open longitudinally. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days. The L*, a* and b* values were recorded and used to calculate the hue angle (H) according to McLellan *et al* (1995) where:

Hue angle (H°) = arctan (b/a) + 180 (for -a and +b values) or = arctan (b/a) + 180 (for -a and –b values)

3.3 Evaluation of the Effect of Waxing on the Postharvest Quality Attributes of 'Apple' and 'Ngowe' Mango Fruits Stored Under Different Storage Conditions

In the second experiment, best performing waxes from experiment1 were used to coat 'apple' and 'ngowe' mango fruits. The fruits were harvested and handled as described in section 3.1 above. In the laboratory, the fruits were pre-treated by washing with water mixed with 0.018% Calcium Chloride to disinfect, gently brushed with Decco clear (Decco clear mixed with water 1:1), dipped in hot water (45-55°C) for 10 seconds and placed on wire shelves for air drying. Upon drying the different varieties were batched into three groups for the different treatments which included Mango wax+prochloraz, 5% Shellac wax and Untreated. Wax was applied by dipping

the fruits in bowls with wax and placing the fruits on wire mesh for air drying. After drying, the fruits were packed in open carton boxes and stored in ambient (25°C) and simulated commercial cold storage (12°C) to undergo normal ripening. Three fruits were randomly picked from each treatment and storage condition after every 3 and 7 days (ambient and cold storage respectively) for analysis of biochemical attributes associated with postharvest quality of mango fruits. These included total soluble solids (TSS), total titratable acidity (TTA), Beta carotene, Vitamin C and simple sugars (sucrose, fructose and glucose). The quality attributes were analyzed using the following procedure:

3.3.1 Total Soluble Solids (TSS)

An Atago hand refractometer (Model 500, Atago, Tokyo, Japan) was used to determine the TSS levels. Fruits from each treatment were randomly picked and a blender used to macerate the pulp. The pulp was then placed on the glass prism and an average of three readings recorded. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold (12ºC) storage for a period of 28 days.

3.3.2 Total Titratable Acidity (TTA)

The TTA was determined by titration. Ten grams of the fruit pulp was grounded and diluted with 90mL of distilled water. 10ml of the dilute solution was obtained, mixed with 2-3 drops of phenolphthalein indicator (colorless in acid medium) for titration against 0.1 N sodium hydroxide with constant shaking, till the mixture showed appearance of pink color. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days. The TTA was expressed as percentage citric acid content of the fruit juice (Ueda *et al*., 2000).

Citric acid equivalent (%) = (Sample reading (ml) X Dilution factor) / (Sample weight (mg) x Citric acid factor (0.00064))

3.3.3 Determination of β-carotene content

The β-carotene content was determined by a modified chromatographic procedure (Heionen, 1990). A sample of 5g was macerated in pestle and mortar. A spatula of celite was then added and extracted using 50mL acetone until the residue became white. Partitioning was done using 30mL of petroleum ether in a separating funnel. Distilled water (200ml) was then added along the walls of the funnel. The two phases were separated, and the lower aqueous phase discarded. Acetone residues were removed by washing three times with distilled water without discarding the upper phase. Sodium Sulphate (anhydrous) was added to remove water and the extracts were stored in sample bottles in a dark cabinet. β-carotene content was determined using ultraviolet visible spectrophotometer (Model UV mini 1240, Kyoto Shimadzu) and absorbance read at 440nm. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28days.

The β-carotene content was calculated using the following equation:

$$\beta\text{−carotene } (\mu g/mg) = \frac{A * \text{Volume (ml)} * 10^4}{A^{1\%}_{1cm} * \text{sample weight (g)}}$$

Where A= absorbance; volume = total volume of extract (50 or 25 ml); $A^{1\%}_{1cm}$ = absorption coefficient of β−carotene in PE (2592).

3.3.4 Ascorbic Acid content

The ascorbic acid content was determined by high-performance liquid chromatography (HPLC) method (Vikram *et al*., 2005). Two grams of the sample was weighed and extracted with 0.8% Metaphosphoric acid. This was made to 30ml juice, and the juice centrifuged at 100rpm for

10 minutes. The supernatant was filtered and diluted with 0.8% Metaphosphoric acid to the 50mL mark of volumetric flask. This was then filtered using cotton wool, micro-filtered through 0.45µ filter and 20 µL injected into the HPLC machine. Various concentrations of ascorbic acid standards were also made to make a calibration curve. HPLC analysis was done using Shimadzu UV=-VIS detector. The mobile phase was 0.8% Metaphosphoric acid, at 1.1ml/min flow rate and wavelength of 266.0nm. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days.

The following formula was used to determine vitamin C level.

Ascorbic acid (mg/100ml) = (peak area from graph/y) X (Dilution volume/sample weight (g)) X (100/1000)

Where y=calibration coefficient obtained from standard regression curve when y-intercept is zero (AOAC, 1998).

3.3.5 Simple sugars (fructose, sucrose and glucose)

The total soluble sugars were analyzed using AOAC (1996) method. Two to three grams of pulp was refluxed in ethanol for 1hr. The sample was then concentrated by rotary evaporation and diluted with 50% acetonitrile. Each sugar was analyzed using a high liquid performance chromatograph (HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with a refractive index (RI) detector having the following conditions: Oven temperature; 35^0C, flow rate; 0.5-1.0mL/min, injection volume; 20uL, Column; NH2P-50E. Data was collected after every 3 days under ambient room conditions (25ºC) for 14 days and after every 7 days in cold storage (12ºC) for a period of 28 days. A graph was plotted for the concentration of the standard (X-axis) versus absorbance (Y-axis). Carbohydrate concentration was calculated as:

Amount of carbohydrates present in sample (%mg) = (Sugar value from graph (mg)/Aliquot sample used) X (Total volume of extract (ml)/Weight of sample (ml)) X 100

3.4 Statistical Data Analysis

The data was subjected to analysis of variance (ANOVA) using Genstat statistical package 15th edition and means compared by least significant difference at $P \leq 0.05$.

CHAPTER FOUR

4.0. RESULTS

4.1 The Effect of Different Waxing Technologies on Shelf Life of 'Apple' and 'Ngowe' Mango Fruits Stored Under Different Storage Conditions

4.1.1 Cumulative weight loss (%)

There was a gradual weight loss in all the fruits as ripening progressed during storage as observed in the increase in cumulative weight loss (Figure 1) regardless of treatment, variety or storage conditions. A combination of cold storage and waxing reduced weight loss indicating influence of storage temperature on efficacy of waxing. Untreated apple mango fruits stored under ambient conditions (25°C) lost 12.4% of its initial weight by day 10 compared to an average of 7.75% for the treated fruits which occurred by day 14 (Figure 1A). For the apple mango fruits stored under cold storage (12°C), untreated fruits lost 5.5% by day 22 compared to an average of 3.7% for the treated fruits by end of storage period (day 28) (Figure 1B).

For the 'ngowe' mango fruits under ambient storage (25°C), untreated fruits lost 5.3% of their initial weight (day 7) compared to an average of 4.96% for the waxed fruits which occurred by end of storage period (day 10) (Figure 2A). In cold storage (12°C), untreated fruits lost 3.8% (day 22) compared to an average of 3.75% for the waxed fruits occurring by end of storage period (day 28) (Figure 2B).

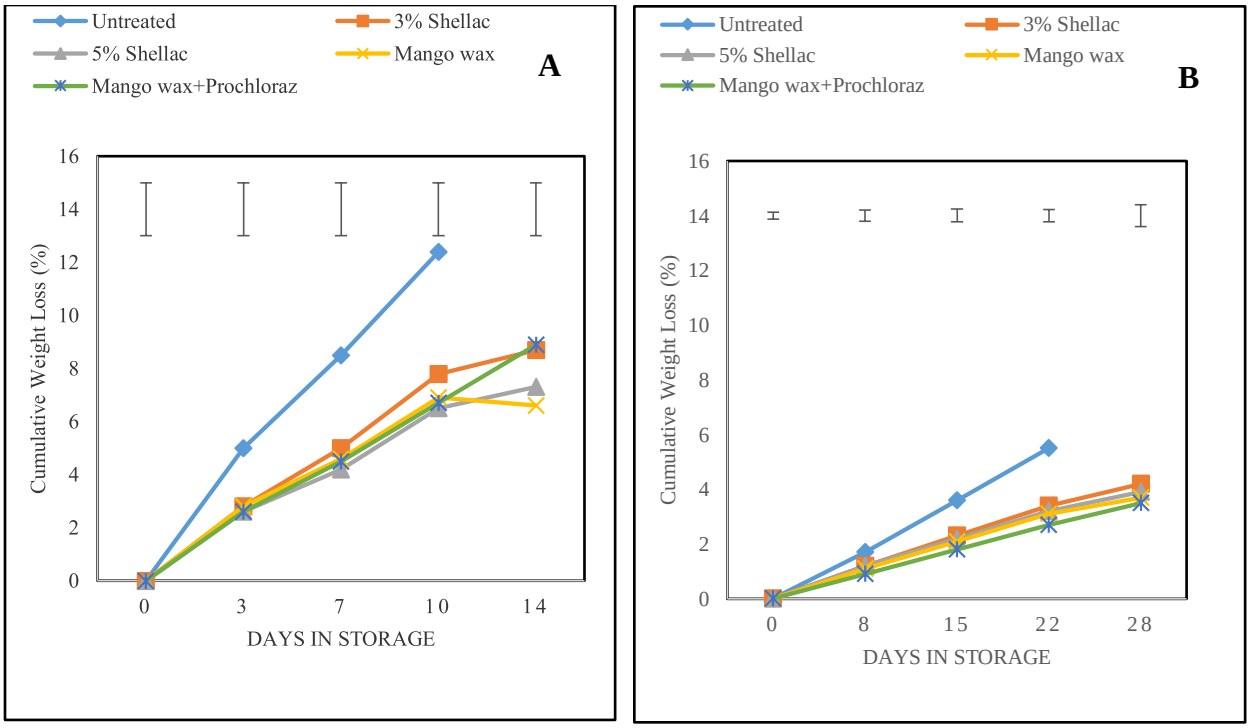

Figure 1: Cumulative weight loss (%) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

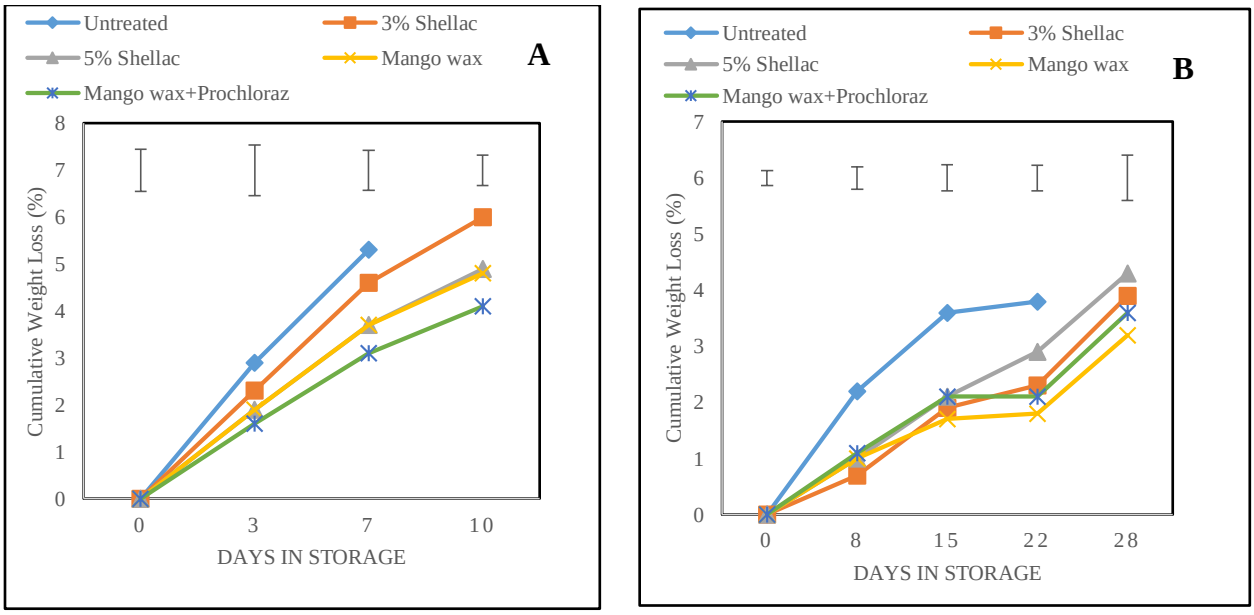

Figure 2: Cumulative weight loss (%) for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored

in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

4.1.2 Changes in respiration

Carbon dioxide concentration increased in all fruits as ripening progressed during the storage period for both varieties under the different storage conditions (Figure 3). Carbon dioxide levels for the treated fruits increased gradually and then remained fairly constant throughout storage in both storage conditions compared with untreated except for 'ngowe' mango fruits under ambient storage (25°C) (Figure 3A). Waxed-cold stored fruits had lower respiration rates throughout storage period compared to ambient stored (25°C) fruits, indicating effect of storage temperature on the efficacy of waxing.

For the 'ngowe' mango fruits under ambient storage (25°C), untreated fruit's CO_2 concentration increased rapidly from an initial 18.05ml/kg hr to a high level of 88.11ml/kg/hr (day 3) compared to treated fruit's CO_2 concentration that had a low average peak of 50.76ml/kg/hr on the same day of sampling (Figure 3A). Cold stored (12°C) 'ngowe' mango fruit had relatively low CO_2 concentration when compared to ambient stored (25°C) fruits (Figure 3B). The untreated fruit's CO_2 concentration increased to a level of 39.94ml/kg hr by day 15, compared to an average low level of 30.51kg/ml/hr (day 15) for the treated fruits (Figure 3B).

For 'apple' mangos stored under ambient conditions (25°C), CO_2 concentration for untreated fruits increased from an initial 30.04ml/kg hr to a high average level of 85.09ml/kg/hr (day 7) compared to a low average level of 51.55ml/kg hr for the treated fruits which occurred by day 3 and remained fairly constant to the end of storage period (Figure 4A). The case was similar for cold stored (12°C) 'apple' mango fruits as the untreated fruits CO_2 levels increased to a high

level (43.15ml/kg/hr) (day 15) compared to a low average peak (30.38ml/kg/hr) (day 15) for the waxed fruits (Figure 4B).

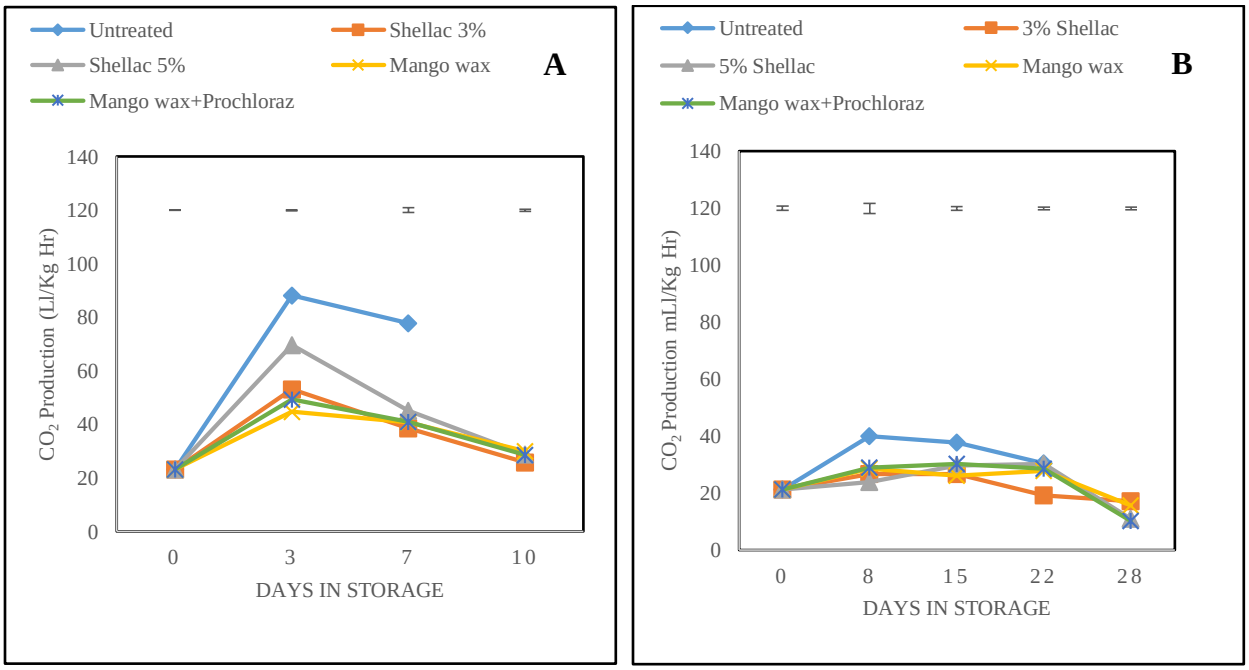

Figure 3: Changes in CO_2 concentration for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

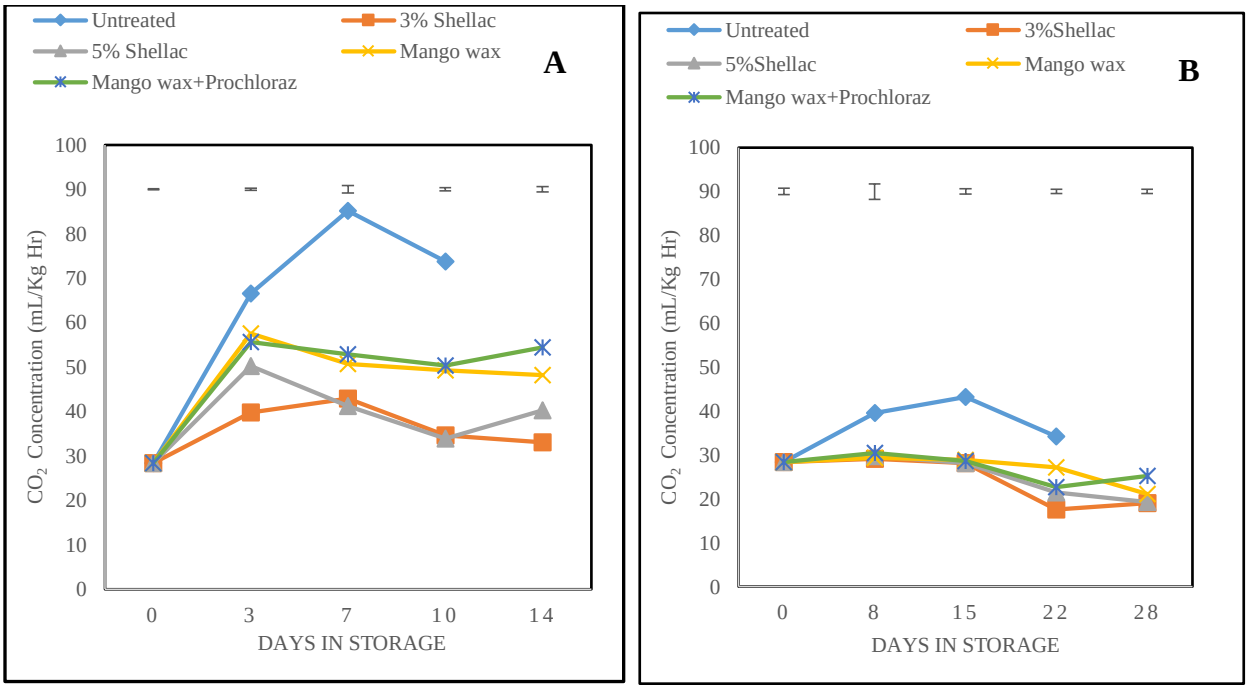

Figure 4: Changes in CO_2 concentration for 'apple' mango fruits treated with either 3% Shellac wax or 5% Shellac wax or Mango wax or Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

4.1.3 Changes in peel firmness

There was a gradual decrease in peel firmness for all fruits as ripening progressed irrespective of storage and treatment (Figure 5 and 6). A combination of cold storage (12°C) and waxing reduced rate of firmness loss each sampling day compared to fruits stored at ambient conditions (25°C) (Figure 5B and 6B) indicating effect of storage temperature on the efficacy of waxing. 'Apple' mango fruits were firmer compared to 'ngowe' mango fruits throughout the storage period under both storage conditions. There was a significant ($p<0.05$) interaction between variety, storage and treatment. Under ambient storage conditions (25°C), untreated 'ngowe' mango fruit's firmness decreased from an initial 105.68N to 10.2N by end of storage period (day 7) compared to an average of 19.33N for the treated fruits which occurred by end of storage period

(day 10) (Figure 5A). Cold temperature stored (25°C) 'ngowe' mango fruit's firmness decreased gradually compared to ambient stored (25°C) fruits. The untreated fruit's firmness decreased to 14.6N (day 22) compared to an average of 18.77N for the treated fruits by day 28 (Figure 5B).

For the 'apple' mango fruits stored under ambient conditions (25°C), untreated fruit's peel firmness decreased from an initial of 115.78N to 14.46N (day 10) compared to a higher average peel firmness (20.77N) for the treated fruits which occurred by day 14 (Figure 6A). Treated cold stored (12°C) 'apple' mango fruit remained firm longer than the untreated. Treated fruit's firmness decreased from 115.78N to 29.05N (day 22) compared to 14.19N (day 28) for the untreated fruits (Figure 6B).

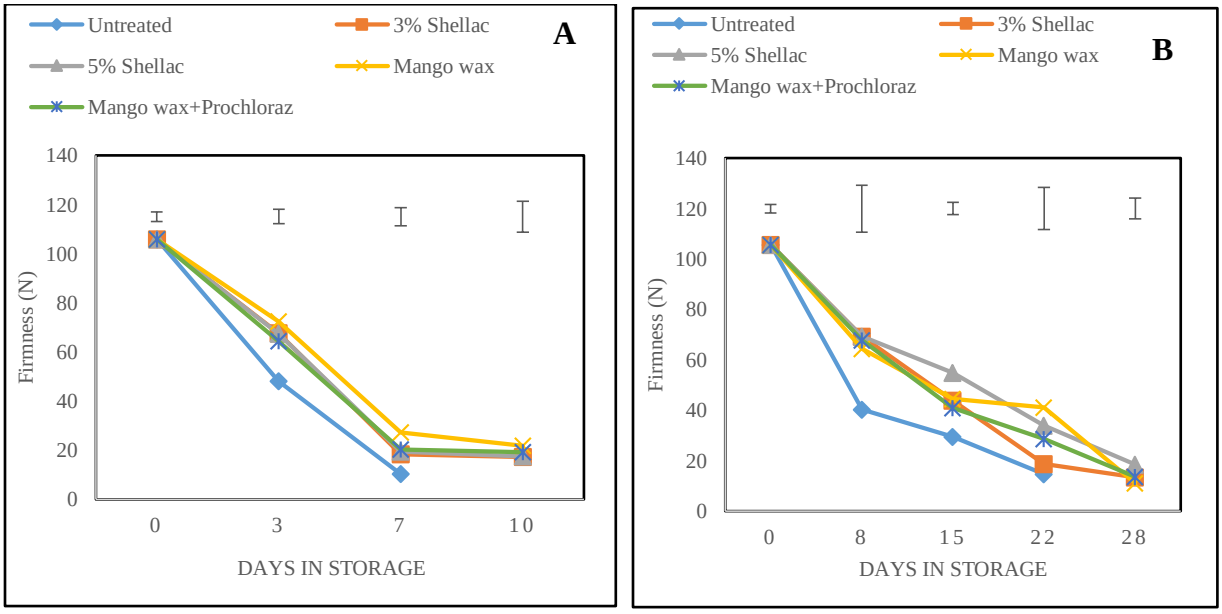

Figure 5: Changes in peel firmness (N) for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

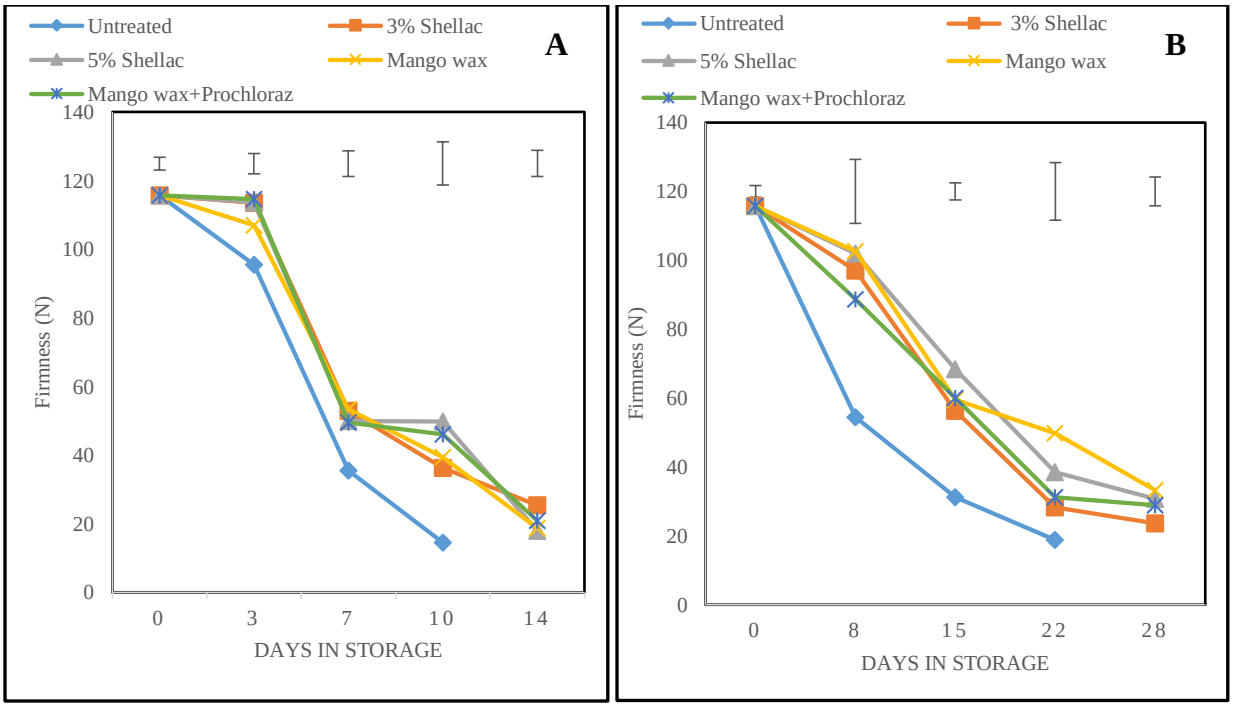

Figure 6: Changes in peel firmness (N) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

4.1.4 Changes in pulp firmness

Pulp firmness decreased as ripening progressed for all the fruits in the different storage conditions. Cold stored (12°C) fruits had a higher pulp firmness each sampling day compared to ambient (25°C) stored fruits (Figure 7 and 8) throughout storage. Waxing slowed the rate of loss of pulp firmness compared to the untreated fruits in both storage conditions. A combination of cold storage and waxing retained pulp firmness longer indicating influence of storage temperature on efficacy of waxing. There was no significant ($p<0.05$) difference between the different waxing options. Pulp firmness for untreated ‘ngowe’ mango fruits stored at ambient storage conditions (25°C) decreased from an initial 40.16N to 9.13N (day 7) compared to an average of 10.77N for the treated fruits which occurred by day 10 (Figure 7A). For the cold stored ‘ngowe’ mango fruits,

untreated fruit's pulp firmness decreased to 2.81N (day 22) compared to an average of 4.57N (day 28) for the treated fruits (Figure 7B).

For the 'apple' mango fruits stored at ambient storage conditions (25°C), untreated fruit's pulp firmness decreased from an initial 64.28 to 5.83N (day 10) compared to an average of 10.77N (day 14) for the treated fruits (Figure 8A). The cold stored (25°C) 'apple' mango fruit's pulp firmness for the untreated decreased to 11.9N (day 15) compared to an average of 25.29N for the treated fruits on the same day of sampling (Figure 8B).

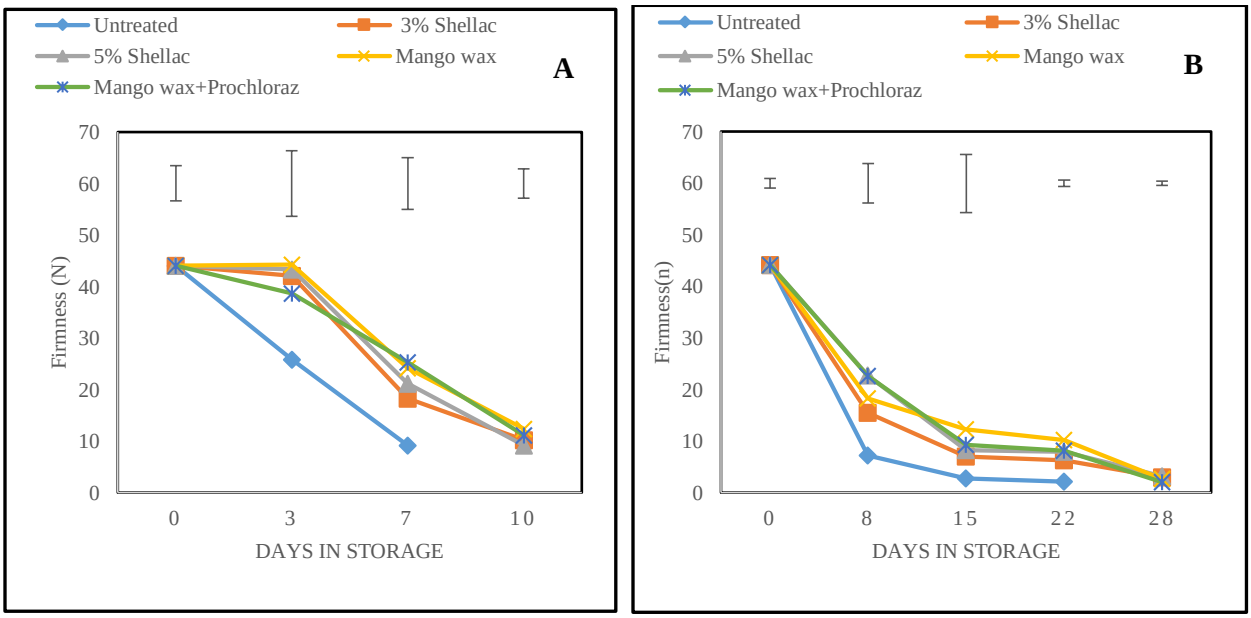

Figure 7: Changes in pulp firmness (N) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

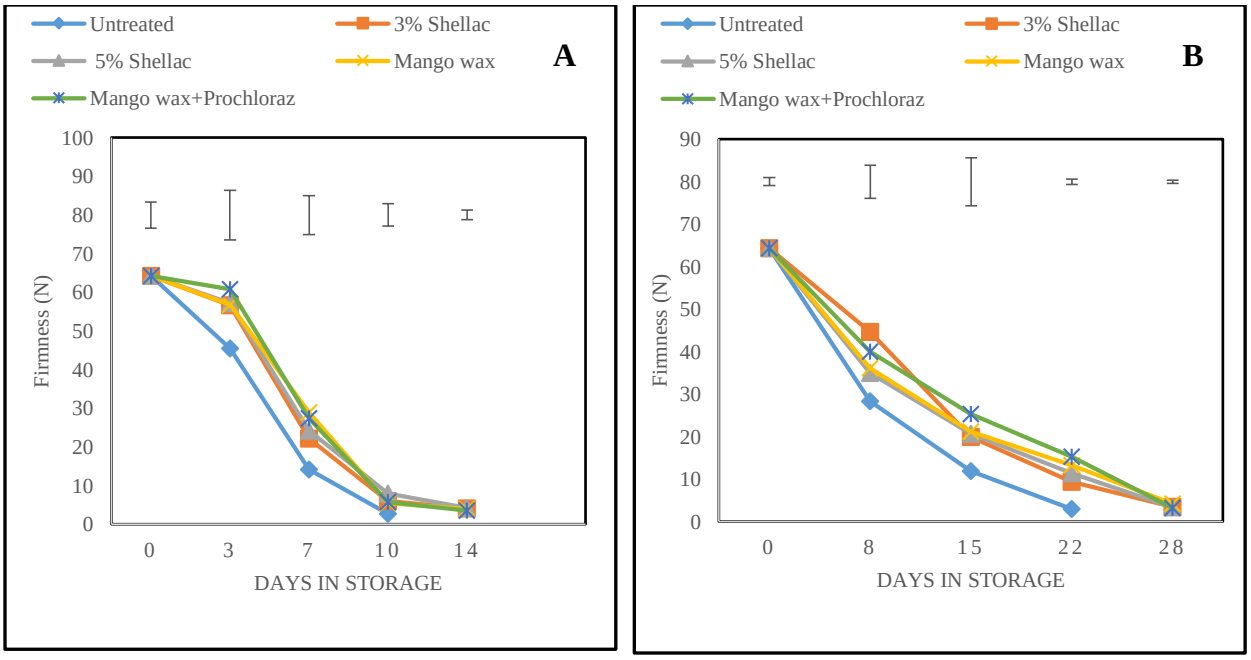

Figure 8: Changes in pulp firmness (N) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

4.1.4 Changes in peel hue angle

A general decrease in peel hue angle was observed in all fruits irrespective of treatment or storage conditions. Cold stored (12°C) fruits had a delayed color development compared to ambient stored fruits (25°C) of both varieties, indicating effect of storage temperature on efficacy of waxing (Table 1B and 2B). 'Ngowe' mango fruits retained high peel hue (plate 4 and 5) than 'apple' mangos (plate 2 and 3) in all storage conditions throughout the storage time. For the 'ngowe' mango fruits stored under ambient storage (25°C), untreated fruit's peel hue decreased from an initial of 116.31° to 87.12° (day 7) compared to an average of 97.26° (day 10) for the treated (Table 1A). For the cold stored (12°C) 'ngowe' mango fruits, peel hue angle for the

untreated reduced to 100.22° (day 22) compared to an average of 103.64° (day 28) for the treated fruit (Table 1B).

For the ‘apple’ mango fruits stored under ambient storage (25°C), untreated fruit’s peel hue decreased from an initial 112.78° to 63.13° (day 10) compared to an average of 75.99° (day 14) (Table 2A). For the cold stored ‘apple’ mango fruits, peel hue angle decreased to 70.04° for the untreated by day 22, compared to 86.4° for the treated fruits which occurred by day 28 (Table 2B).

Table 1A: Changes in Peel Hue angle (H°) for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	116.31a	101.23a	87.12a	
3% Shellac Wax	116.31a	111.23b	104.98b	99.23a
5% Shellac Wax	116.31a	113.13b	107.76b	96.26a
Mango Wax	116.31a	110.12b	106.56b	92.34b
Mango Wax+Prochloraz	116.31a	114.16b	103.48b	101.24a
MEAN	116.31	109.97	101.98	97.26
LSDs	2.649	2.45	5.58	5.634

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 1B: Changes in Peel Hue angle (H °) of 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	116.31a	101.23a	88.24a	83.56a	
3% Shellac Wax	116.31a	109.89a	101.83b	98.12b	92.76a
5% Shellac Wax	116.31a	115.58b	110.38b	99.16b	95.13a
Mango Wax	116.31a	116.88b	109.45b	100.34b	96.34a
Mango Wax+Prochloraz	116.31a	114.16b	112.2b	103.78b	99.26b
MEAN	116.31	111.53	104.42	96.99	95.87
LSDs	2.649	9.251	5.04	5.58	4.51

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 2A: Changes in Peel Hue angle (H °) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	112.78a	90.12a	68.98a	63.13a	
3% Shellac Wax	112.78a	106.45b	95.14b	86.34b	68.23a
5% Shellac Wax	112.78a	109.34b	92.95b	85.31b	78.45b
Mango Wax	112.78a	105.87b	90.94b	87.12b	79.33b
Mango Wax+Prochloraz	112.78a	101.56a	91.23b	84.34b	77.97b
MEAN	112.78	102.66	87.84	79.24	75.99
LSDs	2.649	2.45	5.58	5.634	3.39

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 2B: Changes in Peel Hue angle (H °) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in storage				
TREATMENT	0	8	15	22	28
Untreated	112.78a	96.43a	81.45a	70.04a	
3% Shellac Wax	112.78a	109.8b	101.99b	103.41b	98.77a
5% Shellac Wax	112.78a	107.4b	102.83b	100.11b	87.84b
Mango Wax	112.78a	110.72b	103.3b	89.31c	82.49b
Mango Wax+Prochloraz	112.78a	109.33b	102.37b	87.83c	76.48c
MEAN	112.78	106.73	98.38	90.14	86.3
LSDs	2.649	9.251	5.4	5.58	4.51

Means within each column followed by different letter differ significantly at ($p<0.05$)

At Day 0

Plate 2: Peel color change by end of storage period for ‘apple’ mango fruits which were stored in ambient room conditions (from day 0 to day 10)

At Day 0

Plate 3: Peel color change by end of storage period for 'apple' mango fruits which were stored in cold temperature (12°C) conditions (from day 0 to day 28)

Untreated-Day 0 | Untreated Day 7 | 3% Shellac wax Day10

5 % Shellac Wax Day 10 | Mango wax | Mango wax +Prochloraz

Plate 4: Peel color change by end of storage period for 'ngowe' mango fruits which were stored in ambient room conditions (from day 0 to day 10)

At Day 0

Plate 5: Peel color change by end of storage period for 'ngowe' mango fruits which were stored in cold storage conditions (from day 0 to 28)

4.1.5 Changes in pulp hue angle

A general decrease in pulp Hue angle was observed in all fruits as ripening progressed irrespective of treatment or storage conditions. Cold storage (12°C) combined with waxing delayed color development compared to waxing combined with ambient (25°C) storage, indicating effect of storage temperature on efficacy of waxing. 'Ngowe' mango fruits retained higher hue angle compared to 'apple' mango fruits in the different storage conditions. There was no significant difference between the different waxing options. The hue angle for the untreated 'ngowe' mango fruits stored at ambient temperature (25°C) decreased from an initial 92.51° to 76.38° (day 7) compared to an average of 82.19° (day 10) for the treated fruits (Table 3A). For the ngowe mango fruits under cold storage, untreated pulp hue decreased to 78.39° (day 22) compared to an average of 81.71° (day 28) for the treated fruits (Table 3B).

Pulp hue for untreated apple mango fruits at ambient (25°C) decreased from an initial 91.47° to 69.17° (day 10) compared to an average of 67.9° (day 14) for the treated fruits (Table 4A). For the cold stored apple mango fruits, untreated pulp hue decreased to 70.49° (day 22) compared to an average of 70.28° (day 28) for the treated fruits (Table 4B).

Table 3A: Changes in Pulp hue angle (H°) for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	92.51a	81.8a	76.38a	
3% Shellac Wax	92.51a	91.3b	82.4b	82.56a
5% Shellac Wax	92.51a	89.3b	80.78b	81.05a
Mango Wax	92.51a	87.1b	85.16c	82.59a
Mango Wax+Prochloraz	92.51a	85.8b	81.19b	82.57a
MEAN	92.51	87	81.18	82.19
LSDs	2.196	3.543	2.844	4.92

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 3B: Changes in Pulp hue angle (H°) for 'ngowe' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	92.51a	83.7a	81.69a	78.39a	
3% Shellac Wax	92.51a	84.23a	84.5a	83.54b	80.62a
5% Shellac Wax	92.51a	84.86a	85.55a	84.48b	80.6a
Mango Wax	92.51a	83.79a	83.1a	81.82b	83.94a
Mango Wax+Prochloraz	92.51a	83.48a	83.9a	81.68b	81.66a
MEAN	92.51	84.01	83.75	81.98	82.27
LSDs	1.093	4.264	4.626	1.878	3.329

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 4A: Changes in Pulp hue angle (H °) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	91.47a	90.4a	70.22a	69.17a	
3% Shellac Wax	91.47a	91.4a	84.83b	71.05a	65.75a
5% Shellac Wax	91.47a	90.7a	74.71c	77.64b	69.59a
Mango Wax	91.47a	90.6a	73.87c	74.59a	68.12a
Mango Wax+Prochloraz	91.47a	90.7a	75.62c	73.24a	68.14a
MEAN	91.47	90.76	75.85	73.14	67.9
LSDs	2.196	3.543	2.844	4.92	3.494

Means within each column followed by different letter differ significantly at ($p<0.05$)

Table 4B: Changes in Pulp hue angle (H °) for 'apple' mango fruits which were treated with either 3% Shellac wax, 5% Shellac wax, Mango wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	91.47a	77.41a	71.86a	70.49a	
3% Shellac Wax	91.47a	89.57b	80.9b	75.13b	70.59a
5% Shellac Wax	91.47a	84.31b	85.11b	76.54b	70.25a
Mango Wax	91.47a	85.54b	76.68a	71.46a	70.85a
Mango Wax+Prochloraz	91.47a	81.15a	86.58b	72.81a	71.7a
MEAN	91.47	83.6	80.23	73.29	70.28
LSDs	1.093	4.264	4.626	1.878	3.329

Means within each column followed by different letter differ significantly at ($p<0.05$)

4.2 The Effect of Waxing on the Postharvest Quality Attributes of ‘Apple’ and ‘Ngowe’ Mango Fruits Stored Under Different Storage Conditions

4.2.1 Changes in Total Soluble Solids (TSS)

An increase in TSS was observed in all fruits as ripening progressed. Cold storage (12°C) slowed the rate of increase of TSS compared to ambient storage (25°C). Waxing combined with cold storage (12°C), reduced increase in TSS in both varieties (Table 5B and 6B) indicating effect of storage temperature on the efficacy of waxing. ‘Apple’ mango fruits had higher TSS levels compared to ‘ngowe’ mango fruits in both storage conditions (Table 6Aand B). Under ambient storage conditions (25°C), untreated ‘ngowe’ mango fruits TSS level increased from an initial 10.5° brix to 20.3°brix (day 7) compared to a low level of 18.5°brix and 19.4°brix for 5% Shellac wax and mango wax+prochloraz respectively occurring by day 14 (Table 5A). Cold stored (12°C) ‘ngowe’ mango fruits TSS for untreated increased to 21.7°brix (day 15) compared to treated fruits TSS levels which was low 19.55°brix (day 15) and 19.05°brix (day 22) for 5% Shellac wax and mango wax+prochloraz respectively (Table 5B).

For the ‘apple’ mango fruits, TSS for untreated fruits increased from an initial 7.55°brix to 15.47°brix (day 10) compared to 15.95°brix and 13.1°brix for 5%Shellac wax and Mango wax+prochloraz respectively by day 14 (Table 6A). For the ‘apple’ mangos in cold storage, untreated TSS levels increased to 20.88°brix (day 15) compared to 19.65°brix (day 15) and 19.05°brix (day 28) for 5% Shellac and Mango wax +Prochloraz respectively (Table 6B). Overall, Mango wax+Prochloraz was effective in retaining higher TSS throughout storage for both ‘ngowe’ and ‘apple’ mango fruits.

Table 5A: Changes in total soluble solids (°Brix) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient.

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	10.5a	15.97a	20.03a	
5% Shellac Wax	10.5a	13.43b	18.85a	18.5a
Mango Wax+Prochloraz	10.5a	14.55b	19.15a	19.4a
MEAN	10.5	14.65	19.34	18.95
LSDs	1.427	1.647	1.889	3.258

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 5B: Changes in total soluble solids (°Brix) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	10.5a	18.37a	21.43a	16.54a	
5% Shellac Wax	10.5a	16.5a	19.55b	15.9a	17.2a
Mango Wax+Prochloraz	10.5a	15.65a	15.45c	16.13a	22.2b
MEAN	10.5	16.84	18.81	16.19	19.7
LSDs	1.427	2.866	2.055	2.984	3.082

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 6A: Changes in total soluble solids (°Brix) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient.

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	7.55a	8.5a	14.2a	15.47a	
5% Shellac Wax	7.55a	7.75a	12.73a	12.63a	15.95a
Mango Wax+Prochloraz	7.55a	7.4a	12.13a	13.9a	13.1a
MEAN	7.55	7.88	13.68	14	14.52
LSDs	1.427	1.647	1.889	3.258	3.798

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 6B: Changes in total soluble solid (°Brix) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	7.55a	17.75a	20.88a	17.05a	
5% Shellac Wax	7.55a	15.25b	19.65a	17.9a	17.52a
Mango Wax+Prochloraz	7.55a	14.33b	16.3b	16.25a	19.05a
MEAN	7.55	15.77	18.94	17.06	18.28
LSDs	1.427	2.866	2.055	2.984	3.082

Means within each column followed by different letter differ significantly at ($p<0.05$).

4.2.2 Total titratable acidity (TTA)

A general decrease in TTA content was observed in all fruits as ripening progressed, but the rate was lower in cold storage (12°C) compared to ambient storage (25°C) (Table 7B and 8B). 'Apple' mango had slightly higher TTA compared to 'ngowe' mango fruits. Under ambient storage conditions (25°C), untreated 'ngowe' mango fruit lost 86.35% equivalent of citric acid by day 7

compared to an average of 62.78% for the treated fruits that occurred by day 10 (Table 7A). For the cold stored ‘ngowe’ mango, untreated fruits TTA decreased to 0.205% (day 22) compared to 0.244% and 0.222% for 5% Shellac wax and Mango wax+ prochloraz (day 28) (Table 7B).

For the ‘apple’ mango fruits stored under ambient conditions (25°C), the untreated fruits lost 77.57% equivalent of citric acid by day 10 compared an average of 79.39% for the treated fruits by day 14 (Table 8A). For the cold stored (12°C), ‘apple’ mango, untreated fruits lost 2.79% more citric acid 6 days earlier than the treated fruits (Table 8B).

Table 7A: Changes in Total Titratable acidity (% citric acid) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	0.755a	0.378a	0.103a	
5% Shellac Wax	0.755a	1.150b	0.180a	0.288a
Mango Wax+Prochloraz	0.755a	1.133c	0.467b	0.274a
Means	0.755	0.887	0.25	0.281
LSDs	0.265	0.230	0.112	0.081

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 7B: Changes in Total Titratable acidity (% citric acid) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	0.755a	0.352a	0.395a	0.205a	
5% Shellac Wax	0.755a	0.778b	0.660b	0.404b	0.244a
Mango Wax+Prochloraz	0.755a	0.667b	0.533c	0.364b	0.222a
Means	0.742	0.599	0.531	0.324	0.233
LSDs	0.2529	0.106	0.065	0.118	0.049

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 8A: Changes in Total Titratable acidity (% citric acid) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	0.932a	0.818a	0.278a	0.209a	
5% Shellac Wax	0.932a	1.126b	0.598b	0.323b	0.191a
Mango Wax+Prochloraz	0.932a	1.150b	0.427c	0.297b	0.194a
Means	0.932	1.064	0.434	0.278	0.192
LSDs	0.265	0.230	0.112	0.081	0.111

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 8B: Changes in Total titratable acidity (% citric acid) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage.

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	0.932a	0.397a	0.381a	0.268a	
5% Shellac Wax	0.932a	0.772b	0.624b	0.555b	0.303a
Mango Wax+Prochloraz	0.932a	0.682b	0.491c	0.469b	0.285a
Means	0.932	0.617	0.499	0.430	0.294
LSDs	0.265	0.106	0.065	0.118	0.049

Means within each column followed by different letter differ significantly at ($p<0.05$).

4.2.3 Beta-carotene

There was a gradual increase in β-carotene content as ripening progressed in all fruits, but the rate was slower in cold (12°C) stored fruits compared to ambient stored (25°C) fruits (Figure 9 and 10). 'Apple' mango had higher β-carotene content compared to 'ngowe' mango fruits in both storage conditions (Figure 9 and 10). Waxing delayed β-carotene development in both varieties in the irrespective of storage conditions. β-carotene levels for the untreated ambient stored (25°C) 'ngowe' mango fruits increased rapidly from an initial 3.31µg/100ml to 5.30µg/100ml by day 7 compared to 5.17µg/100ml and 4.83µg/100ml for 5% Shellac wax and Mango wax+prochloraz respectively by day 10 (Figure 9A). The trend was similar for cold stored (12°C) 'ngowe' mango fruits. The untreated fruit's β-carotene content increased to a high level of 11.09µg/100ml (day 22) compared to 4.06 µg/100ml and 4.75 09µg/100ml for 5% shellac wax and Mango wax +Prochloraz by day 28 (Figure 9B).

β-carotene content for the untreated 'apple' mango fruits under ambient storage conditions (25°C) increased from an initial of 1.83µg/100ml to a high level of 7.52µg/100ml (day 10) compared to the treated fruits whose beta carotene content increased to 5.51 µg/100ml and 5.15 µg/100ml for 5% Shellac wax and Mango wax+Prochloraz respectively by day 14 (Figure 10A). For the cold stored (12°C) 'apple' mango fruits, untreated fruit's beta carotene increased to a high level (11.88µg/100mL) by day 22 compared to 5.35 µg/100ml and 7.64 µg/100ml for 5% Shellac wax and Mango wax+Prochloraz respectively by day 28 (Figure 10B).

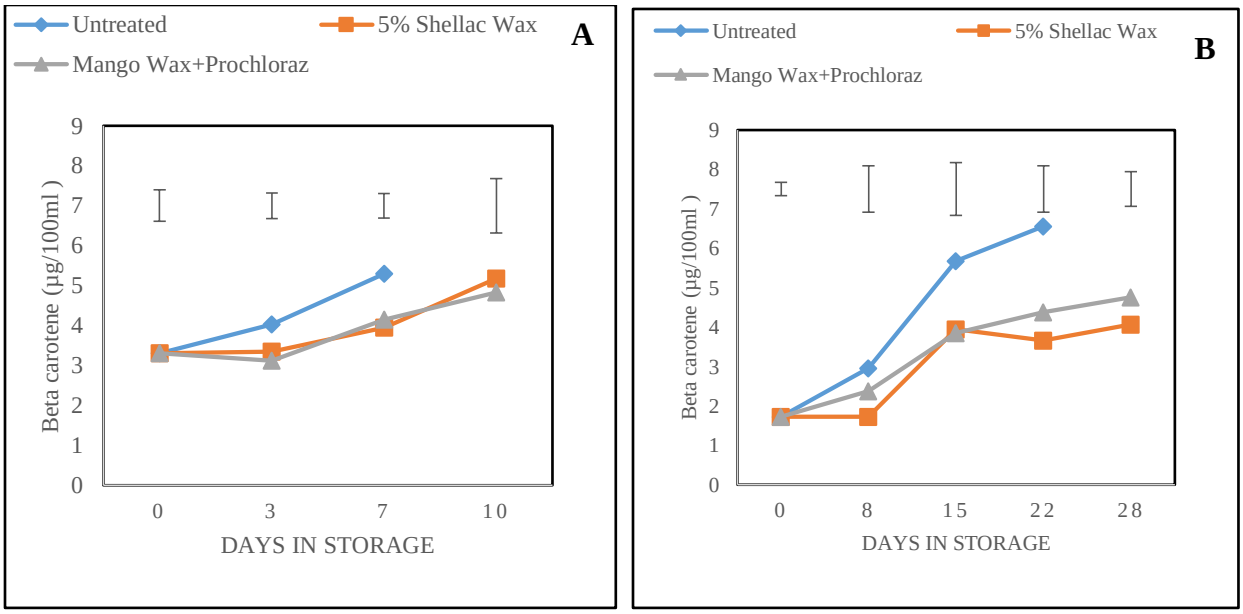

Figure 9: Changes in Beta carotene (µg/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

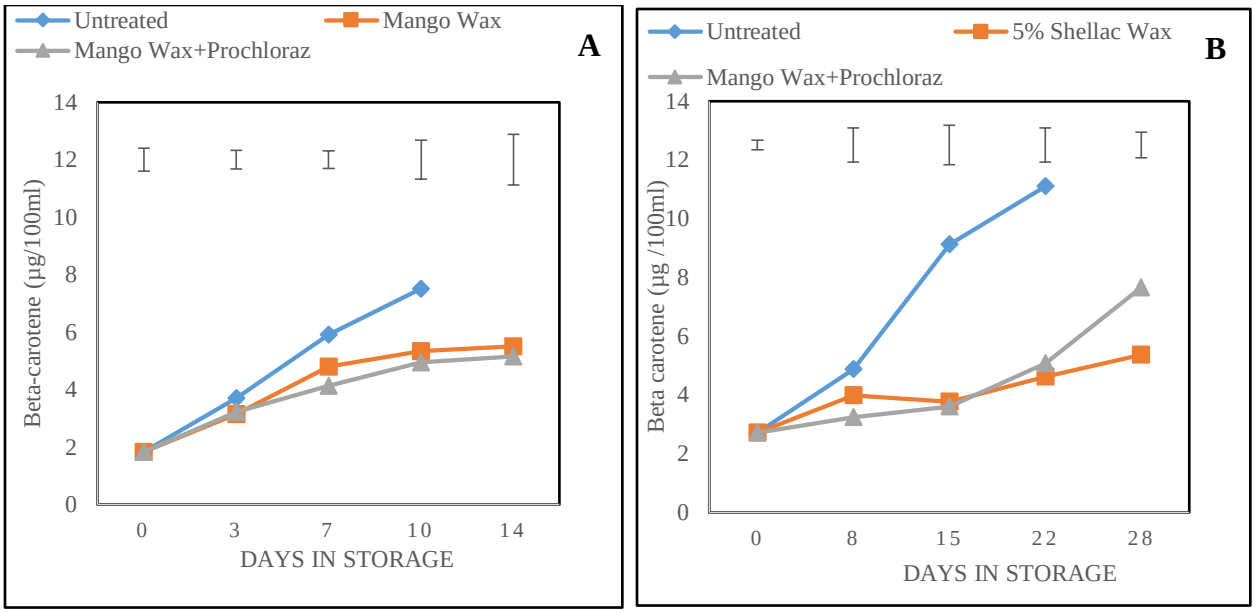

Figure 10: Changes in Beta carotene (µg/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated and stored in ambient (A) and cold storage (B) respectively. Top bars represent least significant difference (LSD) of means (p=0.05)

4.2.4 Vitamin C

Vitamin C content for all the fruits gradually decreased as ripening progressed in both varieties under the different storage conditions (Table 9 and 10). The decrease in vitamin C content was affected by the interaction between variety and coating. 'Apple' mango had slightly higher vitamin C content in both storage conditions compared to ngowe. Fruits stored in cold storage (12°C) had significantly ($p<0.05$) reduced rate of vitamin C loss compared to ambient stored (25°C) fruits. There was no significant difference between the different waxing options in the different storage conditions except after day 15 and day 22 for 'apple' mango in cold storage (Table 10D). Vitamin C content for the untreated 'ngowe' mango fruits under ambient storage (25°C) decreased rapidly from an initial 45mg/100ml to 6.15mg/100ml by end of storage period (day 7) compared to 5.05mg/100ml and 5.55mg/100ml for 5% Shellac wax and Mango wax+Prochloraz

respectively by day 10 (Table 9A). For the cold stored ‘ngowe’ mango fruits, untreated fruit’s vitamin C content reduced to 13.65mg/100ml (day 22) compared to 18.2 mg/100ml and 14.6mg/100ml for the treated fruits occurring by day 28 (Table 9B).

The trend was not different for ‘apple’ mango fruits. The ambient stored (25°C) untreated fruits vitamin C content reduced from an initial 71.5mg/100ml to 20.6mg/100ml (day 10) compared to 26.59mg/100ml and 26.84mg/100ml for 5% Shellac wax and Mango wax+Prochloraz respectively on the same day of sampling (Table 10A). ‘Apple’ mango fruits under cold storage retained the highest vitamin C content by end of storage compared to ambient stored (25℃) fruits. The untreated fruit’s vitamin C content decreased to 36.2mg/100ml by day 22 compared to 55.37mg/100ml and 44.25mg/100ml for % Shellac wax and Mango wax+Prochloraz respectively on the same day of sampling (Table 10B).

Table 9A: Changes in Vitamin C (mg/100ml) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

		Days in Storage		
TREATMENT	0	3	7	10
Untreated	45a	21a	6.15a	
5% Shellac Wax	45a	25.9a	14.06b	5.05a
Mango Wax+Prochloraz	45a	27.3a	12.58b	5.55a
Means	45	24.73	10.93	5.3
LSDs	20.69	9.21	5.494	2.252

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 9B: Changes in Vitamin C (mg/100ml) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	45a	23.7a	17.86a	13.65a	
5% Shellac Wax	45a	36a	21.25a	17.74a	18.2a
Mango Wax+Prochloraz	45a	31.8a	19.18a	20.49a	14.6a
Means	45	30.5	19.43	17.29	16.4
LSDs	20.13	9.28	5.365	8.362	12.5

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 10A: Changes in Vitamin C (mg/100ml) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	71.5a	29.6a	26.52a	20.6a	
5% Shellac Wax	71.5a	45.5b	36.76b	26.59b	11.48a
Mango Wax+Prochloraz	71.5a	40.2b	31.56b	26.84b	12.32a
Means	71.5	38.43	31.61	24.67	11.9
LSDs	20.69	9.21	5.494	2.252	4.024

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 10B: Changes in Vitamin C (mg/100ml) for 'apple' mango fruit which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	71.5a	56a	40.93a	36.2a	
5% Shellac Wax	71.5a	59.7a	57.21b	55.37b	29.3a
Mango Wax+Prochloraz	71.5a	64.2a	64.33c	44.25a	38.3a
Means	71.5	59.96	54.15	45.27	33.8
LSDs	20.13	9.28	5.365	8.362	12.5

Means within each column followed by different letter differ significantly at ($p<0.05$).

4.2.5 Changes in sugars

4.2.5.1 Fructose

Fructose content increased with progress in ripening in all fruits irrespective of coating and storage conditions, but the rate of increase was slower in cold temperature (12°C) stored fruits than ambient stored (25°C) fruits (Table 11 and 12). The increase in fructose content for both varieties was affected by waxing and storage conditions. Waxing combined with cold storage retained higher fructose levels than untreated control fruits in both varieties. Waxed ‘apple’ fruits retained higher fructose content compared to ‘ngowe’ mango fruits (Table 12A and 12B). There was no significant difference among the different waxing options but Mango wax+prochloraz retained slightly lower fructose content in all storage conditions except for ‘ngowe’ mango fruits in cold storage. Fructose content for the untreated ‘ngowe’ mango fruits in ambient storage (25°C) increased from an initial 2.04g/100g to a high level of 5.56g/100g by end of storage period (day 7) compared to 6.43g/100g and 5.99g/100g for 5% shellac wax and Mango wax+Prochloraz by

day 10 (Table 11A). For the ‘ngowe’ mango fruits in cold storage (12°C), untreated fruit fructose content increased to a high level of 7.04g/100g (day 22) compared to 7.93g/100g and 7.87g/100g for 5% shellac wax and Mango wax+Prochloraz by day 28 (Table 11B).

The trend in fructose content for the ambient stored (25°C) ‘apple’ mango fruits was not different from that of ‘ngowe’ mango fruits. The untreated fruit’s fructose content increased from an initial 5.99g/100g to a high level of 11g/100g (day 10) compared to 9.71g/100g and 9.53g/100g for 5% shellac wax and Mango wax+Prochloraz by day 14 (Table 12A). For the cold stored (12°C) ‘apple’ mango fruits, the untreated fruits fructose increased to a high level 10.48g/100g (day15) compared to 10.45g/100g and 11.45g/100g for 5% shellac wax and Mango wax+Prochloraz by day 28 (Table 12B). Although 5% Shellac wax and Mango wax+prochloraz maintained relatively lower fructose levels compared to the untreated during the storage period, retained relatively higher fructose levels to the end of storage period.

Table 11A: Changes in fructose content (g/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

		Days in Storage		
TREATMENT	0	3	7	10
Untreated	2.04a	5.01a	5.56a	
5% Shellac Wax	2.04a	5.25b	6.24b	6.43a
Mango Wax+Prochloraz	2.04a	5.73c	5.88b	5.99b
Means	2.04	6.01	5.89	6.79
LSDs		0.25	0.4	0.299

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 11B: Changes in fructose content (g/100g) for 'ngowe' mango fruit which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	2.04a	3.02a	6.74a	7.04a	
5% Shellac Wax	2.04a	2.12b	4.77b	5.85b	7.93a
Mango Wax+Prochloraz	2.04a	2.42b	5.05b	6.57b	7.87a
Means	2.04	2.52	5.52	6.49	8.02
LSDs		0.138	0.187	0.901	0.319

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 12A: Changes in fructose content (g/100g) for 'apple' mango fruit which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	5.99a	9.11a	11.57a	11a	
5% Shellac wax	5.99a	5.03b	7.67b	9.54b	9.71a
Mango Wax+Prochloraz	5.99a	4.27c	7.02b	9.57b	9.53a
Means	5.99	6.14	8.75	10.04	9.62
LSDs		0.25	0.4	0.29	0.089

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 12B: Changes in fructose content (g/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	5.99a	9.14a	10.48a	8.8a	
5% Shellac Wax	5.99a	7.01b	9.94b	10.74b	10.45a
Mango Wax+Prochloraz	5.99a	7.76c	8.81b	8.4c	11.45b
Means	5.99	7.97	9.74	9.31	10.95
LSDs		0.138	0.187	0.901	0.319

Means within each column followed by different letter differ significantly at ($p<0.05$).

4.2.5.2 Glucose

Just like fructose, glucose levels in all the fruits increased with progression in ripening of the fruits, but the rate of increase was slower in cold stored fruits than ambient stored (Table 13B and 14B), indicating influence of storage temperature on efficacy of waxing. The increase in glucose content was significantly ($p<0.05$) affected by the interaction between waxing and variety. ‘Apple’ mango had slightly higher glucose content compared to ‘ngowe’ mango in both storage conditions. In ambient storage conditions (25°C), untreated ‘ngowe’ mango fruits glucose levels increased from an initial 0.92g/100g to a high level of 4.81g/100g (day 7) compare to 4.15g/100g and 3.32g/100g for 5% shellac wax and Mango wax+Prochloraz respectively by day 10 (Table 13A). For the cold stored (12°C) ‘ngowe’ mango fruits, untreated fruit’s glucose content increased to 5.1g/100g (day 22) compared to 4.74g/100g and 4.74g/100g for 5% shellac wax and Mango wax+Prochloraz respectively by day 28 (Table 13B).

Increase in glucose content for the ‘apple’ mango fruits followed a similar trend as that of ‘ngowe’. Untreated fruits glucose content under ambient storage (25°C) increased from an initial

of 1.38g/100g and increased to a high level of 5.02g/100g (day 10) compared to 4.28g/100g and 4.02g/100g for 5% shellac wax and Mango wax+prochloraz respectively by day 14 (Table 14A). For the ‘apple’ mango fruits in cold storage (12°C), untreated fruits glucose content rose to a high level of 6.97g/100g (day 22) compared to 5.75g/100g and 6.06g/100g for 5% shellac wax and Mango wax+Prochloraz respectively by day 28 (Table 14B).

Table 13A: Changes in glucose content (g/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	0.92a	3.12a	4.81a	
5% Shellac Wax	0.92a	2.62b	3.09b	4.15a
Mango Wax+Prochloraz	0.92a	2.70b	3.33b	3.32b
Means	0.92	2.82	3.74	3.74
LSDs		0.173	0.133	0.204

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 13B: Changes in glucose content (g/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	0.92a	2.70a	4.55a	5.10a	
5% Shellac Wax	0.92a	2.50b	3.83b	4.00b	4.74a
Mango Wax+Prochloraz	0.92a	2.30b	3.30c	3.66c	4.74a
Means	0.92	2.50	3.89	4.25	4.68
LSDs		0.113	0.12	0.158	0.129

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 14A: Changes in glucose content (g/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	1.38a	3.67a	5.55a	5.02a	
5% Shellac wax	1.38a	1.88b	3.22b	3.54b	4.28a
Mango Wax+Prochloraz	1.38a	2.12c	2.46c	3.36b	4.02a
Means	1.38	2.56	3.6	3.98	4.1
LSDs		0.173	0.133	0.204	0.297

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 14B: Changes in glucose content (g/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	1.38a	3.0a	5.62a	6.97a	
5% Shellac Wax	1.38a	2.1b	3.69b	4.05b	5.75a
Mango Wax+Prochloraz	1.38a	2.9c	3.84b	5.72c	6.06b
Means	1.03	2.6	4.38	5.58	5.95
LSDs		0.113	0.12	0.158	0.129

Means within each column followed by different letter differ significantly at ($p<0.05$).

4.2.5.3 Sucrose

Sucrose content increased gradually as ripening progressed in both varieties irrespective of treatment and storage condition, but the rate of increase was slower in cold stored fruits than

ambient stored. The increase in sucrose content was significantly ($p<0.05$) affected by the interaction between variety and treatment. ‘Apple’ mango fruits had higher sucrose content compared to ‘ngowe’ mango fruits (Table 16). There was no significant ($p<0.05$) difference among the two waxes except in day 7 for ‘ngowe’ (Table 15A) and day 7 and 10 for ‘apple’ in ambient storage (25°C) (Table 16A) storage. In cold storage (12°C) the difference was observed in day 22 for ‘ngowe’ (Table 15B) and day 8 for apple mango fruit (Table 16B).

The sucrose level for the untreated ‘ngowe’ mango fruits under ambient storage (25°C) increased from an initial 3.93g/100g to a high level of 8.26g/100g (day 7) compared to 8.84g/100g and 9.10g/100g for 5% shellac wax and Mango wax+prochloraz by day 10 (table 15A). Similar trend was observed in cold stored (12°C) fruits. The untreated ‘ngowe’ peaked to 6.01g/100g (day 22) compared to 5.46g/100g and 5.18g/100g for 5% shellac wax and Mango wax+Prochloraz respectively by day 28 (Table 15B).

For the ‘apple’ mango fruits in ambient storage (25°C), sucrose content increased from an initial of 1.88g/100g to a high level of 8.39g/100g (day 10) compared to 9.81g/100g and 8.90g/g for 5% shellac wax and Mango wax+Prochloraz respectively by day 14 (Table 16A). For the cold stored (12°C) ‘apple’ mango fruits, the untreated fruit sucrose level increased to 9.75g/100g (day 22) compared to 10.42g/100g and 9.86g/100g for 5% shellac wax and Mango wax+prochloraz respectively by day 28 (Table 16B).

Table 15A: Changes in sucrose content (g/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage			
TREATMENT	0	3	7	10
Untreated	3.93a	7.94a	8.26a	
5% Shellac Wax	3.93a	5.72b	6.17b	8.84a
Mango Wax+Prochloraz	3.93a	5.94b	7.04c	9.10a
Means	3.94	6.54	7.16	8.97
LSDs		0.276	0.341	0.201

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 15B: Changes in sucrose content (g/100g) for 'ngowe' mango fruits which were treated with either 5% Shellac wax or Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	3.93a	3.48a	5.49a	6.01a	
5% Shellac Wax	3.93a	2.05b	4.42b	4.94b	5.46a
Mango Wax+Prochloraz	3.93a	1.95b	4.19b	4.11c	5.18a
Means	3.94	2.49	4.7	5.02	5.25
LSDs	0.121	0.161	0.319	0.182	0.112

Means within each column followed by different letter differ significantly at ($p<0.05$).

2Table 16A: Changes in sucrose content (g/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in ambient

	Days in Storage				
TREATMENT	0	3	7	10	14
Untreated	1.88a	4.95a	9.03a	8.39a	
5% Shellac wax	1.88a	2.98b	8.01b	9.75b	9.81a
Mango Wax+Prochloraz	1.88a	3.02b	7.21c	8.95c	8.9b
Means	1.89	3.65	8.09	9.03	8.95
LSDs		0.276	0.341	0.201	0.381

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 16B: Changes in sucrose content (g/100g) for 'apple' mango fruits which were treated with either 5% Shellac wax, Mango wax+prochloraz or left Untreated (Control) and stored in cold storage

	Days in Storage				
TREATMENT	0	8	15	22	28
Untreated	1.88a	4.82a	7.51a	9.75a	
5% Shellac Wax	1.88a	3.68b	4.38b	7.97b	10.42a
Mango Wax+Prochloraz	1.88a	2.97c	4.23b	8.14b	9.86a
Means	1.89	3.82	5.37	8.62	10.21
LSDs	0.121	0.161	0.319	0.182	0.112

Means within each column followed by different letter differ significantly at ($p<0.05$).

CHAPTER FIVE

5.0 GENERAL DISCUSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

Waxing is a simple and easy to adopt postharvest technology that has been used for several decades to preserve perishables (Baldwin, 1994). Waxing helps to extend shelf life of fresh commodities by altering the internal gas composition and by reducing the rate of transpiration. In climacteric fruits like mango, the altered internal atmosphere (high CO_2, low O_2 and high humidity) results in beneficial effect such as reduced respiration rate, water loss (Dia-Mulla *et al*., 2011) and other physical and biochemical changes associated with fruit ripening (Karacay and Ayhan, 2009).

In the first experiment, the efficacy of waxing to extend shelf life was established in 'ngowe' and 'apple' mango fruits. Different waxing options were compared with untreated fruits in different storage environments. Results showed that waxing was effective in extending shelf life of 'apple' and 'ngowe' mango fruits by delaying ripening-related attributes such as respiration, weight loss, color and firmness changes. Under ambient room conditions, waxed fruits had an extended shelf life of 3 and 4 days for ngowe and apple respectively, and for 6 days under cold storage conditions (12ºC). Findings from this study compare with other findings on effect of waxing on mango and bananas (Khaliq *et al.,* 2015; Moalemiyan *et al*., 2012; Maqbool *et al*., 2011).

Weight loss, a major contributor to the postharvest deterioration of harvested perishable commodities occurs mainly due respiration and transpiration. In the present study, cumulative weight loss was observed in all fruits under the different storage conditions. Fruits under cold

storage lost less weight compared to the ambient stored. This could be attributed to high relative humidity and low temperature. Further, waxed fruits stored in the different storage conditions lost less weight compared to untreated. Case example of 'apple' mango fruits in which treated fruits lost 3.7% and 7.75% weight compared to the untreated 5.5% and 12.4% under cold and ambient storage conditions respectively. The observed reduced weight loss in the waxed fruits could be attributed to high relative humidity inside the fruits created by the coating which acted as a barrier to water movement from the fruit to the environment. In addition, the modified condition created by coating, may have contributed to reduced weight loss due to reduced respiration rates which translated into slower breakdown of stored carbohydrate reserve. The mediated effect on cumulative weight loss reduction by coating has been reported on mango treated with gum Arabic where untreated fruits lost 12% compared to 4% weight loss for the treated fruits (Khaliq et al., 2015). Positive effect of coating has also been reported on other commodities such as tomato (Ali *et al*., 2010), banana (Maqbool *et al*., 2011) and mango (de S. Medeiros *et al*., 2012). Overall, waxing had more effect on cumulative weight loss of 'apple' mango fruits under cold storage compared to apple in ambient and 'ngowe' mango fruits in either storage conditions.

Respiration rate increased as ripening progressed regardless of the storage conditions. The rate of respiration was higher under ambient (25°C) storage compared to cold (12°C) storage for the two mango varieties, as observed in 'apple' mango fruits stored in ambient (25°C) conditions whereby the untreated fruit CO_2 concentration increased to a high 85.09ml/kg hr compared to a low average peak 43.15ml/kg hr for the treated fruits by the end of storage period. The relatively low rate of respiration coupled with low respiratory peak for treated 'ngowe' and 'appl'mango fruits stored in both storage conditions could be attributed to low permeability to gases across the fruit surface. Similar results have been reported by Khaliq *et al* (2015) whereby mango coated

with chitosan had a low (18ml/kg hr) CO_2 concentration on the 14th day of storage compared to a high (58ml/kg hr) CO_2 concentration for the untreated on the same day (day 14) of sampling. Other deteriorative activities such as the effect of ethylene could have been slowed down due to the antagonistic nature of high CO_2 conditions created by the coating. Generally, coating and cold storage had a more synergistic effect on lowering respiration rate for the two mango varieties.

Peel and pulp firmness for all the fruits decreased with ripening during the storage period. Waxing coupled with cold (12°C) storage retained higher fruit firmness compared to waxed-ambient (25°C) stored fruits as observed in 'apple' mango fruits where the cold-stored fruit's peel firmness decreased to 29.05N (day 28) compared to 20.77N (day 14) for the ambient stored fruits. Decrease in firmness during ripening is associated with activities of the enzymes involved in cell wall metabolism including pectin methylesterase (PME), polygalacturonase (PG), endo-B-1,4-glucanase (EGase) and pectatelyase activities (Cheng *et al*., 2009). The delayed firmness loss in the waxed fruits could be attributed to reduced enzyme activity due to modified conditions of low O_2 and high CO_2 created by the coating. The study confirms other results reported on effect of coating on mango (Choke anan variety), whereby chitosan treated fruits retained high firmness (45N) compared to untreated fruit's low firmness (20N) by end of storage period (day 28) (Khaliq *et al*., 2015). Positive effect of coating on fruit's firmness has further been reported on mango (Moalemiyan *et al*., 2012) and banana (Maqbool *et al*., 2011).

Color (intensity and uniformity) is an important aspect most easily evaluated by consumer to define freshness and ripeness. Color change from green to orange is attributed to the loss of chlorophyll and appearance of other pigments (Medlicott *et al*., 1986). In the present study, peel and pulp hue angles decreased progressively with ripening in all fruits irrespective of treatment,

variety and storage. Cold stored fruits retained peel color longer compared to ambient stored fruits as evident by 'ngowe' mangos where the treated mangos peel hue decreased to 97.26° (cold stored) compared to 87.12° (ambient stored). Waxed fruits in both storage conditions had a reduced rate of chlorophyll breakdown compared to untreated which can be attributed to reduced enzyme activity due to conditions of high CO_2 levels inside the coated fruits. During mango ripening, it has been found that chlorophyll reduces substantially while other pigments such as carotenoids increase in concentration and anthocyanins decreases gradually (Medlicott *et al*., 1986).

In the second experiment, the best waxing option was identified, and the fruits' postharvest quality under different storage conditions evaluated. Although most of the waxing options performed well, Mango wax mixed with prochloraz (fungicide) and 5% Shellac wax preserved the fruit quality far above the untreated. Postharvest quality attributes of 'ngowe' and 'apple' mango fruits analyzed included TSS, TTA, beta carotene, vitamin C and soluble sugars.

Total soluble solids (TSS) and total titratable acidity (TTA) which are closely related influences consumers' acceptability. Increase in TSS during ripening is associated with the breakdown of stored carbohydrates to yield respiratory substrates necessary for maintaining the metabolic activities (Saranwong *et al*., 2003). In both storage conditions, TSS increased gradually for all fruits as ripening progressed, but the rate was relatively low each sampling day for the cold stored fruits compared to ambient stored. Further, cold storage and waxing delayed increase in TSS levels throughout the storage time compared to untreated and this could be attributed to reduced enzymatic activity due to low temperature and low metabolic activity due to low O_2 and high CO_2 concentration inside the fruits as created by the coating which was evident by high brix (20.88°brix) by day 15 in the untreated fruits compared to a low brix (19.05°brix) by day 28 for

the cold stored ‘apple’ mangos. Similar results have been reported on the effect of Chitosan on cold-stored mango where the untreated had high brix (22°brix) compared to low brix (11°brix) for the treated by end of storage period (day 28) (Khaliq *et al*., 2015). This correlates with the changes observed in major sugars (fructose, glucose and sucrose). The gradual increase in reducing sugars in waxed fruits can be attributed to slow ripening process (Youssef *et al*., 2000). The rapid increase in reducing sugars in the uncoated fruits might be due to a faster conversion of starch to sugars and reduction in acidity by physiological changes (Giradi *et al*., 2005). Ripening process leads to hydrolysis of starch into simple sugars, where sucrose, fructose and glucose become dominant (Ito *et al*., 1997). Starch is hydrolyzed by the activities of enzymes such as sucrose synthase, invertase and amylase producing sucrose (Kumar *et al*., 1994). Edible coating created a semipermeable membrane around the fruits which modifies the internal atmosphere leading to an increased CO_2 and decreased O_2 production (de S. Medeiros *et al*., 2012). Low respiration leads to a decreased metabolic activity and slow conversion of starch to sugars, a possible explanation of low sugar in the coated fruits. TTA decrease with ripening during storage can be attributed to organic acids being used as respiratory substrates (Giradi *et al*., 2005). TTA decrease was slower in waxed fruits compared to the control fruits throughout the storage period. The slowed change can be attributed to decreased metabolism due to low O_2 and high CO_2 and hence the slow loss of the respiratory substrate such as citric acid (Girardi *et al*., 2005).

Fruits are natural sources of vitamin C, but it has been found to decrease in levels during the ripening process. In general, a decrease in vitamin C levels was observed in all fruits in both storage conditions throughout the storage period. However, the highest loss of the vitamin was recorded in the untreated at the end of storage period. A combination of waxing and cold storage

reduced the rate of loss of vitamin C compared to ambient stored fruits which can be associated with low enzymatic activity due to low temperatures. The decrease in vitamin C can also be attributed to degradation through oxidation (Appiah *et al*., 2011). In the study (both experiment 1 and 2), waxed-cold stored fruits maintained high vitamin C content compared to the untreated by end of the storage period which could be attributed to low O_2 and high CO_2. 'Apple' mangos treated with mango wax+prochloraz retained high vitamin C content (38.3mg/100g) by day 28 compared to low vitamin C content (36.2mg/100g) for the untreated by day 22. This compares with studies where mango fruits treated with chitosan combined with gum Arabic retained a high vitamin C content (13.85mg/100mg) compared to low level (11.83mg/100mg) for the untreated by end of storage period (day 28) (Khaliq *et al*., 2015). In addition, vitamin C being water soluble, its relatively high retention in the waxed fruits could be attributed to the reduced water loss from the fruits through transpiration (Valero and Serrano, 2010). Generally, waxing had more effect on vitamin C retention in 'apple' mangos than 'ngowe' mango fruits.

The change of mango pulp color from cream to yellow/orange is attributed to accumulation of beta carotene. In the study, beta carotene content increased with storage time and as the fruits ripened but the increase was gradual for cold stored fruits compared to ambient, which could be attributed to reduced enzymatic processes due to low temperature (Jarimopas and Kitthawee, 2007).

Beta carotene content development for the waxed fruits in both storage conditions was delayed compared to untreated fruits probably due to delayed synthesis and accumulation of beta carotene as a result of low O_2 and high CO_2, which interfered with the enzymes involved in the synthesis or unmasking of preexisting color pigments (Mathooko, 2003: Artes *et al*., 2006), as

observed in ‘apple’ mangos under cold storage where the treated fruit had a low beta carotene content (6.50µg/100mL) compared to a high beta carotene content (11.09µg/100mL) for the untreated fruits by end of storage period.

5.2 Conclusion

Findings from this study show that waxing is an effective postharvest technology which can be used in postharvest handling mangos. Due to the modified conditions, fruit’s shelf life was prolonged, and quality preserved as evidenced in the instrumental analysis where waxed fruits outperformed the unwaxed fruits. In addition, cold storage and coating resulted in a synergistic effect that resulted in an extended shelf life and quality preservation far above the ambient stored ‘ngowe’ and ‘apple’ mangos. Cold-stored waxed fruits had a shelf life of 28 days for both mango varieties compared to 10 and 14 days for ‘ngowe’ and ‘apple’ mango fruits under ambient storage respectively. Although the different waxing options significantly prolonged shelf life and preserved postharvest quality, mango wax+prochloraz was proffered above the others for it deterred fungal infection. Therefore, Mango wax+prochloraz can be promoted as an alternative postharvest technology for handling mango fruits.

5.3 Recommendations

- The two waxes used in this study significantly extended the shelf life and preserved postharvest quality of apple and ngowe mangos compared to the fruits that were untreated. This study therefore recommends the use of Mango wax and Shellac wax as alternative technologies for postharvest handling mango fruits. Although both waxes performed better

in both storage conditions and for the two mango varieties, Mango wax mixed with fungicide was effective in deterring fungal infection.

- Cold storage in combination with waxing was effective in prolonging shelf life and preserving postharvest quality over treated ambient room stored mangos. This could be exploited by shippers to export mangos through the sea.
- Developers of waxing technologies recommend waxing to be used under cold storage conditions, but this study showed a significant shelf life extension under ambient room conditions and this could be used by smallholder farmers who may not have access to refrigerators.
- In the present study, two mango varieties (‘ngowe’ and ‘apple’) from low potential zones were used. Studies should be conducted to evaluate effect of wax on other mango varieties from different Agro-Ecological Zones.
- Although the cold-stored fruits performed better than the fruits stored under ambient room conditions, additional studies should be conducted to determine shelf life and postharvest quality preservation after cold storage.

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APPENDICES

APPENDIX1: Analysis of Variance (ANOVA) table for the effect of waxing on weight loss of 'apple' and 'ngowe' mango fruits stored in ambient

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
VARIETY	1		1093.6883	1093.6883	5253.27	<.001
TREATMENT	4		495.4645	123.8661	594.96	<.001
DAY	4		17340.7936	4335.1984	20823.09	<.001
VARIETY. TREATMENT	4		437.3437	109.3359	525.17	<.001
VARIETY. DAY	(1)		369.0487	123.0162	590.88	<.001
TREATMENT. DAY	14	(2)	586.5147	41.8939	201.23	<.001
VARIETY. TREATMENT. DAY	10	(6)	211.6139	21.1614	101.64	<.001
Residual	82	(18)	17.0717	0.2082		
Total	122	(27)	16883.8798			

APPENDIX2: Analysis of Variance (ANOVA) table for the effect of waxing on weight loss of 'apple' and 'ngowe' mango fruits stored in cold storage

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
VARIETY	1		71.08628	71.08628	906.09	<.001
TREATMENT	4		485.45143	121.36286	1546.93	<.001
DAY	4		5775.06240	1443.76560	18402.66	<.001
VARIETY.TREATMENT	4		67.39217	16.84804	214.75	<.001

VARIETY.DAY	4		161.01660	40.25415	513.09	<.001
TREATMENT.DAY	15	(1)	219.03117	14.60208	186.12	<.001
VARIETY.TREATMENT.DAY	15	(1)	104.78775	6.98585	89.04	<.001
Residual	96	(4)	7.53160	0.07845		
Total	143	(6)	6055.64585			

APPENDIX3: Analysis of Variance (ANOVA) table for the effect of waxing on Respiration of 'apple' and 'ngowe' mango fruits stored in ambient

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
VARIETY	1		699.9423	699.9423	1986.52	<.001
TREATMENT	4		16826.3469	4206.5867	11938.79	<.001
DAY	4		20498.7050	5124.6762	14544.44	<.001
VARIETY. TREATMENT	4		2470.7205	617.6801	1753.05	<.001
VARIETY. DAY	3	(1)	2447.3224	815.7741	2315.26	<.001
TREATMENT. DAY	14	(2)	4390.5868	313.6133	890.07	<.001
VARIETY. TREATMENT. DAY	11	(5)	1614.0680	146.7335	416.45	<.001
Residual	84	(16)	29.5971	0.3523		
Total	125	(24)	44546.8487			

APPENDIX4: Analysis of Variance (ANOVA) table for the effect of waxing on respiration of 'apple' and 'ngowe' mango fruits stored in cold storage

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**

DAY	4		2744.188	686.047	537.21	<.001
TREATMENT	4		2284.533	571.133	447.23	<.001
VARIETY	1		612.378	612.378	479.53	<.001
DAY.TREATMENT	15	(1)	583.960	38.931	30.48	<.001
DAY.VARIETY	4		755.522	188.881	147.90	<.001
TREATMENT.VARIETY	4		25.266	6.317	4.95	0.001
DAY. TREATMENT. VARIETY	15	(1)	532.014	35.468	27.77	<.001
Residual	96	(4)	122.597	1.277		
Total	143	(6)	7524.731			

APPENDIX5: Analysis of Variance (ANOVA) table for the effect of waxing on Pulp Hue angle of 'apple' and 'ngowe' mango fruits stored in ambient

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
TREATMENT	4		1099.627	274.907	214.04	<.001
VARIETY	1		421.233	421.233	327.97	<.001
DAY	4		9816.751	2454.188	1910.82	<.001
TREATMENT.VARIETY	4		466.949	116.737	90.89	<.001
TREATMENT.DAY	15	(1)	963.022	64.201	49.99	<.001
VARIETY.DAY	3	(1)	553.603	184.534	143.68	<.001
TREATMENT.VARIETY.DAY	10	(6)	390.836	39.084	30.43	<.001
Residual	84	(16)	107.887	1.284		
Total	125	(24)	10705.736			

APPENDIX6: Analysis of Variance (ANOVA) table for the effect of waxing on Pulp Hue angle of 'apple' and 'ngowe' mango fruits stored in cold storage

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
VARIETY	1		1064.445	1064.445	280.22	<.001
TREATMENT	4		356.613	89.153	23.47	<.001
DAY	4		4679.205	1169.801	307.95	<.001
VARIETY.TREATMENT	4		128.366	32.091	8.45	<.001
VARIETY.DAY	4		736.544	184.136	48.47	<.001
TREATMENT.DAY	15	(1)	323.039	21.536	5.67	<.001
VARIETY.TREATMENT.DAY	15	(1)	199.648	13.310	3.50	<.001
Residual	96	(4)	364.667	3.799		
Total	143	(6)	6829.707			

APPENDIX6: Analysis of Variance (ANOVA) table for the effect of waxing on Beta carotene of 'apple' and 'ngowe' mango fruits stored in cold storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DAY	4	88.5887	22.1472	136.83	<.001
TREATMENT	4	43.2973	10.8243	66.88	<.001
VARIETY	1	21.7579	21.7579	134.43	<.001

DAY.TREATMENT	10	27.0259	2.7026	16.70	<.001
DAY.VARIETY	4	3.5197	0.8799	5.44	<.001
TREATMENT.VARIETY	4	8.3227	2.0807	12.85	<.001
DAY. TREATMENT. VARIETY	10	8.0651	0.8065	4.98	<.001
Residual	76	12.3012	0.1619		
Total	113	212.8786	1.8839		