HARVESTING, POSTHARVEST HANDLING AND THE PHYSIOCHEMICAL CHANGES DURING STORAGE OF GUAVAS IN TWO COUNTIES OF KENYA

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DEPARTMENT OF FOOD SCIENCE, NUTRITION AND TECHNOLOGY
FACULTY OF AGRICULTURE
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2020

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DEDICATION

I dedicate this work to my late mother Mrs. Josephine Musyawa Ndeme and my loving family for their unending support and prayers during my study period.

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ABBREVIATIONS AND ACRONYMS

AOAC-Association of Official Analytical Chemists

DFSNT-Department of Food Science, Nutrition and Technology

FAO-Food Agricultural Organization

HCD-Horticultural Crops Directorate

HCDA-Horticultural Crops Development Authority

ODK-Open Data Kit

TTA-Total Titratable Acidity

TSS-Total Soluble Solids

USA-United States of America

WHO–World Health Organization

GENERAL ABSTRACT

The guava (*Psidium guajava*) fruit is highly nutritious and commonly found in almost all ecological regions in Kenya, however, its highly perishable and prone to postharvest losses. The fruit suffers huge losses which are attributed to the low consumption and marketability as it is neglected by farmers and consumers. Standard postharvest handling, storage and marketing are not practiced and most of it is left to rot in the farm. The current findings indicate that guava harvesting practices are substandard and skin colour was the main maturity index in Kitui and Taita Taveta, 98.6% and 92.1% respectively. There was no organized storage and packaging of guavas in Kitui and Taita Taveta as farmers harvested just enough for household consumption hence no bulk handling of the fruit. A cluster analysis of hygiene knowledge of farmers revealed that Kitui farmers had higher knowledge scores (71.9%) as compared to those from Taita Taveta (49.8%). Findings indicate that there is lack of postharvest handling practices in Kitui and Taita Taveta which is a contributing factor to the huge guava losses incurred in Kenya.

The influence of storage conditions on the physicochemical changes of guava during storage was evaluated on day 0, 2, 3, 5, 7 and 11 by analysing changes in moisture, weight, beta carotene, ascorbic acid, total soluble solids, total titratable acidity and pH as influenced by storage factors specifically washing, modified atmosphere packaging and temperature. Temperature of storage significantly ($p<0.05$) accelerated the rate of physicochemical changes of the net bags as compared to modified atmosphere. Fruits stored at 20-25℃ and 28-30℃ recorded the higher change in weight loss, moisture content, vitamin C and beta carotene as compared to those at 8-10℃. The study concluded that storage at 8-10℃ afforded the fruits a shelf life of 11 days. Modified atmosphere packages best lowered the rate of deterioration based on the changes in ascorbic acid, beta carotene. Guava shelf life can be extended Best storage is obtained by storing in modified atmosphere packaging at 8-10℃.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Guava is one of the broadly cultivated and consumed tropical fruits worldwide (Omayio *et al.*, 2019). The fruit is formally cultivated in countries such as India, Mexico, Brazil, Thailand, Portugal, Pakistan, Spain , Southern France, Israel, Costa Rica, Panama, Malaysia , Nicaragua, Bolivia, USA (Hawaii, and Florida and California), New Zealand, Philippines, Indonesia, China, Java , Cuba, Venezuela, Australia and in Africa (Pommer *et al*., 2009). In Kenya, a wide variety of both indigenous and exotic guava fruits are grown in various agro-ecological zones (Simitu *et al*. 2008). The major guava growing areas in Kenya are; Elgeyo-Marakwet, Kakamega ,Uasin-Gishu, Kwale, Kilifi, Meru, Homabay, Siaya, and Vihiga, Mombasa, Kitui and TaitaTaveta (Chiveu *et al.,* 2019). The majority of guavas are harvested for the domestic market or home consumption and when in excess given to neighbors fed to animals (Omayio *et al*., 2019). As per the Horticultural Crops Directorate (HCD, 2014), the guava trees are mostly unattended and grow from seeds spread not deliberately by animals, birds and other agents.

Guava fruit is used to make several nutritious products such as juices, guava paste, jellies, dried guava, guava pulp concentrates (Garg, 2015; Omayio *et al*., 2019).There are two main varieties of guava, the white fleshed and the pink fleshed. White fleshed guavas are favored for dessert, while the pink fleshed are used for value addition through processing (Singh, 2011). It is considered a super fruit as it is a good source of folic Acid, dietary fiber, vitamin A, and the dietary minerals of potassium, manganese and copper (Omayio *et al*., 2019). The ascorbic acid contents guavas are about four to five times higher than those of the citrus fruits, amounting to 200-400mg per 100g of fresh fruit (Augustin and Osman, 1988; Crane and Balerdi, 2015; Naseer *et al.*, 2018). The pink-fleshed guava has high level of carotenes and polyphenolic compounds which are the major groups of antioxidant compounds giving them a fairly very high antioxidant activity among the diverse plant materials (Chiveu *et al.*, 2017). Guava fruit produces a pleasant sweet aroma which is satisfyingly and refreshingly acidic in its flavor (Harb and Hasan, 2012).

Guava fruit experiences huge postharvest losses (25-30%) every year (Jatinder Singh, 2017; Omayio *et al*., 2019). It is a very delicate fruit; prone to physical and chilling injuries, diseases, insects and pests (Singh, 2011). The main deteriorative factors include physiological (shriveling, chilling injury), pathological and enzymatic activity (yeasts, molds, bacteria) and physical damage (Paull and Chen, 2014). Mechanical bruising occurs during harvesting and handling leads to bruising and skin opening which causes decay creating openings for entry of pathogens and activity of enzymes (Soares-colletti *et al.*, 2014). The fruit is susceptible to physicochemical changes that influence sensory and nutritional quality (Jain *et al*., 2003). The ripening process causes a decrease in chlorophyll content and an increase in beta carotene changing the skin color from green to yellow (Singh, 2011).The fruit softens and the rate of fruit softening is dependent on the cultivar and variety. Changes in total soluble solids, vitamin C, beta carotene, pH, titratable acidity and sugars occur during storage (Augustin & Osman, 1988;Singh, 2011) and have a significant influence on the nutritional value of guava fruits (Mahajan, Sharma and Dhall, 2009).

In Kenya, guava is a neglected crop (Kindt *et al.*, 2015) thus there is minimal consumption of fresh fruit and value addition. The fruit production is not commercial thus minimal marketing and processing. This has contributed to high postharvest losses as most of the fruit is not harvested and is left to rot and decay in the farm (Omayio *et al*., 2019). However, guavas have a high production and commercialization potential as they can thrive in almost all the agro-ecological zones in Kenya (Chiveu *et al*., 2019). Postharvest losses are attributed to poor postharvest management as farmers consider the fruit to be of low economic value due to low demand by consumers. Formal storage of the harvested fruit is virtually unknown leading to spoilage, low value addition and marketing. These postharvest losses are however not well documented. This study was designed to establish the postharvest handling practices of guava fruit and the physicochemical changes during storage.

1.2 Statement of the Research Problem

There is very little information available on harvesting and post-harvest control practices including storage and processing of guava in Kenya probably due to the fact that the fruit is not commercialized, such that the standard maturity indices, methods of harvesting and post-harvest handling including storage are not practiced. Harvesting and post-harvest losses are therefore likely to be high. Little knowledge exists among the consumer on the nutritional and health benefits of the fruit. There is also very little marketing of the fresh fruit. On the other hand, guava storage life is very short and is affected by diseases leading to huge postharvest losses. The major contributing factors are physiological; shriveling, chilling injury, wilting, pathological and enzymatic activity by yeasts, molds and bacteria and physical damage. Poor harvesting and postharvest handling contributes to guava losses in Kenya. Most farmers store the guavas under room temperature where the shelf life can only be 3-4 days and if not consumed promptly, they rot and are fed to animals or disposed. Additionally, there is little information regarding storage methods and characterization of guava in Kenya which has affected production and value addition.

1.3 Justification

The outcomes of this study will aid in developing a policy that can convert the guava to a viable commercial horticultural crop in the Country through organized production and marketing by farmers. The farmers will gain an additional horticultural crop from which to generate revenue and the Country will be able to earn foreign exchange through processing and marketing of the crop. This will achieve poverty reduction and improvement of welfare of the farming communities as well as raising the GDP of the Country. Guava fruit is a neglected but it is an economically potential crop that can be used to make nutritious products for human consumption and animal feeds hence can contribute to farmer's economic returns. Increasing utilization through improved shelf life and consumption of guava will contribute to food and nutritional security by contributing diversity of food and nutrient sources, health benefits. The study will contribute to food safety policy by ensuring good postharvest and storage of guava to prevent food borne illnesses. It will also contribute to food and nutrition policy of people by increasing consumption of guava which is highly nutritious. Prolonging the storage life of guava will reduce the huge postharvest losses and will increase its productivity and marketability. This will reduce the amount of inputs used and increase the yield hence higher returns to farmers. This study will provide vital information that can be used to also equip farmers, marketers and processors with knowledge on post-harvest management, health and economic benefits of guava to increase its utilization and promote its use. Kitui and TaitaTaveta Counties were selected as the study sites because there is high production of guava fruit and they are dry areas hence this study will contribute towards fighting food insecurity by enabling the farmers to gain economic returns by increasing sales and value addition of guava.

1.4 Study Objectives

1.4.1 General objective

To assess harvesting and post-harvest handling practices and the physiochemical changes during storage of guava fruit.

1.4.2 Specific Objectives

i. To assess harvesting and postharvest handling practices of guava fruit in Kitui and Taita Taveta counties of Kenya

ii. To determine the effect of storage conditions on the physicochemical changes of guava during storage

1.5 Hypothesis

i. There is no difference between the Harvesting and postharvest handling practices of guava fruit in Kitui and Taita Taveta counties of Kenya

ii. There is no significant change on the physicochemical characteristics during storage of the guava fruit.

CHAPTER TWO: LITERATURE REVIEW

2.1 The Guava Fruit

2.1.1 Botany

The guava fruit (Psidium guajava) belongs to the family of myrtaceae which includes numerous aromatic fruits (Chiveu *et al.*, 2019). There are various varieties of guava including strawberry guava, paraguava, pitanga, grumichama and rose apple. These varieties are either pink and white fleshed guavas ((Masud *et al,* 2018).

2.1.2 Plant description

Guava tree can grow to become a large bush or undersized tree, spreading rather freely close to the ground. The tree generally grows to 1-6 m high, however, sometimes a height of 10m is attained (Masud *et al*., 2018).When trimmed through pruning, it can to grow evenly to a tree with scattering top and is low-headed (Fagundes *et al*., 2013). The stem is slightly slim and twisted having a greenish brown scaly bark. Some of the stems are covered with a fine bark that is light reddish-brown that falls off as flakes. In most cases the young stems a green in color and are hairy *(*Masud *et al*., 2018). The color of the leaves is light green with sphere-shape, 3 to 6 inches in length (Menzel and Paxton, 1986). The white flowers are held by leaves, either separately or two and three together on slim peduncles (Singh, 2007). The white flowers have curved inwards petals having a nice aroma. The flowers have 4 to 6 petals and yellow anthers that attract insects for pollination (Naseer *et al.*, 2018). The fruit is grown from unselected seeds show a wide difference in appearance, size, flavor, acidity, texture and color. The flesh color may be white, salmon, yellow, pink, or carmine (Abreu *et al*., 2012).

Guava fruits are known for their sweet and strong flavors which are desirable characteristics to consumers. There are many uses of guava other than a source of nutrients. Many people term it a "magical" fruit due to its range of benefits both nutrients and medicinal uses. Guava has a high ethno-medicinal historical background (Masud *et al.*, 2018). Various parts of the guava are used in a variety of medicinal values, mainly to treat several gastrointestinal disorders. Some of the medicinal and health related uses include the leaves extract to treat ulcers, bruises, cuts, boils, skin and soft tissue disease infections (Naseer *et al.*, 2018).

2.1.3 Ecological requirements

2.1.3.1 Soil and climate

The Guava trees are very resilient and can flourish in all types of soil types from alluvial to that of the lateritic, but they are susceptible to water logging (Barboza *et al.*, 2016). They flourish in well drained soils. The best soils for guava production are friable, deep and with good drainage. It can grow in soils with a PH of 6.5 to 8.5 (Crane and Balerdi, 2015). Guava can successfully grow under tropical and subtropical climatic conditions (Menzel and Paxton, 1986). In areas that have a distinct winter season, the yield is more and of superior quality. It can grow from an altitude of about 5,000 Feet (1,515 Meter). It needs an annual rainfall below 40 Inches (1,016 Millimeter) (Singh, 2007; Crane and Balerdi, 2015). Guava trees thrive well at a temperature of 15 to 46℃ and the optimum temperature of 23 and 28℃ during flowering and fruiting (Singh, 2007).

2.1.4 Propagation and Fruit Growth

Guava is propagated using seed, grafting, air layering, tissue culture and cuttings (root or shoot) (Crane & Balerdi, 2015; Pommer *et al.*, 2009; Singh, 2007). The flowering and fruiting in guavas happens throughout the year under conditions of mild subtropical and tropical (Singh, 2011) with an optimum temperature of 23 to 28℃ (Singh, 2007).

Biochemical changes also happen during fruit growth and development which lead to an increase in total soluble solids, titratable acidity, vitamin C and beta carotene (Singh, 2011)

2.1. 5 Guava Yield

Guava yield varies significantly depending on variety and agro-ecological conditions predominant in the region. The production starts with 8 tons per hectare from the third year and increases to 25 tons per hectare (Crane and Balerdi, 2015). Guavas can bear fruits up to 40 years especially were cultivation and management practices are right (Singh, 2007). The most economic bearing period of guavas is within the first 20 years. Guava yield is highly influenced by the variety and climate and is mostly productive in the tropical and sub-tropical regions (Bakshi, 2015).

2.1.6 Pests and Diseases

Guava is susceptible to fungal diseases which include guava wilt, dieback, anthracnose ,canker, dry rot and fruit rot which contribute to postharvest losses (Crane & Balerdi, 2015; Singh, 2007). Guava is infested by more than 80 insect spp. but only a few of them cause economic damage to the fruit. Major notorious pests are fruit-flies, scale insects, bark-eating caterpillar, lepidopterous fruit-borers and mealy bugs (Singh, 2007). Measures of biological control by the use of predators have been formulated for aphids, scales and mealy bugs (Bashir and Kabbashi, 2014). Postharvest fruit fly has been the major cause of postharvest losses in guavas and it sets in during the ripening stage (Singh, 2017; Rawan *et al.*, 2017). Guava white fly, Caribbean fruit fly, guava moth and the red-banded thrips are the most common in guavas (Crane and Balerdi, 2015).

2.2 Guava Production

2.2.1 World production

Guava is broadly accepted among other Tropical Fruits worldwide. Worldwide, guava is cultivated in India, Mexico, Brazil, Thailand, Portugal, Pakistan, Spain , Southern France, Israel, Costa Rica, Panama, Malaysia , Nicaragua, Bolivia, , USA (Hawaii, and Florida), New Zealand, California, Philippines, Indonesia, China, Java , Cuba, Venezuela, Australia and in Africa (Pommer *et al*., 2009). India is the leading producer of guava in the world and South Africa, Egypt and Sudan are leading in Africa (Miele and Rizzon, 2017).

2.2.2 Guava production in Kenya

In Kenya there are several agro-ecological zones which are contributing to production of a widespread variety of both indigenous and exotic fruits (Omayio *et al*., 2019). The major Guava growing areas in Kenya are; Kakamega ,Uasin-Gishu, Kwale, Kilifi, Meru, Homabay, Siaya, Vihiga, Mombasa, Kitui, Taita Taveta among others (Chiveu *et al*., 2019). Furthemore, there is low consumption of local indigenous fruits and as such, some of the indigenous fruit such as guava are neglected (Fukushima *et al*., 2010). This indicates that their potential contribution to food security, income generation and health benefits is unexploited (Omayio *et al*., 2019).

In Kenya, fruit cultivation is generally done by farmers that have a low resource base and their diversification of fruit species is very minimal (Mbora *et al*., 2008). Guava trees can survive in most agro ecological zone in Kenya except the very arid areas and highlands. However, since it was first introduced in Kenya the fruit is not well known. It grows wild and on farmer's fields hence termed as the 'poor man's food' because many people take it as a wild fruit (Krishna and Kabir, 2018). Guavas are consumed fresh and there is limited processing (Chiveu *et al*., 2019; Omayio *et al*., 2019). As per the Horticultural Crops Directorate (HCD,(2014), the guava is mostly unattended and grow from seeds that are spread by animals, birds and other agents by chance . Despite this, there was an increase in the consumption, production, productivity and value of Kenyan guava fruits over the years (Figure 2.1).

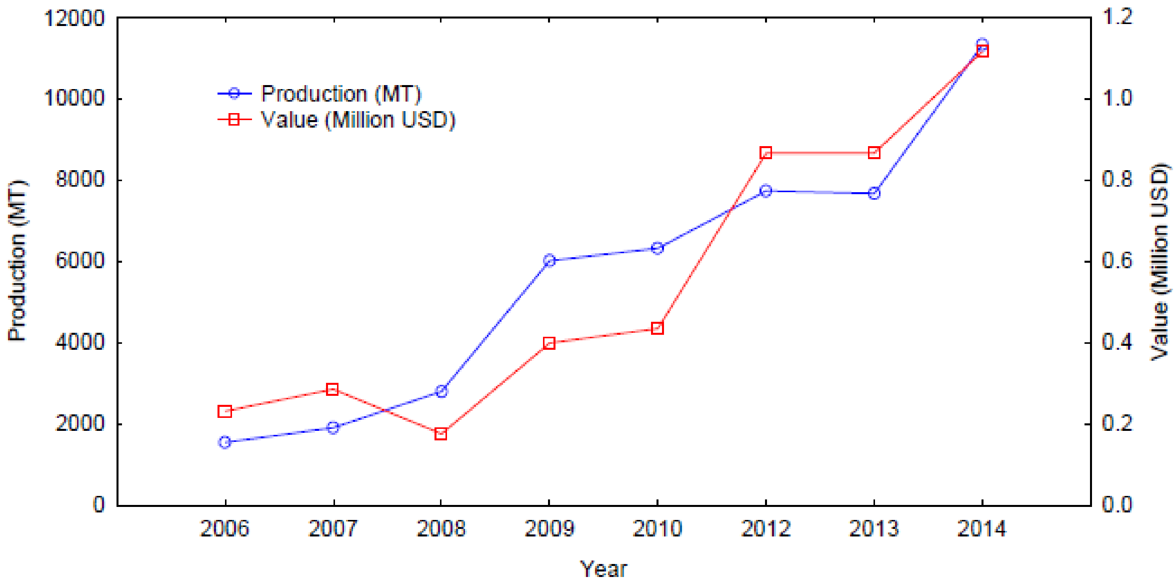


Figure 2.1: The trend in production and guava fruit value 2006-2014.

Source: HCD (2014).

2.3 Guava Harvesting

2.3.1 Maturity and maturity indices

Maturity is a stage of growth and development of fruits that leads to the realization of horticultural and physiological maturity (Cantwell, 2014). Physiological maturity is the phase whereby a fruit is mature but has the ability to undergo further development or ripening after harvesting, Horticultural maturity is the period of growth and development during which a plant or plant part attains the pre-requisites for a particular purpose as per customer preference for example becoming ready for harvest (Bakshi, 2015). The stage of maturity at harvest determines the shelf life and ultimate fruit quality (Mitra *et al.*, 2012) . The more mature the product, the shorter is its post-harvest life. The stage of maturity is important in the choice of methods of storage, shelf-life evaluation, choice of processing operations for the fruit value addition (Cavalini *et al*., 2006). The maturity indices are currently used are on the basis of a compromise between the indices that ensure good and most excellent eating quality to the consumer and those that give the required flexibility in marketing (Garciá-Jiménez *et al.*, 2018). Maturity indices for guavas include physicochemical measurements that vary noticeably along fruit stages of ripening. This ensures the production of high quality fruits concerning sensory attributes and enabling appropriate performance during storage and handling (Bakshi, 2015). The fruit skin color as a maturity index gives differentiation of the fruit using changes in color during stages of ripening , with unripe guavas having high hue color angle than ripe ones (Deepthi *et al.*, 2016).

Fruit size is also used to determine maturity of guavas (Bakshi, 2015). Mature guavas are bigger in size as compared to immature ones. However, use of size may have negative implications by leading to harvesting of immature guavas. Changes in texture during ripening are also used to indicate maturity by using a penetrometer (Kamsiati, 2016). The texture decreases due to breakdown of pectins during ripening (Vishwasrao and Ananthanarayan, 2016).

Fruits harvested immature are subjected to shriveling, insect damage, weight loss and mechanical bruising, and have poor flavor, quality when they ripen (Cavalini *et al.*, 2006). Fruits that are over-ripe are prone to softening and becoming mealy with a superior taste after harvest (Paull and Chen, 2014). Fruits harvested either too early or too late are mostly vulnerable to post-harvest physicochemical and physiological disorders and a higher rate of deterioration than fruit harvested at the appropriate maturity. Vitamin C is higher in fruits picked at a later stage of ripening (Cavalini *et al.*, 2006; Deepthi *et al.*, 2016).

2.3.2.1 Harvesting

Maturity of guava at harvesting time is a major aspect that determine its shelf stability and quality (Paull and Chen, 2014). Unripe guavas are prone to wrinkles and physical injuries, and have a poor flavor when they ripen (Kamsiati, 2016). Ripe guavas soften with ease and have plain flavor after harvest. Fruits that are harvested too quickly, more vulnerable to physicochemical and physiological changes than fruits that harvested at the appropriate maturity stage (Kamsiati, 2016). The guavas are to be harvested when color changes from dark green to light green or yellowish (Keder, 2009). Field heat should be managed after harvesting the guava; storing under a shade during harvesting, harvesting early in the morning or late evening, hydro cooling, contact icing, air cooling, evaporative cooling and vacuum cooling (Kamsiati, 2016; Omayio *et al*., 2019).

2.3.2.2 Methods of harvesting

The most significant handling points of any fruit are harvest stage. It is the starting point for the postharvest handling and management of the fruit to ensure quality (Deepthi*et al.*, 2016).Guava is fragile and extremely perishable fruit that call for careful and appropriate handling during harvesting and transportation to reduce damage and preserve quality (Prasad, Jacob and Siddiqui, 2020). The fruits should reach the consumer in a firm condition. Guavas can be harvested by hand harvesting or mechanical harvesting (Bakshi, 2015). Guava harvesting is done through various methods (Table 2.1). Hand harvesting preserves quality than mechanical harvesting. In Kenya, guavas are harvested using hand harvesting method.

Table 2.1: Guava harvesting methods

Method of harvesting	Description	Advantages	Disadvantages
Hand harvesting	-This method is frequently carried out in traditional ways. -Harvesting is done by simply removing fruits from the plant and putting them into a suitable container.	-Harvesting of fruit is carried out at appropriate maturity. -The produce suffers minimum damage.	-It is a time consuming process. -More labor is needed during harvesting season.
Mechanical harvesting	-Guava fruits for processing is harvested by tractors mounted machines with combing fingers which will run up the stems, pulling of the fruit bunches as well as a high proportion of the leaves.	-Fast harvesting of the produce -Less manpower is necessary as compared to hand harvesting.	-Physical injury can occur to crops. -Not suitable for fresh commodity marketing.

Source: (Bakshi, 2015)

2.4 Postharvest handling of guava

The perishability of guavas calls for control of fruit ripening and the use of new technologies to extend shelf stability, to ensure transportation to reach distant markets and thus improve the marketability (Mitra *et al*., 2012).The main aim of postharvest management is to minimize respiration rate, transpiration, ethylene production, ripening, senescence and disease control to prolong the storage life of the guavas (Deepthi *et al.*, 2016). Guava postharvest handling includes sorting, washing, packaging, storage and transportation. Guava storage and transportation are discussed in details later in this chapter.

2.4.1 Sorting

The guavas are sorted by separating healthy fruits from bruised, wounded and damaged fruits (Barboza, Mamede, Soares, Neves, & de Oliveira Fonseca, 2016; Omayio *et al*., 2019). The fruits should be; whole, compact, fresh appearance, free from bruises that cause changes in taste and appearance, clean, consumable, free from foreign materials, free from foreign flavor and aroma free of pests and diseases, free of abnormal external moisture, condensation except immediately after removal from cold storage areas, , and free of bruises (Paltrinieri, 2014).

2.4.2 Washing and packaging

Good and quality guavas are washed to remove dirt, dust and reduce microbial load on the surface and removes field heat (Krishna and Kabir, 2018). The disinfectants in the water prevent spoilage by bacteria and fungi (Omayma *et al*., 2010). Guava can be packaged using primary and secondary package (Rana *et al*., 2015; Singh *et al*., 2014). Primary package is the one in direct contact with guavas (Paltrinieri, 2014) while the Secondary package is the second layer that offers extra protection to the product (Kamsiati, 2016). Edible coating is one type of primary packaging (Vishwasrao and Ananthanarayan, 2016). Packaging has to meet the requirements of quality, ventilation, hygiene and durability to ensure suitability for handling and provision to maintain quality (Kamsiati, 2016).

2.5 Fruit storage

Storage is normally done for various reasons, for marketing it is usually a very short period to allow for product accumulation by a farmer or a group of farmers to send to the market (Kamsiati, 2016). Some marketers store to wait for the prices to increase to fetch more returns (Keerthi, 2008). Guava fruits can be stored before transporting to the market or awaiting consumption. Fruit condition and market life are influenced by temperature, relative humidity and the composition of the atmosphere (Barboza *et al.*, 2016), the level of damage imposed on them and the extend of infection by microorganisms (Paltrinieri, 2014). Guava degradation during storage through; moisture loss, loss of stored energy, physical losses through pests and diseases and losses due to physiological disorders (Mahajan *et al*., 2009). Guava should be handled in a manner that reduces all the deteriorative factors to ensure minimal losses during storage (Sharma, 2018). They should be stored under conditions that slow rate of deterioration. Guavas have a very fragile skin that is susceptible to mechanical damage and require careful handlingto minimize damage (Augustin and Osman, 1988). The treatments that reduce mechanical damage like waxing also reduce moisture loss and bruising. Sorting of guava; to separate ripe, rotten, unripe, bruised, insect damaged because they ripe, damaged guavas have high ethylene production that increases ripening and senescence of the unripe fruits (Keerthi, 2008; Paltrinieri, 2014).

2.5.1 Storage methods and treatments during fruit storage

These are common methods in storage of fruits and vegetables and are applicable to guava fruits in Kenya.

2.5.1.1 Common storage at room temperature

Guavas have a very short storage life and are vulnerabile to disease and chilling injury (Mahajan *et al*., 2009; Pal, 2009). Guava ripens rapidly at room temperature within a few days. It is a climacteric fruit that has its highest rate of respiration and ethylene production during ripening (Kamsiati, 2016). Studies have shown that guava has a short storage life of 7 days at room temperature, however, most of the quality attributes are retained at this storage (Rodrigues *et al*., 2018; Sharma, 2019).

2.5.1.2 Low-Temperature Storage of Guavas

Guava storage can be done at low temperatures of about 8-10°C which is recommended as the optimum temperature of storage for guavas that are at the green mature (Barboza *et al*., 2016). Researchers have suggested 5°C as the optimum temperature for storage of guavas and maturity of guavas at harvest may affect its sensitivity to chilling injuries during storage (Paull & Chen, 2014). Guava fruits that are at the color turning stage can be stored for three weeks at 7°C and have superior appearance, and experience minimal decay of the fruits than those at the green mature stage.

2.5.1.3 Modified-Atmosphere Storage

It is the storage of guava at an environment of reduced oxygen level and elevated carbon dioxide level (Barboza *et al*., 2016). Guava fruits that are packaged in low-density polyethylene films have reduced ripening and rate of deterioration hence extended shelf life (Mitra, Chakraborty, Majhi, & Pathak, 2015). Wrapping of guavas in low density polyethylene bags reduces dehydration, chilling injury and disease severity (Pal, 2009).

2.5.2 Commodity treatments for shelf life prolongation

2.5.2.1 Calcium Treatment

Some products are usually given calcium dips, with the aim of firming the structure to reduce mechanical damage (Deepthi *et al*., 2016). The calcium binds with pectin to form insoluble calcium pectate (Alba-Jiménez *et al*., 2018). Fruits treated with 10% $CaCl_2$ at room temperature reduce softening and lowers the rise in soluble pectin content and levels of titratable acid (Deepthi *et al*., 2016) and minimal effect on the attack of the fruit by disease as compared to fruits without calcium treated fruit.

Guava fruits that are treated with Calcium nitrate at 1% levels and stored at 6-8°C have a shelf-life of up to 30 days (Mandal *et al*., 2010). According to Silva *et al*. (2000 use of Calcium Chloride solution at levels of 12% for storing of guavas can extend shelf-life to three weeks at 10°C. Calcium hardens the surface of the guavas and reduces the vulnerability of guava to mechanical injuries and microbial invasion (Alba-Jiménez *et al*., 2018).

2.5.2.2 Treatment with 1-Methyleyclopropene (1-MCP)

1-MCP is an anti-ripening agent that is used to lower the rate of ripening in fruits. 1-MCP can be used to increase the storage life of guava by lowering the ripening rate (Pal, 2009). The efficiency of 1-MCP in extending the shelf-life of guava is dependent on the amount used, duration of exposure, variety, stages of ripening, and exposure temperature (Harb & Hasan, 2012). Guavas treated with 1-MCP of 600 nl L-1 and for 6 h will preserve fruit color, firmness of the flesh and reduce development of disease for 5 days at room temperature of 27°C with relative humidity of 70% hence extending shelf-life of the guavas (Phebe and Ong, 2010).

2.5.2 Waxing

Storage of guavas under a combination of modified-atmosphere and use coating like cellulose (Paull & Chen, 2014) or carnauba especially for mature-green guavas lower development rate of color and reduce the increase in total soluble solids levels (Kamsiati, 2016; Rawan *et al*., 2017). It also reduces softening especially if the fruits are coated with 2 or 4% hydroxyprophy cellulose (Paull & Chen, 2014). Coating of guavas with carnauba can extend the storage time of guavas under refrigeration by applying waxes with 5% oil and 2% sucrose (Espinoza-Zamora *et al*., 2010).

2.5.2.4 Irradiation

The use of irradiation on post- harvest handling of fruits improves the storage time and reduces the fruit fly attack (Pal, 2009). According to Yadav *et al*. (2010) use of irradiation with 100 Gy and combining with waxing at rate of (6% waxol) on the fruits after harvesting results to minimum physiological weight loss and preserve the quality of the fruit during storage for 16 days at room temperature condition (Rajput, Lekhe, Sharma, & Singh, 2008).

2.5.2.5 Hot-Water Treatment

Guavas can be treated using hot water to remove microorganisms and control diseases (Pal, 2009). Immersion of mature fruit in hot water is used as the alternative to methyl bromide for control of infestation by insect-pests that affect fruits and reduce post-harvest diseases that cause spoilage (Kamsiati, 2016). The guavas are immersed in hot water for 35 min at a temperature of 46.1°C eliminate fruit fly infestation that affects storage of fruits (Pal, 2009). According to Sing and Pal (2008), treatment of guavas with hot water for a period of 20 min at a temperature of 49±1°C is used to lower fruit fly infestation rate. Also, disinfection from fruit fly during storage can be achieved using vapor heat treatment at a temperature of 46.5°C for 15 or 35 min.

2.6 Transportation

Transportation is the transfer of the harvested fruits from the farm to the collection and packing house or to consumers (Kamsiati, 2016). This step determines a higher percentage of the fruits' shelf life, approximately 50-75% of the shelf-life of guavas is used up in transport and distribution (Keerthi, 2008). Maintaining guava value during transport and distribution is an important part in the management of the fruit (Singh *et al*., 2014). The major causes of losses during transportation are mechanical damage and overheating and as such temperature is important in preservation of fruit quality (Paltrinieri, 2014). It is essential to keep the temperature of the guava fruit in cold condition (optimum) and prevent the effects of external temperature that may increase deterioration (Barboza *et al.*, 2016). Refrigerated trucks should be used or ensuring the means of transport is well-insulated and well-ventilated to allow air circulation with the product (Singh *et al*., 2014).

Mixing of ripe and unripe guavas should be avoided as the ripe guavas have high ethylene production hence will accelerate the rate of ripening leading to rotting (Singh, 2011). This can be done by sorting and separate packaging. Also, the guavas should not be exposed to direct sunlight during transportation, this will increase the product temperature causing faster ripening and decay (Mahajan *et al*., 2009).

Poor postharvest handling and hygiene will lead to physicochemical changes of guavas during storage. The physical parameters that will be mostly affected are weight by high respiration rates (Vishwasrao and Ananthanarayan, 2016). Moisture loss causes reduction in weight and affects crunchiness and juiciness, firmness and texture is affected by water loss and ripening due to breakdown and solubilization of pectin, diameter is decreased due to development of wrinkles as a result of high water loss (Deepthi *et al.*, 2016). The color of the fruits changes during handling as it ripens, the rate of ripening is increased by poor handling and storage conditions (Ribeiro *et al*., 2006). Mechanical damage will increase the amount of ethylene, which further increases rate of ripening and senescence (Jain *et al.*, 2003). The chemical properties that will be affected are; vitamin C which is lost during poor storage conditions due to its volatility, sensitivity to light and oxygen and decomposes during transportation and storage (Vishwasrao & Ananthanarayan, 2016; Madhav1, Sethi, Sharma, & Nagaraja, 2018).

2.7 Processing and Utilization of Guava Fruit

2.7.1 Nutritional Benefits of Guava

Guava has high Ascorbic acid, riboflavin (Vitamin B2), vitamin A, and minerals like phosphorus, Iron and calcium (Chiveu, 2018; Uzzaman *et al.*, 2018). The ascorbic acid content in guava is about four to five times higher than those of the other citrus fruits. It contains 200-400mg per 100g (Augustin and Osman, 1988; Crane and Balerdi, 2015; Naseer *et al.*, 2018). The skin contains a superior content of vitamin C (Kamsiati, 2016). Guava fruit produces a pleasant sweet aroma which is satisfyingly and refreshingly acidic in its flavor (Harb and Hasan, 2012).

The sweet aroma is due to production of carbonyl compounds (Pal, 2009). The fruit is entirely edible and can be consumed wholly together with its thin skin which is nearly fused together with the pulp (Crane and Balerdi, 2015). The pink-fleshed guava has high carotenes and polyphenolic compounds which are the major groups of antioxidant compounds giving them fairly a very high antioxidant activity among the diverse plant materials (Chiveu *et al.*, 2017). The leaves have essential oils which contain α-pinene, isopropyl alcohol, limonene, βpinene, menthol, caryophyllene, terpenyl acetate, longicyclene and β-bisabolene. Guava leaves have a high content of volatile compounds (Naseer *et al.*, 2018). Guava nutritional composition as outlined in Table 2.2.

Table 2.2: Nutritional properties of guava fruit

Name	Content
Calories	77-86mg
Moisture	2.8-5.5g
Crude fiber	0.9-1.0g
Protein	0.1-0.5
Fat	0.43-0.7mg
Ash	9.5-10mg
Carbohydrate	9.1-17mg
Calcium	17.8-30mg
Phosphorous	0.30-0.70mg
Iron	200-400I.U
Carotene	0.046mg
Thiamine	0.03-0.04mg
Riboflavin	0.6-1.068mg
Niacin	40I.U
Vitamin C(Ascorbic acid)	228.3 mg
Vitamin B3	35I.U
Vitamin G4	36-50mg

Source:(Uzzaman *et al.*, 2018;Omayio *et al.*, 2019)

2.7.2 Health benefits of guava

Guava is good source of fibers, antioxidants, minerals and vitamins (Omayio *et al*., 2019). It is effective in lowering the cholesterol and the blood-sugar levels because of its potassium content and it controls cancer by strengthening the prostate gland (Masud *et al.*, 2018). It's efficient in treating gastrointestinal problems and diarrhea and has antimicrobial and antioxidant activity (Barbalho, 2012). Guava contains astringents that harden the loose bowels. The astringents have disinfectants and anti-bacterial properties that lower the population of microorganisms in the body (Fukushima *et al.*, 2010).

It is also a suitable fruit for curing cough and cold due to the high content of ascorbic acid (Chiveu *et al*., 2019). It assists in fighting gingivitis which is a gum disease, due to its rich concentration of folate help to treat the swollen gums, reduce tooth ache and has anti cancerous effects (Barbalho, 2012). Pink-fleshed guavas have higher pigment content such as polyphone, carotenes and pro-vitamin A, than the white-fleshed variety (Masud *et al.*, 2018). The pink guava is mostly recommended to reduce many health problems such as cholesterol and high blood pressure, treatment of constipation and congested lungs (Naseer *et al.*, 2018). Guava plant has been used over years more various medicinal purposes (Table 2.3).

Table 2.3: Ethinomedicinal use of guava fruit

Plant part	**Compound**	**Ethnomedicinal Use leaves**
Leaves	Phenolic compounds, isoflavonoids, gallic acid, catechin, epicathechin, rutin, naringenin, kaempferol	Hepatoprotection, antioxidant, anti-inflammatory anti-spasmodic, anti-cancer, antimicrobial anti-hyperglycemic, analgesic activity
Pulp	Ascorbic acid, carotecoids (lycopene, β-carotene, β-cryptoxanthin) Glycosids,	Antioxidant, anti-hyperglycemic, Anti-neoplasic Antimicrobial
Seed	Glycosids, Carotenoids, phenolic compounds Phenolic	Antimicrobial activity Improvement
Skin	Phenolic compounds Bark	Improvement of food absorption
Bark	Phenolic compounds	Strong antibacterial activity, stomachache and anti-diarrhoeal activity

Source: (Uzzaman *et al.*, 2018)

2.7.3 Guava processing

Guava fruit is used to make several nutritious products like juices, guava paste, jellies, marmalade, dried guava, guava pulp concentrates (Garg, 2015; Omayio *et al.*, 2019) (Table 2.4). These products can be used to improve the consumption and utilization of guavas. In

Kenya, guavas are mostly consumed fresh and there is minimal value addition (Omayio *et al*., 2019).

Table 2.4: Guava value added products

Guava product	Description
Guava pulp	Extract pulped from fresh guava fruits(peeled or unpeeled) The fruits are pulped using blenders or pulpers
Blended ready to drink guava beverages	Prepared using guava pulp and other fruits' extracts like anola, pineapples, papayas.
Dehydrated guava products	Includes dried guava slices and osmo-dried guava slices
Guava jam and jellies	Produced by cooking guava pulp after addition of sugars
Guava juice and nectars	Prepared from either fresh fruits or guava pulp These juices and nectars can be blended to boost nutritional value

Source:(Omayio *et al.*, 2019)

2.8 Guava Deterioration

2.8.1 Overview of post-harvest deterioration and causes in in Kenya

Guava has a low utilization in Kenya; many communities term it the 'poor man food' or food for children (Chiveu, 2019). A guava tree produces very many fruits in a season; most of them go to waste due to lack of market value and low value addition of the fruits. In most areas the surplus is fed to animals (Mbora *et al*, 2008) . Guava experiences huge postharvest losses of 20-30% annually and this is linked to underutilization and poor postharvest management (Omayio *et al*., 2019).

2.8.2: Factors that Cause Deterioration of Guava

2.8.2.1: Biological causes of loss

a) Respiration

Respiration is one of the main metabolic processes that occurs in harvested or living products (Bashir & Abu-Goukh, 2003). It is due to the oxidation and breakdown of the complex materials usually present in cells such as organic acids, starch, sugars into simpler molecules like carbon dioxide and water and releases energy in form of heat (Vishwasrao and Ananthanarayan, 2016). The respiration rate is an indicator of this metabolism of the tissues hence a helpful guide to the prospective shelf-life of the produce (Ribeiro *et al.*, 2006). The rate of spoilage of harvested products such as guavas is inversely proportional to their rate of respiration (Vishwasrao and Ananthanarayan, 2016). Respiration hastens the rate of senescence. The storage conditions should be modified to reduce the rate of respiration to lower rate of deterioration (Deepthi *et al.*, 2016).

b) Ethylene Production

Ethylene is presumed to be the natural ripening and ageing hormone and is usually active in trace amounts and is a major role in abscission which is an indicator of maturity (Iqbal *et al*., 2017). Exposure of guavas to ethylene accelerates their rate of senescence hence deterioration (Renato *et al.*, 2012). This may occur when the guavas are damaged through bruising which increases the amount of ethylene produced (Iqbal *et al*., 2017). The increase in ethylene is a response to the wound as a protective mechanism to heal the wound (Reyes & Paull, 1995). Also, if unripe guavas are mixed with ripe or rotten ones, they ripen faster due to high ethylene production which stimulates ripening of the unripe guavas. The levels of ethylene production during storage of guavas can be controlled using 1-MCP which is an anti-ethylene chemical (Harb & Hasan, 2012).

c) Transpiration

Water loss is a contributing factor to deterioration and results in direct quantitative losses of fruit water (loss of salable weight) (Becker, Ph and Fricke, 2014) and losses of aesthetic value due to wilting and shriveling and changes in textural quality due to softening, limpness and flaccidity (Holcroft, 2015; Vishwasrao and Ananthanarayan, 2016). The rate of transpiration is regulated by several commodity treatments such as surface coating and packaging in plastic films or through changing storage environment like in modified atmosphere packaging (Pal, 2009). Due to transpiration, guavas experience weight loss and quality changes in storage, especially when stored in a low humidity environment (Mahajan, Sharma and Dhall, 2009).

d) Physical damage

Physical damage occurs in various forms; surface injuries, impact bruising, vibration bruising, picking procedure (Kamsiati, 2016). These injuries reduce the aesthetic value of the commodity, accelerate rate of water loss, provide entry for fungi and other microorganisms, and stimulate carbon dioxide and ethylene production by the guavas (Vishwasrao and Ananthanarayan, 2016). Postharvest handling should ensure minimal physical damage of the guavas to reduce losses. Waxing helps reduce susceptibility to mechanical damage as it makes the skin slippery hence minimal bruising (Pal, 2009; Barboza *et al.*, 2016).

e) Pathological breakdown and pathological causes

This is due to the activity of bacteria and fungi (yeasts and molds) which results from physical damage that creates entry for the microorganisms (Amadi *et al.*, 2014). The beginning of ripening and senescence in fruits leads to their becoming prone to infection by microorganisms (Soares-Colletti *et al*., 2015). Stressing factors such as mechanical damage, sun scald and chilling injury reduces the resistance of fruits to microorganisms (Kamsiati, 2016). Guavas are high in sugars and are highly susceptible to yeasts and molds that are the major pathogens that cause deterioration (Mahajan, Sharma and Dhall, 2009).

2.8.2.2: Environmental factors affecting rate of Deterioration

a) Environmental Temperature

Temperature is a major significant environmental factor that affect respiration rate hence a determinant of guava shelf life. For every increase of temperature by 10°C beyond optimum temperature, it increases deterioration rate by 2-3 folds (Ribeiro *et al.*, 2006). Changes in temperature also determines how rate of ethylene production (Reyes and Paull, 1995; Iqbal *et al.*, 2017), low oxygen levels and elevated carbon dioxide will affect the guava thus the efficacy of post-harvest practices such as modified atmosphere storage are affected by the temperature around the package (Reyes and Paull, 1995). Guavas stored at low temperatures like chilling are prone to chilling injury that affects the storage life. The optimum temperatures depend on the stage of ripening (Mahajan, Sharma and Dhall, 2009).

b) Relative Humidity

The quantity of water loss from harvested perishable product is dependent on the vapor pressure deficit between the produce and the adjacent ambient temperature of the air, which is also determined by the relative humidity and temperature (Vishwasrao and Ananthanarayan, 2016). The vapor pressure deficit is reduced by increasing the relative humidity around the commodity. For guavas modified atmosphere and controlled atmosphere reduce the rate of deterioration, the RH is increased hence reduces the rate of water loss (Mahajan, Sharma and Dhall, 2009).

c) Modified atmosphere packaging and storage

Reduction in levels of oxygen and increase of in levels of carbon dioxide as in controlled and modified atmosphere can lead to either delay or acceleration of deterioration of freshly harvested product. The extent of the effect depends upon; variety, type of commodity, cultivar, physiological age, the oxygen and carbon dioxide concentration, temperature and the time of exposure. If there is external ethylene it will accelerate the rate of ripening(Pal, 2009).

2.8.4: Physico-chemical changes during storage

2.8.4.1 Chilling injury

Chilling injury has several symptoms which includes; inability of mature-green or partially-ripe guavas to ripen, skin and flesh browning, and increased decay due to increased senescence and effects of high temperatures (Mahajan *et al*., 2009). Guavas that are mature-green are more susceptible to chilling injury than guavas that are fully mature (Pal, 2009). The fully-ripe guavas have a longer storage life of a week at 5°C without showing symptoms of chilling injury (Soares-colletti *et al*., 2014).

2.8.4.2 External (skin) and Internal (flesh) browning

Guava fruits are prone to mechanical injuries and injuries which occur during harvesting, handling, transportation, and marketing and consumption stages (Paull & Chen, 2014). This increases the rate of deterioration. The bruised area becomes brown (Singh, 2011). This browning is enzymatic or non-enzymatic. Enzymes may act on the damaged area causing browning or a chemical reaction occurs at the wound to cause browning(Mahajan *et al*., 2009).

2.8.4.3 Sun scald

This occurs when guavas are exposed to direct sun light which causes burn-like scars due to scalding (Paull & Chen, 2014). The symptoms appear like burn marks on the skin (Lisa M. Keith, Velasquez, & Zee, 2007). Also, scalding can occur during transportation and at market place if the guavas are left on direct sunlight (Keith *et al*., 2007). The sun burn scars are susceptible to mechanical damage and attack by pathogens like fungi and bacteria. This increases susceptibility to pests and diseases (Keith *et al*., 2007).

CHAPTER THREE: HARVESTING AND POSTHARVEST HANDLING OF GUAVA FRUIT IN KITUI AND TAITA TAVETA COUNTIES OF KENYA.

3.0 Abstract

The guava (*Psidium guajava*) grows in many parts of Kenya, including in the Counties of Kitui and Taita Taveta, where they grow as single stands on farms or in the bush and remain virtually unattended. Guava fruit value chain is not commercially organized and standard post-harvest handling and storage procedures are not practiced as there is no bulk handling. This study evaluated the harvesting and post-harvest handling practices of the guava fruit handlers in two counties of Kenya. A total of 417 farmers were selected from the two counties (Kitui;n=214) and Taita Taveta (n=203). Using a structured questionnaire, data was collected utilizing Open Data Kit (ODK). Results indicated that the main indicative maturity indices in Kitui and Taita Taveta were skin colour (98.59%, 92.12%) and full ripe (38.79%, 18.72%) respectively. Results indicated that no packaging was done at farm level as only small quantities were harvested. Storage was short term < 4 days by 41.6% and 55.2% handlers in Kitui and Taita Taveta mainly to await consumption or market. Additionally, cluster analysis of knowledge indicated that farmers clustered as having high or low hygiene and postharvest knowledge with Kitui (71.9%) respondents having higher scores than Taita Taveta (49.8%) %). Female farmers (65.4%) were more conversant with post-harvest handling practices than males (55.4%). In conclusion, the guavas were harvested ripe and ready to eat. Post-harvest handling practices were informal with little packaging, poor hygiene practices, short term storage and informal marketing of small quantities in both Counties.

3.1 INTRODUCTION.

Guava (Psidium guajava L.) is a climacteric fruit belonging to the family Myrtaceae (Chiveu *et al*., 2019). There are three main varieties of the fruits with different flesh color namely, pink and white fleshed guava and strawberry guava (Masud *et al.*, 2018). The fruit is, however, highly perishable (Rawan *et al*., 2017).The major guava growing areas in Kenya include Elgeyo-Marakwet, Kakamega ,Uasin-Gishu, Kwale, Kilifi, Meru, Homabay, Siaya, and Vihiga, Mombasa, Kitui, TaitaTaveta among others (Chiveu *et al.*,, 2019). Guava trees survive in most agro ecological zones in Kenya except the arid areas (Omayio *et al.*, 2019). The trees grow naturally unattended and grow from seeds dispersed by animals, birds and other agents (Chiveu, 2019).

Guavas are nutritious and have high levels of ascorbic acid, riboflavin (vitamin B2), vitamin A (beta carotene), and minerals like phosphorus, iron and calcium (Omayio *et al.*, 2019). The ascorbic acid content in guavas is 4-5 times higher than that of citrus fruits; 200-400mg per 100g of guava (Augustin & Osman, 1988; Crane & Balerdi, 2015; Naseer *et al.*, 2018). The nutritional quality of guavas is, however, affected by the maturity levels and postharvest handling of the fruit (Zhou, Paull, & Chen, 2014). The fruit is fragile and is prone to bruising and physical damage (Vishwasrao and Ananthanarayan, 2016). The vulnerability to damage is dependent on the maturity stage and level of ripeness (Kamsiati, 2016). The maturity level at harvest determines the shelf life and ultimate fruit quality (Sharma, 2019). The fruit color is mostly used to assess maturity of guavas (Sharma, 2019). They are harvested at color break when they change from green to light green or slightly yellow (Kamsiati, 2016).

Harvested guavas require proper postharvest handling to maintain quality, increase shelf life and reduce losses (Rawan *et al.*, 2017). The guavas should be sorted by separating healthy fruits from bruised, wounded and damaged fruits (Kamsiati, 2016) and quality guavas are washed to remove dirt, dust and reduce microbial load on the surface and removes field heat. The disinfectants in the water prevent spoilage by bacteria and fungi (Omayma *et al.*, 2010). The fruits can be packaged appropriately and stored to extend shelf life (Sharma, 2019). Manipulation of storage temperature is an effective means to extend the shelf life of guava (Singh, 2017). They can be stored for 7 days at 20^0C and 2-3 weeks at 8-10 ^{0}C and 85-90% relative humidity (Sharma, 2019). Guava postharvest losses are estimated at 25-30% which is attributed to poor storage and postharvest handling (Singh, 2017; Krishna and Kabir, 2018). Damage in guava is caused by rough handling, which results in bruises and wounds that makes it susceptible to microbial spoilage (Augustin & Osman, 1988; Singh, 2011). Good handling practices maintain quality of guava and reduce the huge postharvest losses experienced by farmers (Kamsiati, 2016). In Kenya, guava is neglected with minimal processing and value addition leading to neglected postharvest management (Omayio *et al.*, 2019). In common practice, the guava fruits are harvested by handpicking and are neither sorted nor graded, resulting in heavy economic losses (Kamsiati, 2016). The fruit is also attacked by numerous diseases that cause rotting (Soares-Colletti *et al.*, 2015) which reduces its marketability and processing.

Poor postharvest handling has contributed to huge guava postharvest losses in Kenya as the fruit is neglected and farmers mostly depend on natural production (Omayio *et al.*, 2019). There is high production of the fruit in Kenya with minimal utilization due to short shelf life and low marketability (Chiveu, 2018; Omayio *et al.*, 2019). The study aimed at documenting harvesting and postharvest handling practices and marketing of the guava fruit. Kitui and Taita Taveta counties were selected as they are among the high guava producing areas in Kenya in semi-arid areas in Kenya (Chiveu *et al.*, 2019)**.**

3.2 METHODOLOGY

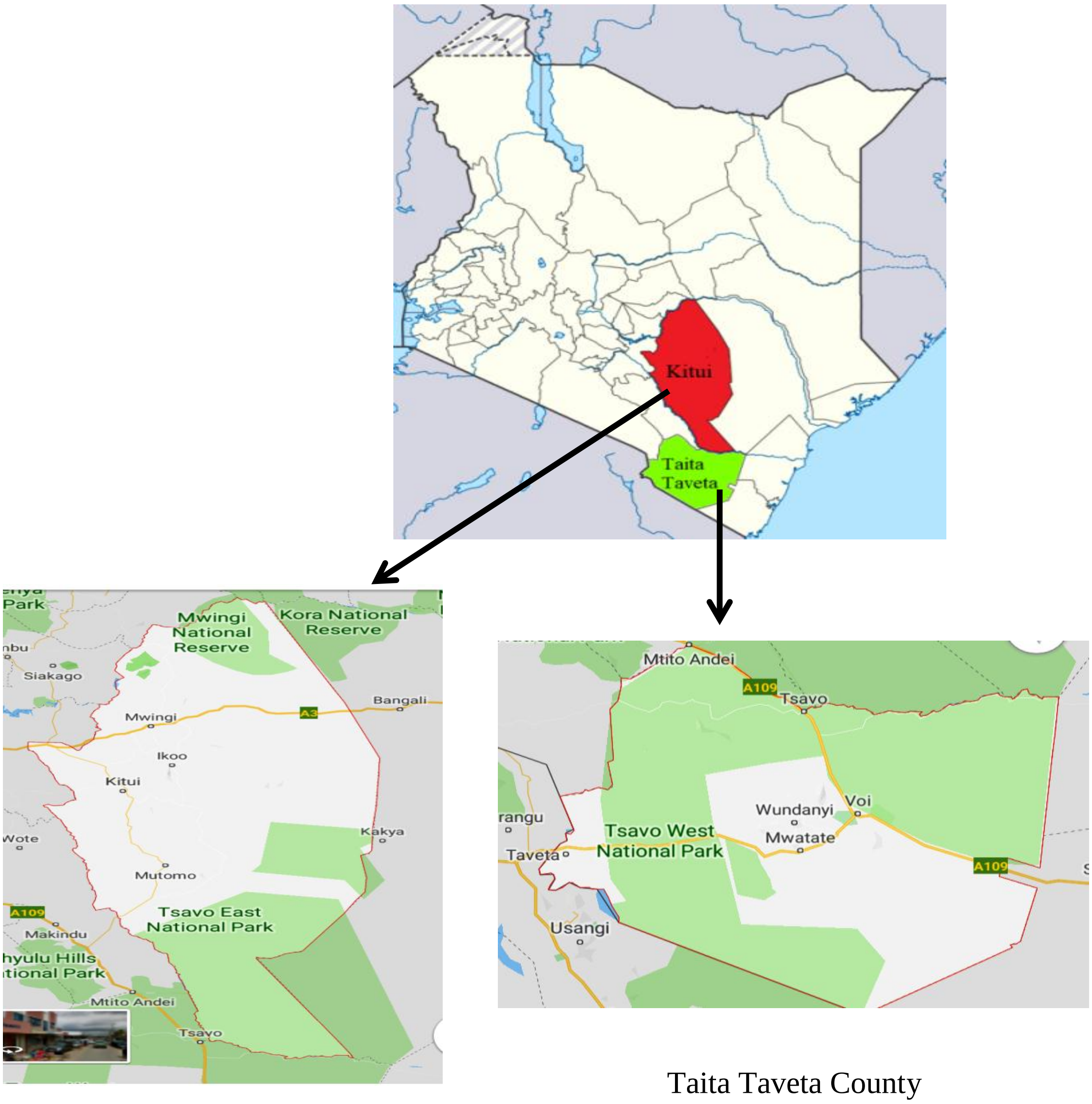
3.2.1 Study Design

The study was cross-sectional in design, comparative between two Counties. Survey was conducted between April and May 2019 in the Counties of Kitui and Taita Taveta. A total of 417 farmers including 214 from Kitui and 203 from Taita Taveta and data were collected using semi-structured questionnaires by use of digital Open Data Kit application. The data pertained to the harvesting, post-harvest handling practices and marketing of guavas from the two Counties.

3.2.2 Methods

3.2.2.1 Study area

The study was conducted in Kitui and TaitaTaveta counties. Kitui County (Figure 3.1) is located in the former Eastern Province of Kenya. It covers an estimated area of 30,496.4 Km^2 and comprises of 1.136 million people according to the 2019 Kenya National Bureau of Statistics census (KNBS, 2019). It is located between latitudes 0° 10" and 3° 0" South and longitudes 37° 50" and 39° 0" East. The altitude of the county ranges between 400m and 1800m above sea level (County Government of Kitui, 2018). It has a low lying topography with arid and semi-arid climate. The rainfall distribution is erratic and unreliable except for the highlands which receive relatively high rainfall annually compared to the lowlands. The annual rainfall ranges between 250mm-1050 mm per annum with 40% reliability for the long rains and 66% reliability for the short rains (Kitui County Intergrated development, 2018). The County experiences high temperatures throughout the year with annual temperature ranges between 26°C and 34°C whereas the minimum mean annual temperature ranges between 14°C and 22°C (Cassim and Juma, 2018). The county is also divided into agro ecological zones which support subsistence crop and livestock agriculture which is the major economic activity (Omayio *et al.*, 2019). The guava trees grow in the highland areas of the county which has sub-humid climate. Other horticultural crops produced in the county are fruit crops such as mangoes, paw paws, water melons, tomatoes, avocado and castor fruit (Kitui County Intergrated development, 2018).



Taita Taveta County

Kitui Countv

Figure 3.1: Map of Kenya showing the location of Kitui and Taita Taveta Counties. Source: Google Maps, (2019)

Taita Taveta County (Figure 3.1) is located in the Coastal region of Kenya bordering Tana River, Kitui Makueni, Kwale and Kilifi, Kajiado and the Republic of Tanzania on the

Southern side. The county covers an estimated area of 17,084.1km^2 and has an estimated population of 340,671 persons according to 2019 census (KNBS, 2019). The county lies between longitude 37^0 36$^{''}$east and 30^0 14$^{''}$ east and latitude 2 ^{0} 46$^{''}$ south and 4^0 10$^{''}$ south. Altitudes range from 500 metres above sea level to almost 2300 m at the highest point in the county Vuria Peak. Taita Taveta is mainly dry, with the exception of Taita Hills which are considerably wet. Rainfall distribution is usually uneven, with higher rainfall amounts being recorded in highland areas as compared to the lowlands. Annually, mean rainfall is 650 mm (County Government of Taita Taveta, 2018). The average temperature in Taita Taveta County is 23^{0}C, with lows of 18^{0}C in the hilly areas and rises to about 25^{0}C in the lower zones (Tirra, Nyang and Wakesho, 2019). Guava grows in the highlands with Sisal estates and hilltop forests occupying less than 100 km^2. The Taita hills form the highlands which support agricultural activities. Horticultural activities include fruit crops (bananas, mangoes, oranges, passion fruit, guavas) (County Government of Taita Taveta, 2018).

3.2.2.2 Study population

The study included farmers in the two Counties. The guava farmers constituted the guava farming households.

3.2.2.3 Sample size calculation

The sample size for the respondents was determined as per the Fisher's formula (Fisher *et al.*, 1991).

$$\mathrm{N} = \frac{Z^2\mathrm{Pq}}{d2}$$

Where;

N -Quantity of sample size desired

P- Proportion of the farmers expected to have guavas in their farms, taken as 50%

q (1-p)- The ratio in the selected population not expected to have guavas in their farms (50%)

d=Level of precision or absolute error (0.048^2)

Z- Normal standard variation at the required confidence level, a 95% confidence level will be used.

Therefore;

N= $(1.962^{*}\ 0.5*0.5) \div (0.048^{2)}$ = 417 respondents

There was no attrition rate because all respondents returned completely filled forms.

3.2.2.4 Sampling procedure

A multi-stage sampling was used in getting the sampling units for the study. The two counties were purposively selected due to their high guava production and the fact that the project that funded this study was based there. Two Sub-counties were purposively selected in each County based on high production quantities from which two wards were selected purposively as the study sites. The respective households were then selected randomly and interviews conducted with a respondent in each household.

3.2.2.5 Data collection tools

Semi-structured questionnaires were used for data collected and were built in the Digital Open Data Kit (ODK) application (Appendix 1).

3.2.2.6 Data collection

Data was collected on the following; (Appendix 1)

a) Socio-demographic and social economic assessment

Data on respondent name, gender, age, level of education, marital status and main source of income for the household was collected.

b) Postharvest handling and preservation of guavas

Data on maturity indices, harvesting, packaging, storage, shelf life, postharvest losses and strategies of extending guava shelf life was collected using a structured questionnaire

c) Hygiene and Knowledge practices

Knowledge and hygiene practices scores of the respondents was assessed using the "Yes", "No" and "Don't Know" statements while the practice was assessed using "Yes" and "No" questions. Blooms cut-off point's was used in assessment of knowledge in previous studies by (Abdullahi *et al*., 2016; Nahida., 2008). Grades of ≤59% were scored as low, 60-79% moderate and 80-100% high. These scores were obtained by summing up correct scores for 1-18 knowledge statements which were categorized with postharvest knowledge having of 10 points and hygiene practices 8 points.

3.2.2.7 Statistical Data Analysis

Data analysis was done using statistical package for Social Sciences Software (IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) and R package for statistical computing (R core team, 2019). Each postharvest handling practices and hygiene knowledge response was transformed and categorized as either correct or incorrect. Frequencies were used to summarize scores for each question on hygiene and practices. Inferential statistics (t-test, chi square, frequencies and correlations) were used to analyze the data. A cluster analysis was done using R for data science to analyze knowledge by clustering the respondents in terms of their levels of knowledge.

3.3 RESULTS

3.3.1 Socio-demographic characteristics of guava producing Farmers

Guava production in both Kitui and Taita-Taveta Counties largely involved women (57.6%). Taita Taveta had more men (51.72%) involved in guava production as compared to Kitui where there were more women (66.35%) than men ($P<0.001$). The mean age of guava farmers differed significantly ($t\ (415) = 2.2$, $P<0.05$) in both counties with Taita Taveta having aged farmers 48.2±15.9 years as compared to Kitui (44.9±15.7**)** years. There was no significant ($P>0.05$) association between county and levels of education of guava producing farmers ($\chi^2=4.3$, $P=0.2$) with most respondents (58.5%) having attained primary education and 10.1% were illiterate. Although the level of tertiary- educated respondents was low, Kitui had a slightly higher number of farmers who had attained tertiary education (7.5%) as compared to Taita Taveta with only 4.4%. Those who attained secondary level were low in both counties 25.9%. The level of education was significantly associated ($\chi^2=23.533$, $P<0.001$) with gender with both counties recording more educated women than men. The major source of household income was farming and it significantly differed ($\chi^2=7.9$, $P=0.1$) in both counties with Kitui (70.9%) and Taita Taveta (74.9%)

Table 3.1: Socio-demographic characteristics of guava handlers in Kitui and Taita Taveta Counties

Demographic characteristic	Levels	Taita Taveta N% N=203	Kitui N% N=214
Gender	Male	51.7	33.6
	Female	48.3	66.4
Age of respondents	Mean	48.4	44.9
Level of education	Did not attend school	8.9	11.2
	Primary	57.6	58.4
	Secondary	29.1	22.9
	Tertiary	4.4	7.5
Marital status	Married	74.8	77.6
	Widowed	2.9	7.9
	Divorced/separated	5.4	0.9
	Single	16.8	13.6

3.3.2 Harvesting practices

Table 3.2: Maturity indices and harvesting practices by guava farmers in Kitui and Taita Taveta counties.

Parameter		Taita Taveta N% N=203	Kitui N% N=214
Maturity Indices	Color	92.1	87.4
	Fruit sizes	18.7	17.8
	Full ripe stage	31.0	29.4
Immediately after harvesting guava	Keep exposed to sunlight	0.5	15.4
	Keep under shades	53.7	76.6
Washing harvested guavas	Yes	56.2	35.0
	No	43.8	65.0

3.3.3 Guava postharvest handling practices

Seven in every ten farmers (70.7%) transported guavas using human labour using sacks, baskets or buckets after harvesting. There were significant differences (χ^2=45.9, P<0.001**)** in methods of transporting guavas between the counties. Manual transportation of guavas was the most common means of transportation in Taita Taveta and Kitui with 77.8% and 64.9% of farmers respectively transporting their fruits from the farms using buckets and sacks. The main packaging materials among the farmers who packaged the fruits (Kitui, n= 214, Taita n=203) in Kitui was sacks (29%) paper boxes (39%) in Taita Taveta. The two counties differed in choice of packaging material as shown in Figure 3.2

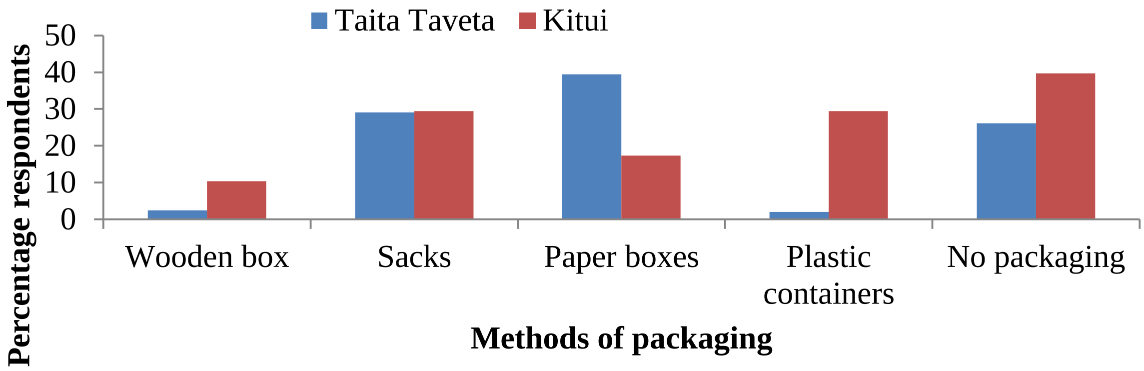


Figure 3.2: Methods used by farmers for packaging guavas in Kitui and Taita Taveta counties, Kenya.

3.3.4 Guava deterioration

On average guavas lasted for 4.1±1.9 days prior to deterioration in both counties. There was a significant difference of guava shelf life between Kitui and Taita Taveta (t (415) =8.4, $P<0.001$) with Kitui having a shorter period (3.4±1.9) compared to Taita Taveta (4.9±1.8). Approximately 76.6% of guava farmers experienced massive postharvest losses which were significantly different (t (415) =-8.3, $P<0.001$) between both counties being more rampant in Taita Taveta where 93.1% of farmers reported postharvest losses as compared to Kitui where only 61.2% did.

Farmers in both counties reported similar kinds of losses and their major causes as shown in Table 3.3. Losses from shriveling were higher in Kitui (20.5%). Most of the fruits were left to rot in the fields as shown Figure 3.3. Approximately 93.8% of farmers experienced pests and diseases with no measures in place to control this. Pests and diseases were more frequent in Kitui (95.3%) than in Taita Taveta (77.8%). Eight in every ten farmers (81.1%) did not have an alternative use for overripe guavas and these were left to rot in the farms (Taita Taveta (84.7%), Kitui (75.7%). Farmers in the two counties used various strategies to reduce guava deterioration with aim of reducing losses (Figure 3.4)

Table 3.3: Types and causes of guava deterioration in Kitui and Taita Taveta counties

Kinds of deterioration	**TaitaTaveta (N%) N=203**	**Kitui (N%) N=214**	χ^2
Mechanical injuries	24.1	21.5	3.1
Over ripening and rotting	87.7	54.6	2.5
Guava shriveling	2.5	20.5	57.1 **
Microbial damage	49.7	30.8	0.3
Causes of guava deterioration in Kitui and Taita Taveta counties, Kenya			
Poor storage	29.6	39.7	4.7*
Pests and diseases	77.8	95.3	27.8**
Inadequate knowledge on postharvest handling	39.5	36.5	0.4
Excess rain	18.7	28.9	5.0*
Lack of market	53.7	12.6	78.9**
Poor packaging	2.9	22.9	36.2**

*Correlation is significant at the 0.05 level, **. Correlation is significant at the 0.001 level (Chi-square tests).

High postharvest losses were reported in Kitui and Taita Taveta as most of the guavas are left to rot in the farm (Figure 3.4).

Figure 3.4: Picture of a guava rotting under a tree in a farm in Kitui, Kenya.

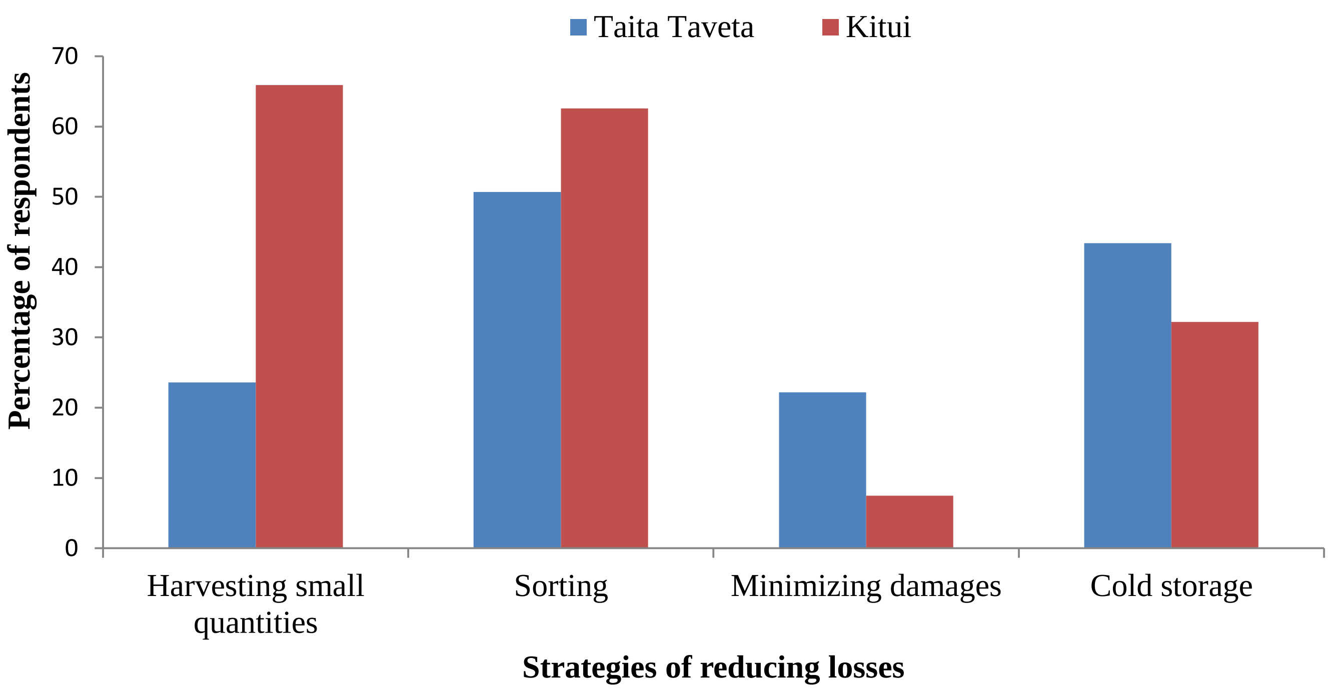


Figure 3.4: A comparison of the strategies for reducing guava deterioration in Kitui and Taita Taveta counties, Kenya (χ^2=149.8, P<0.001).

3. 3.5 Storage of guava fruit

In both counties, guavas were mainly stored for later consumption and sometimes for market. More than half of the farmers (55.1%) did not store guavas after harvesting. Slightly more farmers in Kitui (58.4%) stored guava compared with Taita Taveta where more than half (55.2%) did not. This was due to low commercialization of the fruit. A low proportion of farmers practiced guava storage and there was no significant differences (t (415) =2.8, P=0.05) between the proportions of farmers that stored guavas between the two counties as most farmers in both counties harvested small quantities.

The farmers who stored guavas used various methods of storage (Table 3.4). There was, however, no significant association between the method of storage and the shelf life of guavas (χ^2=24.439, P=0.041). Farmers had employed various strategies of extending guava shelf life which included sorting, harvesting small quantities, cold storage and minimizing mechanical damages (Figure 3.3). There was a correlation between the shelf life of guavas and the county of origin (r = 0.77, P<0.001) hence the county had an influence on how long guavas stored before spoiling.

Table 3.4: Storage containers used to store guavas by farmers in Kitui and Taita Taveta counties

Method of storage	TaitaTaveta (%) N=203	Kitui (%) N=214	χ^2
Crates	11.3	20.1	6.0*
Sealed plastic bags(Modified atmosphere)	0	14.5	31.8**
Low temperature (Refrigeration)	1.9	26.2	49.5**
Carton/plastic papers	27.1	15.4	8.5*
No storage	55.2	41.6	7.7*

***.** Correlation is significant at the 0.05 level, **. Correlation is significant at the 0.001 level

(Chi-square tests)

3.3.6 Hygiene knowledge by handlers in Postharvest handling of guava fruit

Clustering of knowledge on hygiene and postharvest handling practices generated two components that explained more than three quarters of data variability (76.0%) (Figure 3.5), Cluster one had relatively low mean scores of knowledge on food hygiene, household hygiene, harvesting, storage and packaging (Table 3.5). This was lower than the scores of cluster two where those with knowledge had relatively higher scores. Kitui had a higher proportion of farmers (71.9%) with knowledge on hygiene and postharvest handling practices as compared to Taita Taveta (49.8%). Furthermore, the female farmers (65.4%) were more knowledgeable than the male farmers (55.4%). The level of education had an influence on knowledge where a greater proportion of those with knowledge were among the educated farmers who had attained tertiary education (87.5%) compared to those with primary (62.7%) and secondary education (52.8%). The respondents' level of training on hygiene and postharvest practices associated significantly (χ^2= 6.3, P<0.5) with hygiene knowledge on handling of fruits. Farming was the main occupation for both clusters; however, cluster two had the highest number of respondents who were farmers by occupation (60.4%) than cluster one (32.3%). The overall knowledge assessment adopted Blooms cut-off point's grade scores, at p<0.001, t (415) =-6.8, at 95% confidence interval. Kitui county had a higher score (80.8±27.2) compared to Taita Taveta (65.1±19.2) knowledge on post-harvest handling practices. Respondents from both counties had higher knowledge on hygiene practices compared to postharvest handling with Kitui and Taita Taveta scoring a mean of 89.6±17.3 and 81.3±6.3 respectively (t=81.8, P<0.001). Responses on postharvest handling practices lied in the range of 60-79% hence farmers had moderate knowledge on postharvest practices. On hygiene knowledge correct responses were between 80-100% ranges which indicated that the farmers had high knowledge on hygiene.

Table 3.5: General hygiene and postharvest handling knowledge of guava farmers and handlers in Kitui and Taita Taveta counties

	Food hygiene	Household Hygiene	Harvesting	Storage	Packaging
Cluster 1	-0.8707538	-0.9238673	-0.7749838	-0.8656509	-0.8767342
Cluster 2	0.5531847	0.5531847	0.4923427	0.5499429	0.5569841

The means have been standardized to z-distribution with a mean of 0 and standard deviation of 1.

Clustering of farmers in terms of knowledge on hygiene and postharvest handling practices generated two components (Figure 3.5).These components indicated that more than three quarters of data variability (76.0%) indicating varying levels of knowledge among guava handlers. Cluster 1(component 1) had relatively low mean scores of knowledge on food hygiene, household hygiene, harvesting, storage and packaging. This was lower than the scores of cluster (component 2) where those with knowledge had relatively higher scores.

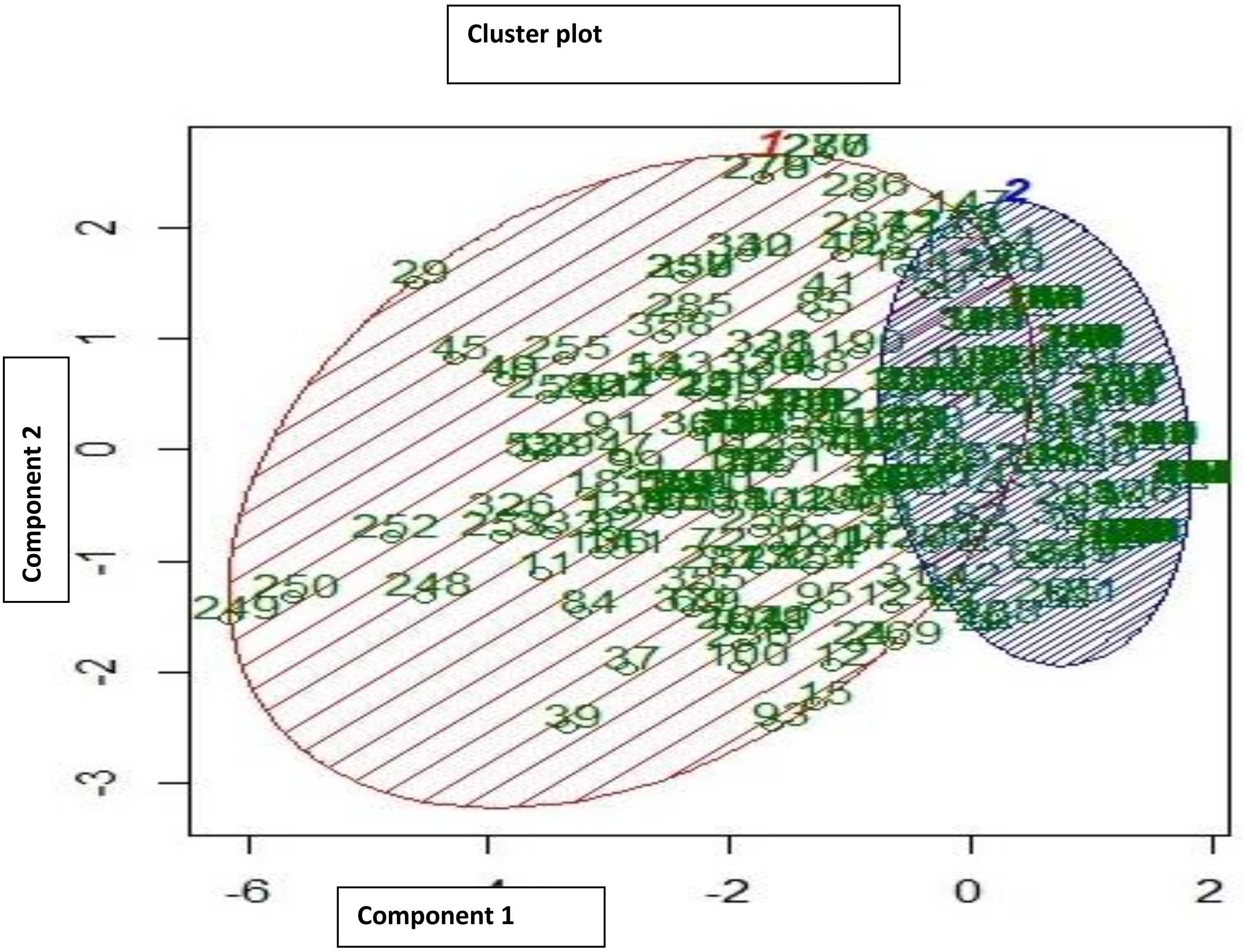


Figure 3.5: WSS plot of knowledge clustering of farmers in Kitui and Taita Taveta counties, Kenya.

3.4 DISCUSSION

3.4.1 Socio-economic and demographic characteristics of guava producing Farmers

The higher involvement of women in guava production in both Kitui and Taita Taveta is linked to factors such as societal roles where women are entitled to carry out farm activities especially for subsistence farming (Ogunlela & Mukhtar, 2009). Majority of farmers had low levels of education which is in agreement with other studies that have reported that most people involved in fruits and vegetable production have low education (Rahiel *et al.*, 2018; Bosibori, 2015). This is attributed to lack of interest in education and high poverty levels in the two counties where most of the household income is used to purchase food (Brewer, Etheridge, & Dea, 2017; Tacoli, 2017). Household education influenced their postharvest handling of fruits where low levels of education led to poor handling practices thus increasing guava losses (Sharif & Obaidat, 2013). This was well reflected in Kitui where there were more educated farmers and equally higher knowledge scores on hygiene and postharvest management compared to respondents from Taita Taveta County. Women were found to be more educated than men in both counties as indicated by the number of females who attended school which can be linked to the increased women empowerment in the country leading to increased their interest in education (Habib *et al*., 2019).

3.4.2 Harvesting practices

The maturity stage at harvest has an implication on the shelf life and quality of guava fruit (Cavalini *et al.*, 2006). The maturity indices for harvest of guava fruits is usually based on subjective evaluation of color, fruit size and texture which vary with location, time, fruit size, type and age of the plant (Kamsiati, 2016). In both Kitui and Taita Taveta, guava fruits were harvested when fully ripe. Fruits harvested at full ripe stage are of high quality but have short shelf life, although if harvested at mature green stage the quality is low with a longer shelf life (Kamsiati, 2016) . On the other hand, harvesting of immature guavas results in product losses due to slow ripening or failure to do so (Singh, 2011; Prasad *et al*., 2020). In Kitui and Taita Taveta, farmers harvested when guavas were fully ripe because they harvested small quantities for household and the rest were left to rot in the farm which contributed to huge postharvest losses (Omayio *et al*., 2019) The fruits should be harvested at mature green stage to ensure effective postharvest management to reduce losses (Cantwell and Davis, 2014). The use of skin color as indicative of the maturity of the fruit in in both counties is in agreement with similar findings reported by Singh (2011) in his study on guavas which indicated that color determines maturity. Additionally, this technique is employed in establishing maturity in several fruits including mangoes, bananas, papayas (Cantwell and Davis, 2014). Removal of field heat from guava fruits was a common practice in both regions by washing or keeping the fruits under shade with the aim of slowing down reactions that lead to rapid ripening and decay (Omayio *et al*., 2019; Rawan *et al*., 2017) therefore reducing postharvest losses of the fruit.

3.4.3 Guava postharvest handling practices

Postharvest handling of guava includes sorting, cleaning, grading, packaging, storage and transportation (Kamsiati, 2016; Sharma, 2019). Postharvest guava storage was not a major practice in both Kitui and Taita Taveta as farmers harvested enough for their consumption. This is explained by the low marketability and consumption of the fruit in Kenya (Omayio *et al*., 2019)**.** After harvesting**,** the guavas were manually transported to the homestead and also to the market using buckets, sacks, crates or cartons. These modes are likely to increase mechanical damage of the fruits especially when harvested at full ripe stage (Bakshi, 2015). Most farmers in Kitui and Taita Taveta did not package guavas as the fruit had minimal economic value. Besides, only small quantities were normally harvested for household consumption. Sacks were mainly used for packaging during storage and transportation of the fruits in Kitui. Although the sacks have air spaces that allow for respiration and prevent anaerobiasis (Momin, Kabir, & Jamir, 2018) they should be discouraged as they cause surface injury. In Taita Taveta, farmers opted to use paper boxes to package guava. This was as recommended by (Kaur & Kaur, 2019) that paper boxes were good in ensuring the lowest weight loss, ethylene and respiratory rates, highest soluble solids and vitamin C concentrations in the fruit. However, these packages can expose the fruits to mechanical damages if used for transportation without cushioning the fruits (Singh *et al.,* 2014). Additionally, the fruit is highly perishable and has a delicate skin that is prone to mechanical damage (Gill, 2018).

3.4.4 Guava deterioration

Most of the households harvested small quantities of guava for home consumption and the rest were left to rot in the field which contributed to huge losses. A study conducted by Shivaraj & Patil, (2017) in India found that guava losses at harvest and postharvest were approximately 16% increasing the economic losses to guava farmers. Overripe guavas were left to rot in the farm with no alternative use due to low value addition of the crop to shelf stable products such as juices, jams, nectars, wine, animal feeds and in compost making (Omayio *et al*., 2019). Microbial attacks and mechanical injuries were the major causative factors of the guava losses as reported in Kitui and Taita Taveta. The fruit is highly prone to fruit fly infestation and other pests which reduce its shelf life increasing losses (Keith & Zee, 2010). Most respondents (93.8%) reported pests and diseases as the major cause of losses to guavas although they did not use any control measures given that the fruits are neglected and have low commercial value (HCD, 2014). Studies indicate that guavas are highly infested by fruit flies during the rainy seasons which increase losses (Jatinder Singh, 2017).

Inadequate knowledge on postharvest handling was reported as the second challenge leading to huge losses in Kitui and Taita Taveta. The significant difference in shelf life of guavas in Kitui (3 days) and Taita Taveta (5 days) is linked to the temperature difference between the counties as Kitui is relatively hotter than Taita Taveta with temperature ranges of 24-34℃ and 21-32℃ respectively (Cassim and Juma, 2018; Tirra *et al.*, 2019). Higher temperatures result to higher respiration rates thus the shorter shelf life in Kitui (Renato *et al.*, , 2012). Guavas have a thin, delicate skin which increases susceptibility to injuries and pest attack (Pal, 2009; Singh, 2011) that reduces its shelf life. The farmers' strategies of extending guava shelf life by sorting, harvesting small quantities and cool storage have been shown to be effective with other fruits like mango, banana, avocadoes and pawpaw (Kamsiati, 2016).

3.4.5 Storage of guava fruit

Farmers harvested guavas when they were at full ripe stage which made them highly perishable and prone to mechanical injuries. This is attributed to high respiration rates that increase ripening during storage (Rawan *et al.*, 2017). The maturity stage highly influences the storage life of the fruit (Prasad *et al.*, 2020) as it affects its postharvest life by influencing the rate of deterioration. Storage of guavas was not a common practice in both counties which could be linked to lack of knowledge on postharvest handling and storage of guavas. In both counties, farmers did not practice cold storage of guavas which was due to lack of electricity and refrigerators. Guavas stored at low temperature (8 to 10^{o}C) had a longer shelf life than those stored at room temperature (20 to 25^{o}C) (Mitra *et al.*, 2012; Sharma, 2019). The strategies put in place to reduce rate of deterioration were sorting of the fruits into unripe, ripe and over ripe and harvesting small quantities. There are other storage methods that were not practiced in Kitui and Taita Taveta but have the potential to extend guava shelf life; use of modified atmosphere storage, individual packaging using cling films, salts (calcium chloride and calcium nitrate) and freeze drying (Omayio *et al.*, 2019).

3.4.6 Knowledge on hygiene and Practices

The clustering of farmers' hygiene and handling knowledge resulted into two major clusters which revealed that guava farmers either had low or relatively high knowledge of hygiene practices. The low knowledge can be linked to the fact that most farmers have low exposure on postharvest handling of the produce (Muhammad, Hionu & Olayemi, 2012). Guava fruit handlers in Kitui had more knowledge on hygienic handling of the fruits which greatly influenced how they handled the fruits after harvest. This could be linked to higher education level of farmers in Kitui than in Taita Taveta. Besides, there was a guava market in Kitui and may have contributed to this as the farmers and guava traders practiced hygienic handling of the fruits to extend shelf life and reduce unnecessary losses from poor handling. A study by

Sharif & Obaidat,(2013a) on food hygiene knowledge and practices showed that knowledge scores increased with the levels of education.

Additionally, gender was found to have an influence on knowledge with women tending to be more knowledgeable on handling and hygiene than men, this attributed to the fact that women had high education level than men (Habib *et al*., 2019). These findings are in agreement with Samapundo *et al.*,(2016) who noted that gender correlates positively with of food safety knowledge, hygiene and practices where women were found to be more hygienic in handling food. Other studies have reported that training on food handling and safety results to increased levels of knowledge (Azmi, 2006). Despite the fact that the respondents from both counties had not received any formal training on postharvest handling of fruits, they displayed somewhat high levels of knowledge which could be influenced by other trainings on food sanitation and food safety. There is therefore need for training of guava handlers on hygiene practices and postharvest handling to reduce losses.

3.5 CONCLUSION

Guava fruit production in Kitui and Taita Taveta is largely subsistent with limited commercialization. Households producing the fruit practiced limited postharvest management to improve the keeping quality of the fruit. However, Limited information is available on postharvest handling properties of the fruit. Despite this, the households had acceptable levels of knowledge on postharvest handling of the fruit although there exists a gap in the actual practice and implementation of the knowledge possessed in actual practice. Harvesting of guava was not a common practice as farmers harvested just enough for household consumption and the rest is left to rot in the farms, eaten by birds and animals. This is due to low value addition of the fruit due to its low economic value.

3.6 RECOMMENDATIONS

1. Training farmers on postharvest management of guavas with the aim of increasing its marketability to enhance its production and increase farmer income from the fruit
2. Development of guava postharvest handling standards, guidelines and manuals to be availed to farmers to enhance their postharvest management with aim of averting the huge losses.

CHAPTER FOUR: EFFECT OF STORAGE CONDITIONS ON PHYSICOCHEMICAL CHANGES OF GUAVA FRUIT DURING STORAGE

4.0 Abstract

Guava is a climacteric fruit which undergoes changes in storage causing deterioration through water loss and rotting and if stored under refrigeration suffer physiological breakdown especially chilling injury. Spoilage depends on treatments prior to storage and prevailing storage conditions. The present study aimed at determining the effects of storage conditions on the physicochemical changes of guava fruit. Mature green fruits of the pink variety were collected from Kitui and Taita Taveta and transported in gunny bags to the laboratory within eight hours, then stored overnight in a cool and dry place. In the morning of the following day the fruits were divided into three batches. One batch remained unwashed, another washed with plain tap water and the other washed with water containing chlorine at 55-70ppm. The fruits batches were each divided into packages of 5 fruits each in a modified atmosphere package and plastic net bag. These packages were divided into three temperatures for storage as 8±2℃, 20±5℃ and 30±2℃. Initially and every two days during storage, the fruit packs were checked for weight loss, moisture content, ascorbic acid, beta carotene, titratable acidity, pH, total soluble solids until the fruits ripened. Storage temperature significantly ($p<0.05$) accelerated the rate of physicochemical changes of fruits stored in the net bags compared to modified atmosphere. Fruits stored at 20-25℃ and 28-30℃ recorded the higher changes in weight loss, moisture content, vitamin C and beta carotene as compared to those at 8-10℃. Storage time had a significant ($p<0.05$) effect on physicochemical changes during storage. The study concludes that storage at 8-10℃ afforded the fruits a shelf life of 11 days. Modified atmosphere packages best lowered the rate of deterioration based on the changes in ascorbic acid, beta carotene. Guava shelf life can be extended through storage in modified atmosphere packaging at 8-10℃.

4.1 INTRODUCTION

Guava *(Psidium guajava. L)* is a perishable fruit commonly grown in the tropical and sub-tropical regions (Salazar *et al*., 2006) with a fragile skin which is prone to damage (Vishwasrao & Ananthanarayan, 2016). Guava varieties include white fleshed, pink fleshed and strawberry (Omayio *et al*., 2019; Vora, Mankame, & Madav, 2018).Others include apple guava and yellow fruited cherry guava (Masud *et al*., 2018) . The fruit is widely known for its characteristic aromatic flavor (Chiveu *et al*., 2019).

The guava fruit is highly nutritious and can be used to diversify the sources of nutrients for consumers and increase income for traders. It has high ascorbic acid, riboflavin (Vitamin B2), vitamin A, and minerals like phosphorus, iron and calcium (Omayio *et al*., 2019). The fruit has a vitamin C content of 200-400mg per 100g of guava (Augustin & Osman, 1988; Crane & Balerdi, 2015) with the skin having a higher amount (Naseer *et al*., 2018). The fruit is entirely edible and can be consumed together with the skin which is nearly fused together with the flesh (Masud *et al*., 2018). Guava is among the most tasty and juicy fruits. The pink-fleshed guava has high carotenes and polyphenolic compounds which belong to the major groups of antioxidant compounds. This gives the fruit a very high antioxidant activity among the diverse plant materials (Chiveu *et al.*, 2017). Pink-fleshed guavas have higher pigment content such carotenes and pro-vitamin A than the white-fleshed variety (Musa, Abdullah, Jusoh, & Subramaniam, 2011).

Guava fruit experiences high postharvest losses and in Kenya over 11000 tonnes of guava go to waste annually (Chiveu *et al*., 2019; Omayio *et al*., 2019). The fruit is susceptible to physical and chilling injuries, insects and pests attacks as well as diseases (Singh, 2011). Guava fruits are also prone to physicochemical changes that influence sensory and nutritional qualities (Jain *et al*., 2003). The main contributing factors are physiological (shriveling, chilling injury, wilting), pathological and enzymatic activity (yeasts, molds and bacteria) and physical damage (Soares-colletti *et al*., 2014). Mechanical damages accelerate secondary decay, bruising as wounding creates openings for entry of pathogens and activity of enzymes (Kamsiati, 2016).

Poor postharvest handling and hygiene contribute to accelerated physicochemical changes of guavas during storage (Krishna & Kabir, 2018) influencing the deterioration in physicochemical quality. The physical parameters mostly affected are weight, due to moisture loss as a result of high respiration rates. The fruits lose crunchiness, juiciness, firmness and texture during storage due to water loss and ripening that cause breakdown and solubilization of pectin (Deepthi *et al*., 2016). The fruit color changes as it ripens. The rate of ripening can be accelerated by poor handling practices, storage conditions and mechanical damage that may influence the rates of ethylene production which further increases rate of ripening and senescence (Iqbal *et al*., 2017; Jain *et al*., 2003; Reyes & Paull, 1995).

The chemical properties that are affected during ripening and storage in guava are vitamin C, total soluble solids, beta carotene, and titratable acidity. Vitamin C is sensitive to light and oxygen and decomposes during transportation and storage (Madhav1 *et al*., 2018; Vishwasrao & Ananthanarayan, 2016). Beta carotene increases during ripening due to accumulation of carotenoids and polyphenols (Singh, 2011). Sugars and total soluble solids also increase with ripening due to breakdown of carbohydrates into sugars (Dolkar *et al*., 2017; Vishwasrao & Ananthanarayan, 2016).

The storage conditions for guavas influence the type and rate of physicochemical changes (Rodeo & Esguerra, 2018a). The fruit has a short shelf life hence there is need for modification of storage conditions aimed at extending the storage period (Momin *et al*., 2018). Guava storage can be done at low temperatures (of about 8-10°C) which is recommended for fruits that are at the mature green stage of maturity (Mitra *et al*., 2012; Ribeiro *et al*., 2006). Guavas fruits packaged in low-density polyethylene films have been found to have reduced rates of ripening and deterioration hence extended shelf life (Rana *et al*., 2015; Singh *et al*., 2014). Additionally, wrapping of guavas in low density polyethylene bags reduces dehydration, chilling injury and disease severity (Mitra *et al*., 2012; Pal, 2009).

Poor storage conditions and techniques aggravate postharvest losses evidenced in guava fruits (Rawan *et al*., 2017). In Kenya, the low economic value attributed to guava fruits among farmers has been a major constraint to guava postharvest management (Omayio *et al*., 2020). Moreover, limited commercialization and processing lead to high annual losses are occasioned during glut (Omayio *et al*., 2019). This calls for improved storage to extend shelf life by minimizing physicochemical changes. The aim of this study was to establish physicochemical changes of guava fruit during storage with the aim of identifying the best alternative to extend shelf life.

4.2 MATERIALS AND METHODS

4.2.1 Procurement of Guava Fruit

Pink fleshed guavas at physiological maturity (mature green) from Kitui and Taita Taveta counties were randomly harvested between April and May 2019. The fruits were packaged in sacks and transported to the University of Nairobi pilot plant.

4.2.2 Storage study design

A full factorial experimental design was used to study the effects of washing, modified atmosphere and storage temperature on the physicochemical changes in pink-fleshed guava fruits during storage. Three main treatment factors were used with each treatment having duplicate replications were done. The guavas were separately sorted and grouped into three treatment batches of unwashed, washed potable water and last batch was washed chlorinated water (Figure 4.1) at a rate of 55-70 ppm of sodium hypochlorite as per Amaral *et al* (2013). The fruits batches were each divided into packages of 5 fruits each in a modified atmosphere package and plastic net bag. Three layers of cling films were used to create modified atmosphere packaging while plastic nets were used for packaging non-modified samples. These packages were divided into three temperatures for storage as 8±2°C, 20±5°C and 30±2°C. Initially and every two days during storage, the fruit packs were checked for weight loss, moisture content, ascorbic acid, beta carotene, titratable acidity, pH, total soluble solids until the fruits ripened.

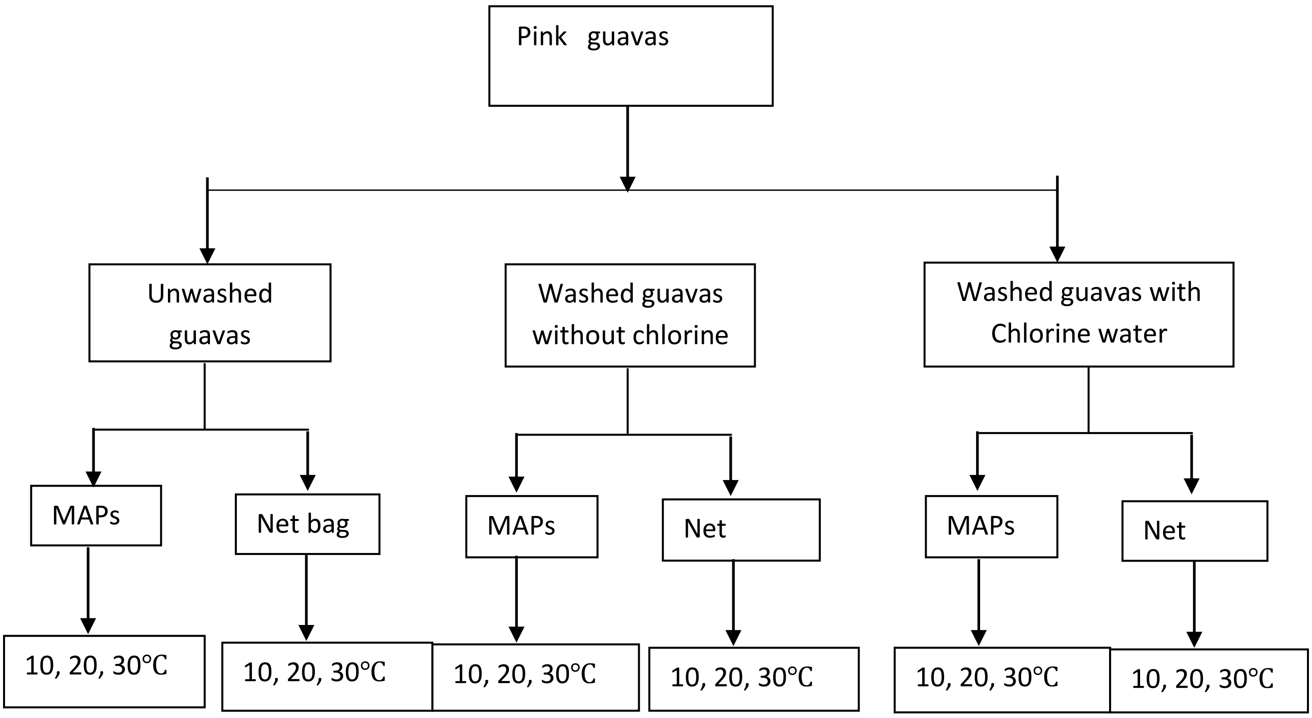


Figure 4.1: Storage study design.

MAP=modified atmosphere packages

4.2.3 Treatment of guavas before storage and analysis

Storage treatment involved other sub-factors (washing, temperature and modified atmosphere). The pink fleshed guava variety batches were each subjected to storage at different temperatures**.** Chlorine dips were used during washing to remove any surface microorganisms. Each stored sample was analyzed for chemical changes (Ascorbic acid, beta-carotene, total soluble solids (TSS), pH and total titratable acidity (TTA) and Physical changes for (color, texture, and moisture content, weight. The stored guavas were analyzed for physicochemical changes under storage at day: 0, 3, 5, 7 and 11. Ripe guavas (ready to eat) were analyzed for physicochemical profile without storage trials.

4.2.4 Storage study

Modified atmosphere was by use of a three layers of cling film on fruits and for non-modified, plastic nets were used. Temperature selection- The temperature ranges selected was based on prevailing temperatures of the study area and ease of improvisation by the farmers. Storage at 8-10℃ was simulating the cold storage methods practiced in Kitui and Taita Taveta counties which included use of charcoal coolers, wet sand in a pot (fruits are placed in a pot containing wet sand to ensure low temperature) and use brix pots. These storage methods can accommodate both net packages and modified atmosphere packages. Storage at 20-25℃ was the room temperature at University of Nairobi college of Agriculture and Veterinary sciences while for 28-30℃ an incubator was used to modify the temperatures and it was mainly simulating the extreme temperature at Kitui and Taita Taveta. The fruits were sampled after every 2 days for analysis.

4.2.5 Analytical methods

4.2.5.1 Determination of moisture content

Moisture content determination was done using method number 930.15 (AOAC, 2005) using a memmert 40500-IP 20 (Germany) oven. A 5 gram sample was weighed into an aluminum dish and placed in memmert oven at 105°C overnight. The sample was weighed using KERN PCB 3500-2(Germany) precision weighing balance. Moisture content was calculated by determining weight loss divided by initial sample weight as a percentage.

4.2.5.2 Determination of weight loss/gain

Initial and final weight of each batch was determined using KERN PCB 3500-2(Germany) precision weighing balance. Weight loss/gain in grams was given by the initial weight minus final weight of the sample of the fruits.

4.2.5.3 Determination of Vitamin C

Vitamin C was determined as reduced ascorbic acid by titrimetric with N-bromosuccinamide (AOAC, 1990). Vitamin C was determined by extracting 2 grams of guava using 25mls of 10% trichloroacetic acid (TCA), 5mls of 4% potassium iodide and starch indicator were added and the mixture titrated using N-bromosucinamide. A standard formula was used to determine the amount of vitamin C in each sample.

4.2.5.4 Determination of beta carotene

Beta carotene was determined using Method No. 44 of International Federation of Fruit Juice Producers adopted in 1972 (IFU, 1972). The color from 2 grams of guava was extracted using a motor and pestle using acetone to 50 ml sample. A water bath was used to evaporate the acetone from 25ml extract to dryness. To the evaporated sample, petroleum ether was added to dissolve beta carotene, which was eluted through a silica gel column and collected into a 25ml volumetric flask. A double beam spectrophotometer was used to read absorbance at 450 nanometer wavelength and a standard curve was used to determine beta carotene concentrations.

4.2.5.5 Determination of total soluble solids (TSS)

TSS was measured using hand-held refractometer model SK106R (SATO, Japan). A sample of five guava fruits was crushed in a motor and pestle to extract the pulp. A dropper was used to place a drop of the extract on the refractometer screen for reading in degrees brix.

4.2.5.6 Determination of total titratable Acidity (TTA)

The total titratable acidity (TTA) of the fruits was determined using (AOAC, 2000) method no.942.15. Ten grams of guava fruit were diluted with 25ml of distilled water and titrated by 10ml aliquot of standard sodium hydroxide at 0.1 N.

4.2.5.7 Determination of pH

pH was determined using Accument portable Fischer scientific PH meter (Germany). The pH was read by inserting the electrodes of the pH meter into guava pulp extracted from the sample.

4.2.6 Statistical data analysis

Data analysis was done using R package for statistical computing, Agricolae package (R core team, 2019). The mean differences of the physicochemical attributes were tested using the analysis of variance (ANOVA). Statistically different means were separated using the Tukey's Honest Significant difference (HSD). Significance was tested at $p<0.05$. The XLstats version 20 for excel package was used to do a data reduction technique of principal component analysis (PCA) diagram to establish relationships amongst parameters.

4.3 RESULTS

4.3.1 Effect of different conditions on physicochemical properties of guava fruit during storage

There were significant difference ($p<0.05$) between the weight, pH, TSS, TTA/100g and moisture content among the guavas obtained from the two counties during storage except for the beta carotene levels (Table 4.1). Equally, the days of storage affected all the physicochemical parameters under study except for the beta carotene. Beta carotene contents were significantly ($p<0.05$) affected by the modified atmosphere packaging only. Moreover, three-way interactions between location, days of storage modified atmosphere and washing had varying significant effects (p<0.05) on the physicochemical properties except for the betta carotene whose changes were majorly insignificant (Table 4.1).

Table 4.1: Type III F- test statistics for comparison of analysis of variance (ANOVA) for the effects of different factors and their interactions on the physicochemical properties of red/pink guava during storage

Source of variation	Parameters						
	Weight Loss/Gain	**Ph**	**TSS**	**TTA**	**Vit C**	**Beta carotene**	**Moisture content**
County	28.406**	7.054*	30.403**	11.446*	109.462**	1.759	7.883*
Day	7.607**	37.075**	2.379	17.697**	5.494*	1.193	4.629*
MAP	78.338**	5.562*	5.439*	6.597*	1.813	4.756*	3.164*
Temperature	18.649**	12.338**	10.553**	45.466**	9.982**	1.891	15.807**
County*Day	8.878**	24.591**	7.260**	10.229**	3.516*	0.467	3.027*
County*MAP	19.332**	3.635*	0.105	0.372	0.456	0.046	0.246
County*Temperature	16.074**	4.560*	8.719**	8.742**	11.737**	0.133	2.053
Day*MAP	6.671**	2.139	3.192*	1.114	0.906	1.109	1.111
Day*Temperature	6.386**	7.917**	17.316**	12.904**	5.790**	0.118	7.544**
MAP*Temperature	5.115*	1.572	6.571*	1.188	5.362*	2.155	7.197*
County*Day*MAP	2.169	1.991	2.547	0.463	1.528	1.088	0.711
County*Day*Temperature	11.496**	3.153*	4.126*	14.427**	1.944	0.557	2.111
County*Map*Temperature	12.932**	2.631	1.065	0.045	2.127	3.021	1.674
Day*MAP*Temperature	2.770*	5.039*	1.029	1.386	3.286*	1.113	15.896**
County*Day*MAP*Temperature	0.422	2.032	3.067*	4.305*	3.775*	2.564	6.683**

** Differences between means are statistically significant at p<0.001, *statistically significant at p≤0.05.
MAP-modified atmosphere packaging

4.3.2 Effect of washing, temperature and modified atmosphere packaging on the physicochemical changes of red pink guavas during storage

4.3.2.1 Moisture Content

The moisture content of guava fruits was not significantly (p>0.05) affected by washing, modified atmosphere packaging and days of storage. However, storage temperature significantly (P<0.001) affected the moisture content of the fruits (Table 4.2 and 4.3). Higher temperatures resulted into significant ($P<0.05$) decrease in the moisture contents with the least moisture contents recorded for storage at 28-30℃ and the least moisture loss recorded at 8-10℃. Moisture loss increased significantly ($p<0.05$) with increase in temperature as fruits stored under low temperature tended to have higher moisture content compared to storage at high temperature. Moisture content at different temperatures for the pink variety from Kitui varied significantly ($p<0.05$) from pink guavas from Taita Taveta with those from Kitui county consistently recorded lower values (Table 4.4).

Table 4.2: Effect of washing on physicochemical changes of pink guava during storage

Day of storage	Guavas	County	Weight Loss/Gain (g)	pH	TSS (ºBrix)	TTA (%)	Vitamin C(mg/100g) dwb	Beta carotene(mg/100g) dwb	Moisture content (%)
0	**Ripe**	**Kitui**	0.00±0^{ab}	4.15±0.01^{a}	8.25±0.35^{abc}	0.36±0.03^{ab}	1074±9.8^{ab}	2.30±0.16^{d}	81.29±0.04^{a}
		Taita Taveta	0.00±0^{ab}	4.13±0.03^{a}	8.25±0.35^{abc}	0.32±0.01^{ab}	1032±4.6^{abc}	2.85±0.05^{d}	80.49±0.14^{a}
	Unripe	**Kitui**	0.00±0^{ab}	3.85±0.01^{ab}	6.75±0.35^{c}	0.58±0.01^{ab}	680±10.9^{abcd}	5.72±0.97^{cd}	79.40±0.23^{a}
		Taita Taveta	0.00±0^{ab}	3.81±0.04^{abc}	6.25±0.35^{c}	0.58±0.01^{ab}	714±55.0^{abcd}	7.67±1.94^{bcd}	80.61±1.69^{a}
3	**Chlorinated**	**Kitui**	-7.46±18.86^{ab}	3.85±0.11^{abc}	7.58±0.87^{bc}	0.28±0.23^{b}	249.9±262.8^{cd}	9.40±2.87^{bc}	78.06±3.63^{a}
		Taita Taveta	14.83±11.44^{ab}	3.39±0.10^{c}	8.83±1.39^{abc}	0.55±0.07^{ab}	1218.3±341.9^{a}	12.22±1.43^{abc}	80.55±1.15^{a}
	Unwashed	**Kitui**	-1.92±8.68^{ab}	3.82±0.07^{abc}	7.96±1.01^{abc}	0.45±0.25^{ab}	186.4±34.6^{d}	10.72±1.57^{abc}	76.10±2.27^{a}
	Washed	**Kitui**	7.68±13.23^{ab}	3.82±0.06^{abc}	7.58±1.55^{bc}	0.30±0.24^{b}	109.1±36.6^{d}	11.84±1.17^{abc}	76.73±2.56^{a}
		Taita Taveta	18.52±17.22^{ab}	3.60±0.31^{bc}	9.33±1.48^{a}	0.50±0.06^{ab}	1165.0±319.5^{a}	9.48±3.32^{bc}	79.46±3.06^{a}
5	**Chlorinated**	**Kitui**	-1.08±2.65^{ab}	3.90±0.16^{a}	8.33±1.01^{abc}	0.47±0.12^{ab}	409.6±337.8^{bcd}	10.67±2.27^{abc}	76.80±3.23^{a}
		Taita Taveta	22.79±25.15^{a}	4.08±0.18^{a}	8.61±0.97^{abc}	0.58±0.13^{a}	877.1±486.4^{abc}	10.93±2.20^{abc}	79.41±0.87^{a}
	Unwashed	**Kitui**	2.48±5.37^{ab}	3.89±0.14^{a}	7.50±1.30^{bc}	0.51±0.06^{ab}	267.4±152.7^{bcd}	10.52±1.46^{abc}	77.46±1.66^{a}
	Washed	**Kitui**	4.29±6.51^{ab}	3.89±0.16^{a}	7.42±1.06^{bc}	0.47±0.09^{ab}	360.0±387.1^{bcd}	13.86±2.68^{a}	80.30±3.49^{a}
		Taita Taveta	23.69±27.99^{a}	3.91±0.25^{a}	7.91±1.11^{abc}	0.56±0.06^{ab}	1145.2±285.0^{a}	12.04±2.49^{abc}	79.38±1.90^{a}
7	**Chlorinated**	**Kitui**	-7.19±21.26^{ab}	3.96±0.25^{a}	7.83±1.17^{abc}	0.55±0.09^{ab}	489.6±274.1^{bcd}	9.97±2.93^{bc}	76.11±4.52^{a}
		Taita Taveta	25.24±21.63^{a}	3.78±0.28^{abc}	9.06±1.08^{ab}	0.63±0.09^{a}	906.0±411.9^{abc}	12.25±2.33^{abc}	78.43±3.53^{a}
	Unwashed	**Kitui**	14.75±17.00^{ab}	4.00±0.13^{a}	7.04±1.16^{c}	0.56±0.14^{ab}	427.1±139.7^{bcd}	11.04±1.61^{abc}	76.63±2.63^{a}
	Washed	**Kitui**	4.10±17.31^{ab}	3.94±0.15^{a}	7.50±0.56^{bc}	0.56±0.14^{ab}	392.6±275.6^{bcd}	11.52±2.21^{abc}	76.81±5.70^{a}
		Taita Taveta	19.33±22.25^{ab}	3.63±0.32^{abc}	9.06±0.58^{ab}	0.61±0.11^{a}	1112±380.4^{a}	9.95±3.77^{bc}	79.41±2.71^{a}
11	**Chlorinated**	**Kitui**	13.36±11.97^{ab}	3.88±0.18^{ab}	7.50±0.41^{bc}	0.55±0.06^{ab}	521.9±208.5^{abcd}	11.73±0.76^{abc}	80.32±1.01^{a}
		Taita Taveta	6.96±2.02^{ab}	4.01±0.01^{a}	8.50±0.41^{abc}	0.63±0.04^{a}	560.1±194.2^{abcd}	10.92±0.37^{abc}	79.56±1.00^{a}
	Unwashed	**Kitui**	25.97±7.59^{a}	3.78±0.03^{abc}	7.00±0.71^{c}	0.53±0.04^{ab}	333.3±116.7^{bcd}	13.54±2.36^{ab}	80.86±1.23^{a}
	Washed	**Kitui**	12.43±1.32^{ab}	3.80±0.03^{abc}	6.75±0.65^{c}	0.53±0.04^{ab}	372.9±173.5^{bcd}	12.14±0.62^{abc}	79.54±0.96^{a}
		Taita Taveta	10.47±2.61^{ab}	4.00±0.03^{a}	8.75±0.65^{abc}	0.65±0.04^{a}	1235.0±220.5^{a}	11.55±1.31^{abc}	80.48±2.61^{a}

Means± standard deviations with the same superscript letters along the column for respective physicochemical changes are not significantly different at the P≤0.05 level (Tukey's HSD test.

Table 4.3: Effect of modified atmosphere packaging on physicochemical changes in pink guava fruit during storage

Day of storage	MAP	County	Weight Loss/Gain(g)	pH	TSS(ºBrix)	TTA (%)	Vitamin C(mg/100g) dwb	Beta carotene(mg/100g) dwb	Moisture content (%)
0	Ripe	Kitui	0.00±0^{cd}	4.15±0.01^{a}	8.25±0.35^{abc}	0.36±0.03^{bc}	1074.5±9.8^{abc}	2.30±0.16^{b}	81.29±0.04^{a}
	Ripe	Taita Taveta	0.00±0^{cd}	4.13±0.03^{a}	8.25±0.35^{abc}	0.32±0.01^{bc}	1032.9±4.6^{abc}	2.85±0.05^{b}	80.49±0.14^{a}
	Unripe	Kitui	0.00±0^{cd}	3.81±0.04^{abc}	6.25±0.35^{c}	0.58±0.01^{abc}	680.6±10.9^{abcd}	5.72±0.97^{ab}	80.61±1.69^{a}
	Unripe	Taita Taveta	0.00±0^{cd}	3.85±0.01^{abc}	6.75±0.35^{c}	0.58±0.01^{abc}	714.6±55.0^{abcd}	7.67±1.94^{ab}	79.40±0.23^{a}
3	Modified	Kitui	-3.85±20.40^{d}	3.85±0.10^{abc}	7.44±1.10^{c}	0.36±0.27^{bc}	141.3±42.5^{d}	10.86±1.71^{a}	77.40±2.11^{a}
		Taita Taveta	5.52±4.72^{cd}	3.50±0.20^{c}	9.33±1.09^{a}	0.53±0.05^{abc}	1227.8±392.0^{a}	10.87±3.24^{a}	81.06±0.88^{a}
	Non-modified	Kitui	2.71±6.00^{cd}	3.81±0.07^{abc}	7.97±1.19^{abc}	0.31±0.23^{c}	222.2±219.3^{a}	10.45±2.63^{a}	76.53±3.56^{a}
		Taita Taveta	27.83±11.88^{ab}	3.49±0.30^{c}	8.83±1.71^{abc}	0.52±0.09^{abc}	1155.5±253.1^{a}	10.82±2.58^{a}	78.96±2.85^{a}
5	Modified	Kitui	-1.37±1.08^{d}	3.91±0.15^{a}	7.50±1.06^{c}	0.48±0.10^{abc}	372.4±354.9^{cd}	12.12±2.32^{a}	78.91±2.52^{a}
		Taita Taveta	5.82±5.90^{cd}	4.07±0.21^{a}	7.72±0.79^{bc}	0.60±0.09^{ab}	945.6±492.9^{abc}	11.46±2.73^{a}	79.66±1.52^{a}
	Non-modified	Kitui	5.17±6.12^{cd}	3.88±0.15^{a}	8.00±1.26^{abc}	0.49±0.08^{abc}	318.9±256.5^{cd}	11.26±2.94^{a}	77.46±3.72^{a}
		Taita Taveta	40.65±26.83^{a}	3.92±0.24^{a}	8.80±1.08^{abc}	0.55±0.10^{abc}	1076.7±323.8^{ab}	11.51±2.06^{a}	79.14±1.38^{a}
7	Modified	Kitui	-4.11±20.72^{d}	3.94±0.20^{a}	7.53±0.50^{c}	0.54±0.09^{abc}	404.8±207.5^{cd}	10.83±2.61^{a}	75.88±5.62^{a}
		Taita Taveta	4.57±2.68^{cd}	3.83±0.19^{abc}	8.86±0.70^{abc}	0.59±0.11^{ab}	1089.3±367.7^{ab}	11.94±2.29^{a}	80.06±1.65^{a}
	Non-modified	Kitui	11.88±17.09^{bcd}	4.00±0.16^{a}	7.39±1.39^{c}	0.58±0.15^{ab}	468.2±262.0^{cd}	10.86±2.11^{a}	77.15±2.54^{a}
		Taita Taveta	40.00±16.06^{a}	3.58±0.35^{bc}	9.26±0.96^{ab}	0.65±0.07^{a}	929.5±434.8^{abc}	10.25±3.97^{a}	77.77±3.83^{a}
11	Modified	Kitui	11.22±7.33^{bcd}	3.77±0.06^{abc}	7.25±0.52^{c}	0.54±0.03^{abc}	267.0±60.6^{cd}	12.06±0.83^{a}	80.48±0.54^{a}
		Taita Taveta	8.46±0.29^{bcd}	4.00±0.03^{a}	8.75±0.65^{abc}	0.65±0.03^{a}	912.7±214.1^{abc}	11.00±0.35^{a}	79.88±0.87^{a}
	Non-modified	Kitui	23.28±8.49^{abc}	3.87±0.12^{ab}	6.92±0.74^{c}	0.53±0.06^{abc}	551.8±125.7^{bcd}	12.89±2.06^{a}	80.00±1.53^{a}
		Taita Taveta	8.97±4.34^{bcd}	4.01±0.01^{a}	8.50±0.41^{abc}	0.63±0.04^{a}	882.3±586.2^{abc}	11.46±1.36^{a}	80.16±2.75^{a}

Means± standard deviations with the same superscript letters along the column for respective physicochemical changes are not significantly different at the P≤0.05 level (Tukey's HSD test).

Table 4.4: Effect of temperature of storage on physicochemical changes in pink guava fruit during storage

Day of storage	Storage Temperature (℃)	County	Weight Loss/Gain (g)	pH	TSS(ºBrix)	TTA(%)	Vitamin C(mg/100g)	Beta carotene (mg/100g)	Moisture content (%)
0	**Room temp**	**Kitui**	0.00±0^{cde}	4.00±0.17^{ab}	7.50±0.91^{cde}	0.47±0.13^{bc}	877.6±227.5^{abc}	4.01±2.06^{bcd}	80.34±1.10^{ab}
		Taita Taveta	0.00±0^{cde}	3.97±0.19^{ab}	7.25±1.19^{de}	0.45±0.15^{bc}	873.7±186.5^{abc}	5.26±2.99^{bcd}	80.55±0.98^{ab}
3	**8-10℃**	**Kitui**	-11.92±17.62^{e}	3.81±0.12^{bcd}	7.00±1.07^{e}	0.59±0.07^{ab}	260.6±260.1^{d}	11.40±1.48^{ab}	77.65±2.01^{ab}
		Taita Taveta	18.09±11.95^{bc}	3.69±0.22^{bcd}	7.50±0.65^{cde}	0.59±0.03^{ab}	956.8±319.2^{abc}	10.55±1.41^{ab}	79.95±2.53^{ab}
	20-25℃	**Kitui**	9.56±12.94^{bcde}	3.88±0.05^{bc}	8.42±1.10^{bcde}	0.13±0.03^{d}	136.7±48.4^{d}	10.70±2.90^{ab}	78.49±1.11^{ab}
		Taita Taveta	9.66±8.00^{bcde}	3.38±0.28^{d}	9.38±1.06^{ab}	0.52±0.05^{ab}	1246.6±275.7^{ab}	10.82±3.67^{ab}	80.80±0.94^{a}
	28-30℃	**Kitui**	0.66±1.50^{cde}	3.80±0.05^{bcd}	7.71±0.92^{cde}	0.31±0.27^{cd}	148.1±47.3^{d}	9.87±1.85^{ab}	74.75±3.66^{ab}
		Taita Taveta	22.27±19.56^{abc}	3.41±0.12^{d}	10.38±0.52^{a}	0.46±0.07^{bc}	1371.6±255.4^{a}	11.16±3.35^{ab}	79.27±3.02^{ab}
5	**8-10℃**	**Kitui**	2.01±4.17^{cde}	3.82±0.15^{bcd}	8.71±0.62^{bc}	0.46±0.05^{bc}	315.4±114.7^{cd}	12.17±2.89^{ab}	78.96±3.05^{ab}
		Taita Taveta	6.28±6.57^{bcde}	3.95±0.17^{ab}	8.41±0.85^{bcde}	0.66±0.05^{a}	786.9±426.3^{bc}	11.46±1.98^{ab}	78.96±0.75^{ab}
	20-25℃	**Kitui**	3.07±8.13^{cde}	3.86±0.12^{bc}	7.46±1.32^{cde}	0.45±0.12^{bc}	614.0±378.4^{cd}	11.66±3.47^{ab}	77.92±4.62^{ab}
		Taita Taveta	19.57±16.71^{bc}	3.87±0.20^{bc}	8.83±1.33^{abc}	0.55±0.09^{ab}	1050.6±448.2^{abc}	11.13±2.79^{ab}	79.67±0.79^{ab}
	28-30℃	**Kitui**	0.63±2.79^{cde}	4.01±0.12^{ab}	7.08±0.82^{e}	0.54±0.06^{ab}	107.6±29.5^{d}	11.22±1.18^{ab}	77.68±1.12^{ab}
		Taita Taveta	43.86±32.76^{a}	4.16±0.23^{a}	7.54±0.60^{cde}	0.50±0.07^{ab}	1195.9±283.1^{ab}	11.87±2.52^{ab}	79.56±2.31^{ab}
7	**8-10℃**	**Kitui**	-0.74±12.48^{cde}	4.01±0.13^{ab}	7.25±1.27^{de}	0.66±0.10^{a}	346.8±271.9^{cd}	11.88±1.38^{ab}	78.77±1.62^{ab}
		Taita Taveta	16.46±18.72^{bcd}	3.80±0.40^{bcd}	8.44±0.51^{bcde}	0.67±0.05^{a}	1019.4±507.9^{abc}	12.89±2.46^{a}	80.97±1.76^{a}
	20-25℃	**Kitui**	19.05±20.97^{bc}	3.83±0.22^{bcd}	7.79±0.96^{cde}	0.57±0.06^{ab}	439.6±284.2^{cd}	11.13±2.63^{ab}	77.41±3.49^{ab}
		Taita Taveta	28.11±23.56^{ab}	3.61±0.12^{cd}	9.69±0.56^{ab}	0.56±0.11^{ab}	999.4±284.1^{abc}	9.31±3.04^{abc}	76.87±2.77^{ab}
	28-30℃	**Kitui**	-6.65±18.25^{de}	4.07±0.09^{ab}	7.33±0.81^{cde}	0.44±0.07^{bc}	523.1±64.8^{cd}	9.53±2.34^{abc}	73.37±5.30^{b}
11	**8-10℃**	**Kitui**	17.25±9.84^{bc}	3.82±0.10^{bcd}	7.08±0.63^{e}	0.54±0.04^{ab}	409.4±176.0^{cd}	12.47±1.56^{a}	80.24±1.12^{ab}
		Taita Taveta	8.72±2.86^{bcde}	4.00±0.02^{ab}	8.63±0.52^{bcd}	0.64±0.03^{a}	897.5±408.9^{abc}	11.23±0.95^{ab}	80.02±1.89^{ab}

Means± standard deviations with the same superscript letters along the column for respective physicochemical changes are not significantly different at the P≤0.05 level (Tukey's HSD test.

Weight Loss/Gain

There were no significant differences ($P>0.001$) in weight between washed, unwashed and chlorinated guavas (Table 4.2). Guavas from Taita Taveta lost significantly ($p<0.05$) more weight compared to Kitui county which also recorded the highest weight loss. Generally, the weight loss significantly ($p<0.001$) increased with days of storage. Modified atmosphere packaging had a significant ($P<0.001$) effect on weight of guavas during storage and recorded the most weight gains on the fruits. The gains were more for fruits from Kitui County which differed significantly ($p<0.05$) from Taita Taveta even for modified packaged samples (Table 4.3). However, Taita Taveta samples had the highest weight loss (40.00g) recorded in fruits stored in non-modified packages (Table 4.4). Temperature of storage had a significant ($P<0.001$) effect on the weight gain or loss during storage. Storage at 8-10℃ had the least weight loss with the highest weight losses being at 28-30℃.Taita Taveta samples experienced the highest weight loss even at cold storage(Table 4.5).

Ascorbic Acid

The average ascorbic acid content of red pink fleshed guavas differed significantly ($p<0.001$) between the two counties with guavas from Taita Taveta having significantly ($p<0.001$) higher amount (1040.31mg/100g) as compared to pink guavas from Kitui (344.15mg/100g) dwb. Vitamin C increased significantly ($p<0.05$) with increase in storage days (Table 4.2, 4.3, 4.5). Washing the fruits before storage had a significant ($P<0.001$) effect on the vitamin C content of the fruits during storage. The vitamin C content increased constantly and peaked at day 7 of storage. The levels however, reduced on day 11 at storage temperatures 8-10℃. Non-modified packaged guavas significantly ($p<0.05$) had higher vitamin C compared to those those stored in modified packages (Table 4.3). Guavas stored at 20-25℃ and 28-30℃ had significantly ($p<0.05$) higher levels of vitamin C as compared to those stored at 8-10℃ (Table 4.4).

Table 4.5: Summary of physicochemical changes of red pink guava fruits during storage

COUNTY	Weight Loss/Gain (g)	pH	TSS(ºbrix)	TTA/100 g(%)	Vitamin C/100g dwb	Beta carotene /100g dwb	Moisture content (%)
KITUI	3.18±15.02[b]	3.89±0.15[a]	7.58±1.08[b]	0.47±0.18[b]	344.15±60.74[c]	10.72±2.01[a]	77.62±3.52[b]
TAITA TAVETA	18.21±20.09[a]	3.78±0.32[b]	8.67±1.21[a]	0.57±0.10[a]	1040.31±74.71[a]	10.69±0.253[a]	79.61±2.19[a]

Means± standard deviations with the same superscript letters along the column for respective physicochemical changes are not significantly different at the P≤0.05 level (Tukey's HSD test).

Beta- Carotene

The mean beta carotene of the guavas was 10.86mg/100g with fruits from Kitui having slightly higher level (10.72mg/100g) dwb compared to Taita Taveta (10.69 mg/100g) (Table 4.5). The beta carotene levels increased significantly ($p<0.05$) with increased storage days and was highest on day 7 (Table 4.2, 4.3, 4.3). The guavas from Kitui had higher beta carotene as compared to those from Taita Taveta. Washing guavas had a significant ($P<0.001$) effect on the beta carotene content with washed guavas tending to have higher beta carotene (Table 4.2). Guavas packaged nets had higher levels of beta carotene as compared to modified-packages (Table 4.3). Temperature significantly ($P<0.001$) affected beta carotene content during storage as an increase in storage temperature caused a significant ($p<0.05$) increase in beta carotene content (Table 4.4). Additionally, beta carotene content differed significantly ($p<0.05$) with days of storage even at same temperature; it peaked at the day 7 and was higher at 28-30℃ as compared to 8-10℃.

Total soluble solids (TSS)

The mean TSS of the guavas was 7.58 and 8.67ºbrix for guavas from Kitui and Taita Taveta respectively (Table 4.5). The TSS increased significantly ($p<0.05$) with length of storage with the highest values being recorded at day 7 for fruits from both counties. Washed guavas had significantly ($P<0.001$) lower total soluble solids during storage compared to the unwashed. Modified atmosphere packaging significantly ($P<0.001$) affected the TSS of guavas during storage with non-modified guavas having higher TSS as compared to modified ones. Temperature had a significant ($P<0.001$) effect on the TSS of the fruits, guavas stored at 20-25℃ had significantly ($p<0.05$) higher TSS values compared to fruits stored at 8-10℃. Guavas stored at 28-30°C recorded lower levels of TSS as compared to storage at 20-25℃ (Table 4.4).

Total titratable acidity (TA)

The average TTA of guavas differed significantly ($p<0.05$) between Kitui (0.47%) and Taita Taveta (0.57%) counties (Table 4.5). TTA also increased significantly ($p<0.05$) with increased days of storage. The pink guavas from Taita Taveta were more acidic with higher values of TTA as compared to Kitui (Table 4.2, 4.3, 4.4). Washing guavas before storage significantly ($P< 0.05$) effected TTA of guavas during storage where guavas washed with chlorine water were found to have more TTA as compared to unwashed and those washed with water only (Table 4.2). Modified atmosphere packaging had a significant ($P<0.001$) effect on the titratable acidity of the fruits having higher values as compared to non-modified packages (Table 4.3). Temperature influenced titratable acidity of guavas during storage with those stored at 20-25℃ and 28-30℃ having significantly ($p<0.05$) lower values as compared to those stored at 8-10℃. An increase in temperature of storage resulted to a decrease in titratable acidity in fruits (Table 4.4).

pH

The fruits had an average pH of 3.89 and 3.78 for Kitui and Taita Taveta respectively (Table 4.5). The pH of the fruits tended to increase throughout the storage period. Washing had a significant ($p<0.05$) effect on the pH of the fruits during storage with those chlorinated ones tending to have lower pH compared to those washed with water only and unwashed (Table 4.2). The use of modified packaging had no significant ($p>0.05$) effect on pH of the fruits during storage (Table 4.4) while the higher temperatures resulted to significant ($p<0.001$)

increase of the pH. The pH was relatively higher at 28-30°C as compared to low temperatures (8-10°C).

4.3.3 Correlation between physicochemical parameters of red pink guava during storage

The fruits' pH and the TSS had a negative correlation. This was equally observed for the -β-Carotene (Figure 4.2). The TTA and the moisture content and vitamin C and weight loss/gain had positive correlation. There was an orthogonal interaction between beta carotene and the moisture content as well as beta carotene and TTA thus their occurrence were independent. This was also the case between TSS and the moisture content and the TTA of the fruits. These correlations accounted for approximately 47% of the variability on the principal component analysis biplot (PCA) for the principal components 1 and 2.

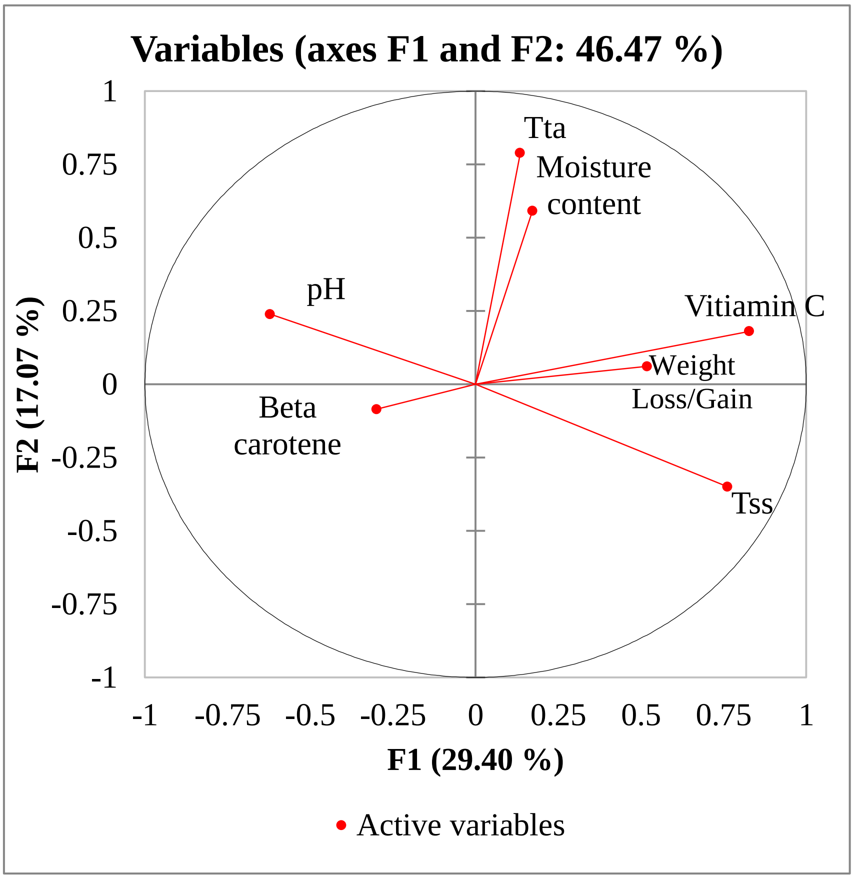


Figure 4.2: Principle component Analysis plot

4.4 DISCUSSION

4.4.1 Effect of different factors on physicochemical properties of guava fruit during storage

County of origin of guavas influenced physicochemical changes during storage due to varying climatic conditions between Kitui and Taita Taveta (County Government of Kitui, 2018; County Government of Taita Taveta, 2018) which contributes to varying levels of moisture content, pH, titratable acidity, total soluble solids, ascorbic acid and beta carotene (Chiveu, 2018). Days of storage influenced all physiological parameters and this could be linked to increased ripening during storage (Rodeo and Esguerra, 2018b).Modified atmosphere packaging using low-density polythene films retards ripening by slowing down softening consequently affecting soluble solids, acidity and ascorbic acid of the fruits which extends guava shelf life (Barboza *et al.*, 2016). Modified atmosphere packaging in combination with low temperature storage has proven effective in extending guava shelf life (Dhillon, Devgan and Sandhu, 2007). Low temperature storage of guavas is effective in slowing down physiological processes like respiration, ethylene production and ripening which determine guava shelf life (Barboza *et al.*, 2016).

4.4.2 Effect of washing, temperature and modified atmosphere packaging on the physicochemical changes of red pink guavas during storage.

Moisture content

Loss in moisture content was not influenced by days of storage in contrast with Singh, (2011) who reported an increase in moisture loss with days of storage which was attributed to heightened rates of respiration and transpiration which increased loss of water vapor from the guavas. Modified atmosphere packaging aimed at reducing rate of moisture loss. The current study showed that modified atmosphere packaging did not influence changes in moisture content. On the contrary, a study by Sudhakar & Shivashankara, (2018) showed modified atmosphere packages have low moisture loss which was attributed to its effectiveness in lowering rate of transpiration and creating a high relative humidity within the package (Rodeo & Esguerra, 2018a). The temperature increased the kinetic energy of water molecules within the guavas causing faster loss of water hence low moisture content (Katul *et al.*, 2012). Kitui has a hotter climate than Taita Taveta (County Government of Kitui, 2018; County Government of Taita Taveta, 2018) thus guavas from Kitui might have undergone desiccation before they were subjected to storage.

Weight loss /Gain

Weight loss is a common phenomenon in guava fruits during storage, which is attributed to increased respiration and transpiration rates during ripening (Rodeo and Esguerra, 2018a). Increased water loss in guava fruits leads to diminished quality during storage. Modified atmosphere packaging caused a gain in weight which could be linked to the fact that cling films caused an increase in relative humidity within the package. The current study agrees with similar studies conducted by Ambuko *et al*. (2018) and Yumbya *et al*. (2014) who reported that modified atmosphere packages reduced weight loss in fruits as the films used hinder water vapor diffusion making the internal atmosphere more saturated with water vapor by creating a high relative humidity which results in a low vapor pressure deficit. However, accumulation of water vapor in the packages may have negative effect on the storage life of the fruits as the gain in weight increases moisture content which lead to increased rates of deterioration and microbial growth (Parry, 2012). Storage at a low temperature of 8-10℃ reduced weight loss as compared to other storage temperatures due to reduced metabolic rates and cellular activities (Ambuko *et al.*, 2018). Weight loss was highest at 28-30℃ since the high temperature and low relative humidity, increased rates of transpiration and respiration increasing water loss in the fruits (Rodeo and Esguerra, 2018a). Guavas from Taita Taveta lost more weight than those from Kitui. This is linked to the fact that Taita Taveta county is cooler compared to Kitui county (County Government of Taita Taveta, 2018) hence their guavas were more succulent as compared to the latter.

Ascorbic acid content

The ascorbic acid content increased gradually with storage due to increased ripening (Mondal *et al.*, 2009) and decreased thereafter due to its oxidation and degradation during storage (Mahajan *et al.*, 2009). Modified atmosphere packaging had a significant ($p<0.05$) effect on ascorbic acid with packaged fruits maintaining higher values of ascorbic acid as compared to non-modified packages (Yumbya *et al.*, 2014). This is because modified atmosphere packages retards ripening slowing softening (Barboza *et al*., 2016). Ascorbic acid increased with increase in temperature and this is linked to the effect of temperature on respiration and ethylene production rates which increased ripening and vitamin C is reported to increase with ripening (Ribeiro *et al*., 2006).However, high temperatures and light cause degradation of vitamin C as its water soluble and highly volatile (Uddin, Hawlader, Ding, & Mujumdar, 2002). Guavas from Taita Taveta had higher vitamin C compared to those from Kitui, this could be due to the temperature difference as Kitui is hotter than Taita Taveta (County Government of Kitui, 2018; County Government of Taita Taveta, 2018).

Beta-carotene content

Beta carotene increased gradually with storage because the partially ripe fruits continued ripening during storage period (Vishwasrao & Ananthanarayan, 2016). The pink variety has been reported to have high levels beta carotene compared to the white fleshed which attributed to the pink pigmentation and high levels of carotenes (Bashir & Abu-Goukh, 2003; Omayio *et al*., 2019).The high levels of carotenes contribute to the high antioxidant activity in pink fleshed guavas (Musa *et al*., 2011). Modified atmosphere packaging reduced the rate of increase in beta carotene during storage, thus lower values were recorded in packaged guavas and this could be linked to the delayed ripening (Mitra *et al*., 2015). Temperature increase caused increase in beta carotene content due to acceleration of ripening and respiration (Ribeiro *et al*., 2006).

Total soluble solids

The total soluble solids increased with storage period due to increased ripening (Bashir & Abu-Goukh, 2003). This is due the fact that during ripening there is conversion of starch to sugars (Dolkar *et al*., 2017). Also, TSS increased with days of storage due to increased rate of ripening (Barboza *et al*., 2016). Storage temperature had a significant effect on the TSS as it hastened the rate of ripening which increased the rate of starch conversion to sugars (Antala, Varshney, Davara, & Sangani, 2015) hence those stored at low temperature have lower TSS levels. Modified atmosphere packaging reduced TSS levels due to their ability to delay ripening and lower starch hydrolysis as compared to non-modified packages as rates of starch conversion to sugars increased with increase in ripening (Kumar, Bhagwan, Kumar, & Venkatlakxmi, 2017). Over-ripening contributed to reduced TSS due to oxidative breakdown of sugars during respiration as senescence increased rates of respiration (Antala *et al*., 2015).

Total titratable acidity

Titratable acidity of increased with ripening of the fruit and decreased thereafter during storage (H. A. Bashir & Abu-Goukh, 2003). Titratable acidity increased with advancement in fruit ripening with the highest levels being recorded at the ripe stage. These results were not in conformity with the findings of Dolkar *et al*. (2017) who reported decline in titratable acidity during ripening of guavas. Kitui and Taita Taveta guavas were less acidic as compared to other studies on guavas which recorded values between 0.62-0.88% (Antala *et al*., 2015) and (Lima, Pires, Maciel, & Oliveira, 2010) which reported titratable acidity of 0.63 to 1.10mg/100g. The Modified atmosphere packaging significantly caused increase in titratable acidity due to slow ripening which slowed down attainment of climacteric peak and decreased fruit metabolism (Yumbya *et al*., 2014). Additionally, the storage temperature caused a reduction of the titratable acidity during storage (Antala *et al*., 2015) as it influenced the rate of ripening shortening the period required to reach climacteric peak (Ribeiro *et al*., 2006).

pH

The average pH of guavas from Kitui and Taita Taveta of 3.89 and 3.78 respectively correlated with the findings by Lima *et al*., (2010) with a pH ranging between 3.65 to 4.00 . The pH increased with the storage period as ripening caused by utilization of acids as respiration substrates hence reducing the acid content and increasing the pH (Yumbya *et al*., 2014). Modified atmosphere packaging had no effect on pH and this outcome differs from a study by Jingyan *et al*.,(2015) on berry fruits which indicated that modified packaging caused increase in pH. Temperature of storage had a significant effect on pH with high temperature having an increases in pH which could be linked to the fact that temperature affects rate of ripening and the pH of guavas increases as they ripen (Mahajan *et al*., 2009; Ribeiro *et al*., 2006).

4.4. 3 Correlation between physicochemical parameters of red pink guava during storage

The inverse proportionality between pH and titratable acidity is linked to the fact that during ripening organic acids are utilized as substrates (Yumbya *et al.*, 2014) for respiration hence the number of hydrogen ions in the fruit reduced causing an increase in pH (Wilkowske, 1954; Lobit *et al.*, 2002). Beta carotene increased with decreasing moisture content and this is due to the fact that beta carotene is not water soluble (Gul *et al.*, 2015) and is more in dry matter basis as compared to wet basis (İncedayi *et al.*, 2016).

4.4.4 Shelf life of guava and recommended factor combination to extend shelf life

Guava physicochemical changes were highly dependent on the storage conditions especially temperature which influenced the rate of ripening (Rawan *et al.*, 2017). Low temperature storage extended guava shelf life to 11 days and this is attributed to the fact that low temperature slowed down cellular metabolic activity hence retard or slow down rate of ripening (Mahajan, Sharma and Dhall, 2009). Other studies by Singh, (2011) recommended storage between 8-10℃ as effective in extending guava shelf life and preventing chilling injuries as the fruit is susceptible to chilling injury at low temperatures (Mahajan, Sharma and Dhall, 2009; Antala *et al.*, 2015). According to the current findings, a combination of low temperature and modified atmosphere packaging proves best alternative to extend guava shelf life and this is linked to their potential to retards physiological processes and cellular metabolism (Barboza *et al.*, 2016).

4.5 CONCLUSION

The prevailing storage conditions affect the shelf life of guava fruits leading to subsequent changes in the physicochemical parameters of the fruit. Guava shelf life is significantly extended to more than 11 days by a combination of storage at 8-10℃ and modified atmosphere packaging.

4.6 RECOMMENDATIONS

Farmers should be trained on various ways of introducing low temperature storage without electricity by use of brick pot, charcoal coolers and use of wet sand in a pot which is very affordable and easily accessible. Additionally, introduce the of modified atmosphere packaging in combination with edible coatings would be more effective in extending guava shelf life

CHAPTER FIVE: GENERAL DISCUSION AND RECOMMENDATIONS

5.1 General conclusion

The current study sort to identify the postharvest handling, hygiene knowledge and practices of guava fruit farmers in Kitui and Taita Taveta counties and determine the physicochemical changes of guava fruit during storage. Based on the current findings, guava farmers in Kitui and Taita Taveta did not practice postharvest management of guava fruits as they consider it non-valuable and they only harvest small quantities for household consumption. This practice significantly affected storage and storage life of the fruit especially where there was a bit of commercialization. Usually, the guavas are left to ripen on the trees and rot in farms. Having no economic value attached to guava fruits in Kenya, it's neglected with minimal value addition and production is majorly dependent on natural or wild guava trees. The county government does not have a value chain for the fruit. Farmers in Kitui had higher knowledge hygiene knowledge and better postharvest handling practices as compared to Taita Taveta. Unfortunately, their knowledge was not put in practice as farmers neglected the crop. The two counties experience huge postharvest losses on guavas attributed to pest and diseases and poor postharvest management. Additionally, the current findings also indicate that guava undergoes physicochemical changes during storage leading to diminished quality. Ascorbic acid, beta carotene, total soluble solids, titratable acidity, pH and moisture content are affected by storage conditions especially temperature of storage. Low temperature and modified atmosphere packaging have a positive effect in lowering the rate of guava deterioration. Guava shelf life was extended to more than 11 days from the 2-3 days storage life as reported by farmers by use of low temperature storage and modified atmosphere packages.

5.2 General and Policy Recommendations

A lot of information particularly on postharvest handling practices needs to be disseminated to reduce postharvest losses by educating farmers on methods to lower losses and extend shelf life. There is need to encourage sprinkling water on the fruits while displayed in the markets to help reduce effects of water loss and heat which are deteriorative factors. To enhance value addition of guava fruits through improvised homemade processing of guava products to increase marketability and economic value to farmers. Additionally, there is need to introduce traditional ways of attaining low temperature storage especially where electricity is a challenge by incorporating use of the brick pot, wet sand, charcoal coolers and cool box. Also, introduction of cold chain with aim of reducing losses during transportation and at market places. Lastly, there is need to aggregate farmers with the aim of increasing guava production and improving their bargaining power thus increasing economic value of the fruit. The Ministry of Agriculture should consider guava fruit as a cash crop with high production and economic potential thus strengthen guava value chain to increase production and utilization by providing incentives, farm inputs and creating a market through value addition.

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APPENDIX 1: POST- HARVEST AND HYGIENE PRACTICES QUESTIONNAIRE

SECTION A: SOCIO-DEMOGRAPHIC AND ECONOMIC INFORMATION

RESPONDENT'S DETAILS

Residence	**Sex** **1=Male** **2=Female**	**Age** **Yrs.**	**Marital** **Status** **(codes)**	**Education** **(codes)**	**Income status**	**Religion** **(codes)**

Marital status	**Education**	**Occupation**	**Religion**
1=Married 2=Separated 3=Widowed 4=Single 5=Divorced 6=N/A	1=College/University 2=Completed Secondary 3=Completed primary 4=Dropped from primary 5=In primary 6=In secondary 7=Literate e.g. Adult Education 8=Illiterate 9=Pre-primary 10= Others (specify)	1=Salaried employee 2=Farmer 3=Self employment 4=Casual labourer 5=Student 6=Housewife 7=Unemployed 8=Others (specify) 9=N/A	1=Christian 2=Muslim 3=Traditionist 4=Others(specify)

Do you have any orientation in food safety?

1=Yes [ ] 2=No [ ]

Do you have any training in post- harvest handling of any fruit?

1=Yes [ ] 2=No [ ]

If yes, elaborate

SECTION B: HARVESTING PRACTICES.

1. What stage of maturity do you harvest the guavas?
    1. Green(unripe)
    2. Green-Yellow
    3. Yellow(Ripe)
2. What time of the day do you harvest?
    1. Early morning
    2. Noon
    3. Evening
    4. Any time of the day

3. What method of harvesting do you use?
    1. Shaking the tree
    2. Use of hands
    3. Sticks

    Other, specify

4. During harvesting, where do you keep the harvested guavas?

    1. Floor
    2. Containers
    3. Sacks

    Other, specify

5. Do you leave the guavas at the farm?

1=Yes [ ] 2=No [ ]

6. Do you use any method of reducing field heat?

1. Icing
2. Water
3. Putting under shade

Others, specify

7. In a year, how many seasons do you harvest guava fruits?_______________

7.1 Approximately, how many kilogrammes of guava fruits do you harvest in each season?________

SECTION C: POST-HARVEST HANDLING OF GUAVA

1. Immediately after harvesting where do you store your guavas?

    1. Exposed to direct sunlight
    2. Put under shades

2. Do you sort harvested guavas? 1=no 2=yes

3. What do you do with the mechanically damaged guavas?

1= Throw them away

2= Use them for juice processing

3= Feed animals

4= store them with the others

4. Do you wash harvested guavas? 1=no 2=yes

3. If yes, is the water used treated and what chemicals are used _____

5. Is it necessary to wash the harvested guavas? 1=no 2=yes

5.1. If yes, why?

6. How are guava fruits transported from the farms?

1. Truck
2. Sacks
3. Carts
4. Containers
5. Others (specify) _

7. How are harvested guava fruits packaged?

1. Wooden box
2. Sacks
3. Paper boxes
4. Plastic containers
5. Others (specify) ________________________________

SECTION D: STORAGE

1. Do you have any knowledge on storage of fruits?

1= Yes [ ] or 2= NO [ ]

2. Do you store each type of fruit separately or mixed storage?

1. Individual storage
2. Mixed storage

3. Do you do any treatments before storage? 1=no 2=yes

If yes (Specify)

4. Do you package the guavas before storage?

1. Plastic bags
2. Plastic jars
3. Cartons

Others (specify)

5. How do you store your guavas?

1= Crates
2=Carton/plastic packages
3=Modified atmosphere packaging
3=Low temperature conditions
4=Any other

5.1.How long do they store before spoiling? ____________ days

4. Do you experience guava postharvest losses? 1=no 2=yes

4.1. If yes where does it occur?

1. during storage
2. at farm level

5. What type of losses do you experience?

1. Mechanical injuries
2. Over ripening and rotting
3. Guava shrivelling

4. Microbial and fungal attack
5 Others (specify)____.

6. What are the causes of spoilage and deterioration?
1. Poor/lack of storage
2. Pests and diseases
3. Inadequate knowledge on postharvest handling
4. Excess rainfall
5. Inaccessible market e.g. distance to the market, poor road network, poor market prices
6. Poor packaging
7. Others (specify)

7. How long (days) do guavas keep during:

1. Wet seasons __________
2. Dry seasons ___________

8. What strategies do you put in place to extend the shelf-life of fresh guava fruits?

1. Harvesting small quantities
2. Sorting fruits according to their ripening stage
3. minimizing mechanical damages
4. Storing in cool conditions
5. Others(specify)_____________________________

9. What do you do with over ripened guava fruits?
1. Sell at lower costs
2. Given as animal feeds
3. Making compost

Others (Specify)____

SECTION D: HYGIENE PRACTICES

1. Do you any knowledge on hygiene handling of foods?

1=Yes [ ] 2=No [ ]

1.1.If yes, what is your level of understanding on hygiene handling of fruits?

1= High
2= medium
3= low

2. Do you wash your hand every time before handling the food?

   1=Yes [ ] 2=No [ ]

3. Guavas can be eaten without washing? 1= Yes , 2= No
4. At what stage do you wash guavas?
   1. After harvest
   2. Before storage
   3. Both
5. What do you use to clean the guavas?

1=Hot water and detergent [ ] 2= Cold water and detergent [ ] 3= Only cold water [ ]

6. Where do you get your water from?

   1=Tap water [ ] 2=Borehole [ ] 3= Rainfall [ ] 4=Any other, specify

7. Do you have any specific clothing you wear while handling guavas?

   1=Yes [ ] 2=No [ ]

8. Can harvested guavas contain any microorganisms?

   1=Yes [ ] 2=No [ ]

   If yes, which are the likely sources?

   1. Contamination
   2. Water
   3. Soil
   4. All of the above
9. Have you observed any kind of worms or maggots when eating guavas? 1=Yes 2= No
10. Eating unclean guavas can lead to food borne illnesses? 1=Yes 2= No
11. Poor hygiene can cause guava losses during storage? 1= Yes, 2= No

If yes, state why?

12. Mixing clean and unclean guavas can lead to contamination and spoilage? 1=Yes 2= No

13. In case of any remains of guavas how do you keep them?

SECTION E: ASSESSMENT OF HYGIENE KNOWLEDGE

Please tick [√] whether the under listed questions are true using the scale (1=Yes, 2=No and 3=Do not know).

Questions	**1=YES**	**2=NO**	**3= DO NOT KNOW**
1. Guavas do not spoil easily even without refrigeration.			
2. Salmonella can't be found in food but only in water.			
3. I do not need a medical clearance to be a food vendor if I'm not feeling sick.			
4. Cooking eliminates all the bacteria and fungi in harvested fruits like guava.			
5. Water for washing fruits should be clean			
6. Food borne illnesses are not that serious to cause death.			
7. Bad odor in food is a sign of food spoilage,			
8. Knives and utensils can result into cross contamination of fruits			
9. Hand washing reduces chances of contamination of food.			
10. Eating rotten guavas can lead to food poisoning			
11. Food contact surfaces should not be cleaned everyday but only when they are dirty.			
12. Fruits and other foods from the supermarket are very clean and can be taken without washing.			
13. Water used in food preparation can be an agent of food contamination.			
14. Using sterile gloves can help prevent food contamination.			
15. All people can be affected by food-borne illnesses.			

THANK YOU FOR PARTICIPATING

APPENDIX 2: GUAVA FARMERS CONCENT FORM

University of Nairobi

Department of Food Science, Nutrition and Technology, Food Safety and Quality Assurance Programme

Judith Katumbi Ndeme is a student from the University of Nairobi studying MSc. in Food safety and Quality Assurance. She is conducting a study on the post-harvest handling and hygiene practices in post-harvest handling of guava fruits produced in Kitui and Taita Taveta counties. In order to get this information, I am pleased to have you take part in this study.

The study involves answering of a few questions with the responses you give being filled in a questionnaire and a checklist to be filled regarding post-harvest handling and hygiene practices in guava farming. The information you will provide will help in instituting measures in the prevention of post-harvest losses of guava by putting measures to extend shelf life and increase its utilization.

The information you will provide is confidential and in as much as a report of the same will be made, no names will be included. There is no way any information will be directly associated with you. I encourage you to participate in the study and your cooperation is highly appreciated.

Please sign below if you accept to be part of the study

Name of Interviewee……………………………………………..

Signature of interviewee………………………………………

Date………………………………..

In case of any problem,

Contact

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