PRODUCTION, UTILIZATION AND PROCESSING OF KENYAN GUAVAS: DEVELOPMENT OF NUTRIENT-ENRICHED GUAVA NECTARS FROM LOCAL VARIETIES

BY

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DECLARATION

This Thesis is my original work and has not been submitted for a degree in any other University.

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DEDICATION

To my late mother, Martha Moraa, a gem who instilled in me the values of education and academic perseverance at a young age and wished for me to attain the highest academic achievements possible, despite all odds. This is also in honor of sister Mercy Nyaboke, who has been a constant pillar of support throughout this journey.

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LIST OF ABBREVIATIONS

AAT	Accelerated Aging Time
AFA	Agriculture and Food Authority
AHC	Agglomerative Hierarchical clustering
ANOVA	Analysis of variance
AOAC	Association of Analytical Chemists
ASALs	Arid and Semi-Arid Lands
CE	Catechin Equivalent
CV	Coefficient of variation
DCPIP	Dicholorophenolindophenol
DPPH	2,2-diphenyl-2- picryl hydrazyl
d.w	Dry Weight Basis
FAO	Food and Agriculture Organization
FRuVaSe	Fruits and Vegetables for All Seasons
f.w	Fresh weight
GAE	Gallic Acid Equivalent
IU	International Unit
KEBS	Kenya Bureau of Standards

KNBS	Kenya National Bureau of Statistics
MLE	Moringa Leaf Extract
MT	Metric Tonnes
PCA	Principal Component Analysis
PCor	Parallel Coordinate Analysis
RTS	Ready-to-Serve
SSA	Sub-Saharan Africa
TA	Titratable acidity
TE	Trolox Equivalent
TSS	Total soluble solids.
TVC	Total Viable Count
USAID	United States Agency for International Development
UV/VIS	Ultraviolet–visible
WHO	World Health Organization

GENERAL ABSTRACT

In Kenya, guava (*Psidium guajava L.*) is a neglected nutrient-dense fruit that grows from randomly dispersed seeds. Despite being highly nutritious, the industrial processing of the fruits is non-existent in the country, with limited traditional and household processing. The goal of this study was to document the current trends in the production, postharvest handling, utilization, processing, and marketing of locally produced guava fruits, as well as to evaluate standardized processing techniques of the local varieties into nutrient-rich nectars. A mixed-methods study design employing qualitative and quantitative approaches was adopted whereby desk reviews followed by a cross-sectional baseline survey on the status quo of the guava value chain Taita Taveta and Kitui Counties of Kenya (n=417) were conducted. Experimental study designs involving completely randomized designs, factorial designs, and comparative analysis were used to evaluate the physicochemical and processing qualities of Kenyan guava varieties, effects of pulping methods on the physicochemical properties of guava pulp, differences in the physicochemical properties of commercially traded nectars, and the effects of blending guava nectars with moringa leaf extract on their acceptability, nutritional profile, and shelf stability.

The results indicate that the crop is highly neglected with limited postharvest handling and preservation, leading to high losses among approximately 77 % of households interviewed. Although the country's annual production exceeds 11 Metric tons, estimated to be worth $ 1.1 million, most yearly produce (84 %) is from sprouts of wild seeds, with red- and white-fleshed varieties growing in 97% and 49 % of the households, respectively. Minimal incomes were realized annually ($ 0.5-400) among homes that sell fresh fruits (30%) due to low farm gate prices of $ 0.08 – 0.10. Guava processing was limited, and only 3% of households reportedly processed guavas due to a lack of value addition techniques (75%) and appropriate processing equipment (66%).

The physicochemical characterization of the guavas indicated significantly (p=0.008) wide intra- and inter-fruit variations among the red-fleshed, white-fleshed, and strawberry guavas. Physically, the fruits' length, diameter, and weight varied with the average pulp to seed ratio significantly (p=0.026) higher in the red guava than in the white and strawberry guavas, at 31.2, 17.8, and 12.1, respectively. The strawberry guava levels of vitamin C were low and averaged 164.11±11.85mg100^{-1}g dry weight (d.w) compared to the white guava's 1665.56±126.50 mg100^{-1}g d.w. The white-fleshed guavas were limiting (p=0.0001) in β-carotenes (0.04±0.06 mg100^{-1}g d.w) in comparison to the strawberry guava's (1.55±0.30 mg100^{-1}g d.w). The red-fleshed guava had significantly (p=0.014) high levels of total phenolics (1649.14±329.70 mgGAE per 100^{-1}g d.w) and antioxidant activities (1989.14± 383.47 µMTE 100^{-1}g d.w). The red-fleshed guava significantly ($p<0.05$) outperformed the white in all key aspects -micronutrients and phytochemical composition (except for vitamin C) and would therefore be the most ideal for processing given its resilience and adaptation across various agro-ecological zones.

The effect of pulping methods on the quality of white- and red-fleshed guavas showed that although hot extraction methods resulted in significantly (p=0.001) high yield (67 -77%) as compared to the cold (62 – 72 %), there were no significant (p=0.0619) differences in the moisture loss during pasteurization, averaging 2.59±5.41 –5.1±2.6%. However, the vitamin C losses were significant (p=0.001), with up to 60% and 64% of the white and red guavas lost respectively. The cold extraction method resulted in significantly ($p<0.05$) better retention of the vitamin β-carotene (1.9±0.4mg), zinc (5.6±2.1mg), iron (20.1±8.6mg), calcium (19.2±4.2 mg), flavonoids (241.3±56 mgCE), phenolics (1548.7±25.8 mg GAE) and antioxidant activities (1998.6±333µMTE) per 100g.

The consumers clearly distinguished formulated guava nectars based on a minimum of 25% of red-fleshed guava pulp and blended nectars with 12.5 - 20% *Moringa oleifera* leaf juice extract inclusion. The formulations' mouthfeel had the highest discriminating power (test power 3.94, p=0.0004), differentiating the nectars. Inclusion of moringa leaf extract up to 12.5% resulted in fairly similar overall acceptability as the unblended nectars at 5.9±0.8 and 5.3±0.9, respectively. The moringa leaf extract significantly ($p<0.05$) resulted in high zinc (4.62±2.14 $mg100^{-1}g$), iron (28.87±6.21$mg100^{-1}g$), potassium (87.4±5.3$mg100^{-1}g$), vitamin C (574.2±116.2 $mg100^{-1}g$), β-carotene (0.34±0.03 $mg100^{-1}g$), flavonoids (217.0±18.8 $mgCE100^{-1}g$), phenolics (1934.8±198.3$mgGAE100^{-1}g$), and antioxidant activity (1934.8±198.3 µMTE $100^{-1}g$) compared to the unblended nectars. The most acceptable nectars would be shelf-stable for at least five months regardless of the packaging type, blending, or length of storage with significant (p=0.000) changes in the TSS, pH, and the TTA. The yeast and molds (<10cfu/g) and the TVCs (<10 cfu/ml) did not surpass the maximum allowable limits of 30 and 100 cfu/ml, respectively. However, considerable ($p<0.0001$) color deterioration was observed, notably in nectars packaged in transparent packaging.

Despite variations in Kenyan guava varieties, the fruits are nutrient-dense, with high annual losses due to limited processing and thus a lack of guava products made from the local fruits. However, this study demonstrated that adopting processing techniques for the red-fleshed guava, which have superior nutritional and processing qualities, at the household and small-scale levels would result in nutrient-enriched guava nectars, which could aid in strengthening the guava value chains by improving guava farmers' livelihoods and consumer access to processed fruits when they are out of season.

CHAPTER ONE : INTRODUCTION

1.1 Background information

Guava, *Psidium guajava* L., is a small evergreen tree belonging to the Myrtaceae family. It is native to southern Mexico and Northern South America (Salazar *et al*., 2006). However, guava trees have now been grown by many other countries with tropical and subtropical climates, allowing production worldwide (Salazar *et al*., 2006). The genus Psidium (Myrtaceae) contains approximately 150 genera and 5000 species widely distributed in the American, Asian, and African tropics. India, Pakistan, Mexico, Brazil, Egypt, Nigeria, Thailand, Columbia, and Indonesia are the primary producers of guavas (FAO, 2011).

Guavas grow well in various climates, including semi-arid lowlands and humid midlands (Barret *et al*., 2005). Small-scale producers use improved guava tree varieties grown from cuttings and grafting or grown from seedlings in commercial production (McMullin *et al.*, 2016; Sarkar & Bulo, 2017; Singh & Puyo, 2014). Guava fruits, often consumed raw, can also be processed into jam, juice, wine, and fruit leather. However, the improved guava has significant market potential, particularly in the juice industry (Barret *et al*., 2005).

The fruit is nutritious, containing a high concentration of micro and macronutrients, including vitamin C, carbohydrates, macro, and microminerals, and may help combat malnutrition (Verma *et al.*, 2013). Guavas are also high in pectin and bioactive components, with a significant concentration of functional bioactive compounds including phenolics, antioxidants, and flavonoids that can improve consumers' physiological, functional, and nutritional well-being (Boora, 2012; Phani *et al.*, 2016; Youssef, 2016). However, the fruit is underutilized in Kenya and is listed among the neglected fruits despite its prospective biological properties and potential economic value, which remains largely unexploited (HCD, 2014a; Williams & Haq, 2000).

The guava is a climacteric fruit with a relatively high rate of perishability (Deepthi *et al*., 2016). The fruit is highly vulnerable to mechanical and chilling injuries, resulting in qualitative losses and decreased market value (Phani *et al.*, 2016; Phebe & Ong, 2010; Rana *et al*., 2015). It is estimated that 20-40% of fruits are lost due to poor on-farm and post-harvest management practices and techniques. However, in Kenya, this quantification has yet to be determined (HCD, 2014a). Furthermore, there is limited research on the postharvest handling of guavas in Kenya, resulting in a lack of information on the practices and methods used by guava farmers to extend the fruit's shelf life (Katumbi *et al*., 2021). This could be attributed to the low adoption of the fruit's processing and preservation techniques, limited research, and a lack of understanding of the fruit's economic potential (Chiveu, 2018; Wasilwa *et al*., 2018). As a result, the guava value chain lacks well-organized marketing, distribution, and handling structures.

Because of the ease of processing, guava nectar production is increasing (Ordóñez-Santos & Vázquez-Riascos, 2010a). Guava nectars are made by homogenously mixing guava pulp, sugars, and optional acidification in drinking water and are typically intended for direct consumption (Krumreich *et al*., 2018). They can be effectively used to increase consumers' micronutrient intake (Krumreich *et al*., 2018). Although processing guavas into nectars is cost-effective and can be adopted by farmers to reduce postharvest losses and commercialization of the fruit for household income generation and improved food security (Gill, 2016), previous research indicates that the processing techniques for the fruit are a limiting barrier in Kenya. This deprives Kenyan consumers of alternative forms of the guava fruit's consumption when out of season

Blending guava nectars with other juices has been shown to improve the products' organoleptic and quality characteristics by reducing the intense acidity and astringency, increasing total

soluble solids, and generally improving the nutrient content of the nectars (Kumari, 2016; Mutsuura *et al*., 2004). Guava nectars have also been blended with aloe vera gels, and the resulting products have been found to have higher nutrient levels than unblended nectars (Abed *et al*., 2016; Rani & Babu, 2015). Other medicinal and edible plants can be combined with fruit nectars and juices to aid in the fight against malnutrition.

There is limited information on guava production and utilization, processing and preservation, and the nutritional composition of guavas and guava-based products in Kenya. Therefore, this study sought to document the guava production and utilization trends and the constraints encountered in processing and preservation techniques. Additionally, this study evaluated standardized processing and preservation techniques for optimal nutrient retention during the development of nutrient-enriched guava nectars through a food-to-food fortification by blending with *Moringa oleifera* leaf juice extracts to boost the vitamin A, zinc, and iron levels of the guava nectars (Gopalakrishnan *et al*., 2016a).

Moringa oleifera is a drought-resistant tree high in macro and micronutrients necessary for human nutrition, including proteins, vitamins, beta carotenes, and minerals such as zinc, iron, potassium, calcium, and phosphorous besides high phytochemical composition (Ravani *et al*., 2017). The tree has been used as a source of food and medicine worldwide, and studies have shown that due to its high levels of essential nutrients, it can help fight malnutrition (Fahey, 2005). However, to increase consumption, blending with fruit juices provides an avenue for increased nutrient intake to help combat micronutrient deficiency.

1.2 Statement of the problem

The most common micronutrient deficiencies worldwide, resulting in nutritional disorders, are vitamin A, iron, and zinc, with the developing countries being the most affected. Lack of

micronutrients has been linked to several health complications, including preventable childhood blindness, stunted growth, mental disorders, diarrhea, physical and skeletal development, among other issues (De Benoist *et al*., 2005; Maret & Sandstead, 2006). However, fortification and the introduction of foods rich in these nutrients have been shown to help combat the conditions (Shahzad *et al.*, 2014). Despite the guava fruit's high nutritional value, palatability, and availability at reasonable prices, the crop's value chain is underdeveloped in Kenya (Chiveu, 2018). Furthermore, limited research programs, documentation, and processing have been geared towards strengthening the crop's value chain (Wasilwa *et al.,* 2018). Guavas are highly perishable fruits with high postharvest losses due to the rotting of mature ripened fruits during glut, necessitating the need for value addition (Singh & Singh, 2017). However, guava processing is limited in Kenya, constraining the fruit's economic and nutritional potential. As a result, low-cost processing technologies for shelf-stable products such as nectars must be adopted to bridge the seasonality gaps. Although some nutrients are lost due to processing regimes, blending through a food-to-food fortification approach can help boost the nutrient content of the resultant products to address micronutrient deficiencies that remain unmet in most households in developing countries, including Kenya (WHO, 2006).

1.3 Justification

In Kenya, guava consumption, utilization, and value addition is extremely low (Chiveu *et al*., 2019). This is despite the high levels of micronutrient deficiency and malnutrition caused by limited access to and utilization of fruits, and a relatively high rate of poverty, which results in food insecurity, particularly in rural areas (Armachius & Vumilia, 2017). Additionally, with low postharvest technologies, high postharvest losses are a constant challenge for guava fruits (Katumbi *et al*., 2021). As a result, there is an urgent need for a structured system for policy

formulation focused on its trade to reduce post-harvest losses, increase employment opportunities, maximize the value of the fruits to farmers and ensure consumer access to processed fruits when out of season. Value addition through new product development while ensuring minimal nutrient destruction is critical to combating malnutrition, particularly during harsh weather conditions, and addressing food security challenges by generating income for farmer households by commercializing guava fruits and their processed products. The feasibility of commercializing processed guava from locally sourced fruits in Kenya has not yet been determined. Adoption of low-cost guava processing is achievable even at the household level, and farmers should be educated on affordable technologies that can help minimize postharvest loss of the fruits. However, care must be taken during processing to ensure that the techniques used to create products are nutritionally, organoleptically, and functionally preservative to ensure minimal nutrient degradation.

Currently, guava juice products are available on the Kenyan markets, though the guava used in processing is imported (Ndemo, 2016; Oyugi, 2018). Additionally, there is a lack of information regarding the nutritional quality and safety of processed local guava products, necessitating the conduct of a study. Guava fruits have excellent qualities that allow them to commercially produce nectar, preventing high post-harvest losses (Bhuvaneswari & Tiwari, 2007). Production of nectars is simple, even at the household level, and will result in more stable products with a longer shelf life and increased utilization. As a result, nectar processing will reduce post-harvest losses and ensure consistent supplies from the production areas to consumers in peri-urban and urban areas. The study sought to provide information on the feasibility of commercializing nutrient-enriched guava nectars processed from local Kenya varieties, generate more interest in guava research, and help generate policies that will strengthen the guava value chains to exploit the fruits' economic and nutritional potential. To address iron, zinc, and vitamin A deficiencies, a food-food-fortification was adopted by

assessing guava nectars' acceptability and nutritional composition blended with *Moringa oleifera* leaf extracts.

1.4 Objectives

1.4.1 Overall objective

To assess the current state of guava production, utilization, processing, and preservation in Kenya while contributing to guava value addition by developing nutrient-enriched guava nectars.

1.4.2 Specific objectives

i. To assess the trends and constraints in guava production, utilization, processing, and preservation in Kenya.
ii. To determine the physicochemical and processing qualities of the Kenyan guava fruit varieties.
iii. To determine the physicochemical and microbiological qualities of Kenyan guava juices and nectars.
iv. To determine the changes in the physicochemical properties of guava during pulping
v. To assess the sensory acceptability and physicochemical properties of nectars blended with *Moringa oleifera* leaf extract.
vi. To assess the changes in the physicochemical and microbiological properties of guava nectars during storage.

1.5 Hypothesis

i. The trends and forms of guava production, utilization, processing, and preservation are not different between Taita Taveta and Kitui counties of Kenya

ii. The physicochemical and processing qualities of the Kenyan white and red-fleshed guava fruits are not different.

iii. The physicochemical and microbiological qualities of Kenyan guava juices and nectars are not different.

iv. The changes in the physicochemical properties of the red and white-fleshed guava fruits during pulping are not different.

v. The sensory acceptability and physicochemical properties of guava nectars blended with *Moringa oleifera* leaf extract are not different from the unblended nectars.

vi. There are no changes in the physicochemical and microbiological properties in the blended and unblended guava nectars during storage.

CHAPTER TWO : LITERATURE REVIEW

Guava, *Psidium guajava L*., is a small monoecious evergreen tree in the Myrtaceae family that grows between 2 and 10 meters (Patel *et al*., 2011). It is native to the tropical areas of southern Mexico and Northern South America (Salazar *et al*., 2006). However, guava trees have now been grown by many other countries with tropical and subtropical climates, allowing production worldwide (Salazar *et al*., 2006). The fleshy fruit, which matures 120 days after flowering, has a distinctive smell and aroma, contains many seeds, and can weigh up to 500g depending on the variety and environment (Patel *et al*., 2011). The guava is highly adaptable to various climatic conditions, including wastelands and soils with much higher pH levels (8.6 to 9.6), though optimal growth is at pH levels between 5 and 7. It is thus widely distributed and, due to its ease of naturalization, it is highly productive and resilient across various agroecological zones (Gautam *et al*., 2010). Guavas have been successfully dispersed by agents such as birds, bats, humans, and other animals (Gautam *et al*., 2010).

Commercial guava production entails propagating improved guava varieties using various techniques, including seed and vegetative propagation (Pereira *et al*., 2016). However, commercial guava cultivation is limited in East Africa (Omurungi, 2012) due to low economic returns from the fruits. Naturally growing guavas are the most prevalent, resulting in a wide range of morphological and genetic diversity among guavas within the region (Chiveu, 2018). Although guava fruits are frequently consumed fresh, they are excellent for processing industrial products such as jam, juice, nectar, wine, and fruit leather (Kumari *et al*., 2017). The fruit is nutritious and contains vitamin C, carbohydrates, minerals, pectin, calcium, and phosphorus, among others, and may help fight malnutrition (Youssef, 2016). Additionally, the crop is used to treat various ailments in Central and South America, West and North Africa,

and Southeast Asia, including gastrointestinal disturbances and cosmetic and dermatological applications (Chiari-andréo *et al*., 2003; Morais-Braga *et al*., 2016).

2.1 Guava cultivation in Kenya

In Kenya, fruit production, including guavas, is primarily carried out by farmers with insufficient resources, impeding the experimentation and diversification of fruit species (Mbora *et al*., 2008). As a result, red/pink-fleshed, white-fleshed, and strawberry guava with diverse morphological and genetic diversities grow in Kenya across different agro-ecological zones (Chiveu, 2018; Gatambia *et al*., 2010; HCD, 2014b; Kidaha *et al*., 2015).

Except in arid regions, naturalized guava cultivation is widespread in rural areas across all agro-ecological zones, both in the wild and on farms in Kenya (Chiveu *et al*., 2016). According to the Horticultural Crops Directorate, guava trees grow rapidly from sprouts of randomly dispersed seeds with little care (HCD, Kenya). According to HCD data, guava production has increased over the years (HCD., 2016; HCD, 2014b). Between 2014 and 2016, the total acreage under guava farming ranged between 1260 and 1806 ha, with production expected to increase in the coming years. During this period (2014 - 2016), the estimated total output ranged between 9800 and 11,327 tons. On the other hand, guava prices provide farmers with low returns due to their low farm gate prices, limited rural purchasing power, and limited commercial processing, which results in significant post-harvest losses. As a result, despite its nutritional and economic potential, the guava value chain remains largely untapped (Oyugi, 2018).

There are, however, few research and development programs in Kenya aimed at domesticating and commercializing the fruit, impeding the establishment and improvement of structured guava value chains in the country (Wasilwa *et al*., 2018). Furthermore, there is scattered and

conflicting information on guava production and minimal documentation on the crop's development programs (Wasilwa *et al*., 2018). Additionally, there is limited information on guava production for consumption and commercial purposes, and no commercial guava plantations exist in Kenya (HCD, 2014b). Besides, the guava varieties and their performance in their respective counties have yet to be profiled, as very few studies on the crop have been conducted. As a result, the climatic, soil, and agronomic conditions necessary for optimal guava cultivation and post-harvest processing technologies in the country are unknown (Chiveu, 2018).

2.2 Nutritional properties of guava

The vitamin C levels in guava fruits are significantly higher (up to 228.3 mg/100 g, fresh weight), 4-8 times higher than in oranges and lemons, with the unpeeled fruits having the highest concentration (Yan, 2006). Essential oils, phenols, triterpenes, flavonoids, saponins, lectins, fiber, and fatty acids, as well as pectin, are all abundant in guavas (Rana *et al*., 2015). In addition, the fruits are high in minerals like phosphorus, calcium, and iron, as well as vitamins like niacin, pantothenic acid, thiamin, riboflavin, and vitamin A (Table 2.1) (Das, 2011; Kamath *et al*., 2008; Rana *et al*., 2015). Guavas are rich in carotenoids and polyphenolic compounds, making the fruit among the highest antioxidant values (Jiménez-Escrig *et al*., 2001). The pigments are responsible for the color of the fruit's skin and flesh. Compared to yellow-green guavas, red-orange guavas have higher polyphenolic constituents, carotenoids, pro-vitamin A substances, and retinoids (Rojas-Garbanzo *et al*., 2017). Oxalic and malic acids, saponin combined with oleanolic acid, and other polyphenolic compounds such as morin-3-O—L-lyxopyranoside and morin-3-O—L-arabopyranoside, flavonoids, guaijavarin, and quercetin are all found in significant quantities in guava fruits (Das, 2011).

Table 2.1: Nutritional composition of the guava fruit

Nutrient	Value per 100 g Fresh weight Basis
Proximates	
Water	80.8 g
Energy	68 kcal
Protein	2.55g
Total lipid (fat)	0.95g
Carbohydrate, by difference	14.32g
Fiber, total dietary	5.4g
Sugars, total	8.92g
Minerals	
Calcium, Ca	18mg
Iron, Fe	0.26mg
Magnesium, Mg	22 mg
Phosphorus, P	40 mg
Potassium, K	417 mg
Sodium, Na	2 mg
Zinc, Zn	0.23 mg
Vitamins	
Vitamin C, total ascorbic acid	228.3 mg
Thiamin	0.067 mg
Riboflavin	0.04 mg
Niacin	1.084
Vitamin B-6	0.11 mg
Folate, DFE	49 µg
Vitamin A, RAE	31 µg
Vitamin A, IU	624IU
Vitamin E (alpha-tocopherol)	0.73mg
Vitamin K (phylloquinone)	2.6
Lipids	
Fatty acids, total saturated	0.272
Fatty acids, total monounsaturated	0.087
Fatty acids, total polyunsaturated	0.401

Adapted from USDA, (USDA, 2018)

Chiveu ((2018) found significantly low levels of vitamin C in Kenyan guavas, ranging from 83-147 mg/100 g of fresh fruit, compared to the USDA's 228 mg/100 g. (Table 2.1). On the other hand, the mineral composition varied significantly, with some varieties having extremely low or high mineral content compared to the USDA data. The white-fleshed guavas generally had more phosphorous, magnesium, sodium, and boron than red-fleshed varieties (Chiveu, 2018). These variations may be attributed to the climatic conditions and the fruits'

morphological traits (Chiveu *et al*., 2019; Ferreira & Rodriguez-Amaya, 2008) and the maturity levels and agricultural practices (Bakshi, 2015; Río Segade *et al*., 2008). Therefore, further research is needed on the nutritional composition of Kenyan guavas and factors influencing the nutrient contents.

2.3 Factors influencing guava nutrient content

The nutrient content of guava fruit is highly dependent on the geographic region in which the fruit trees are grown and the mineral composition of the soil (Flores *et al*., 2015). Furthermore, the climatic conditions in which these trees grow have been shown to significantly impact the nutritional characteristics of the fruit (Chiveu *et al*., 2019). The interactions between soil quality, fruit maturity, varieties, and climate have all been found to significantly result in nutritional differences within the same cultivars between continents and fruits sourced from different regions within the same country due to variations in agroecological zones (Flores *et al*., 2015; Haque *et al*., 2009).

2.4 Postharvest losses of guava fruit

Due to its climacteric nature, the guava fruit has a high rate of perishability (Rawan *et al*., 2017). Most postharvest losses in the fruits are caused by physiological injuries such as wilting, shriveling, and chilling, pathologically by fungi and bacterial attacks, and physically by mechanical injuries (Kader, 2005). According to estimates, losses in developing countries range from 20 to 40%, compared to 10 to 15% in developed countries, depending on the crop and season (Kader, 2005; Madrid, 2011; Mpho, 2012). However, these levels for the Kenyan guavas are yet to be quantified.

Guavas, like other fruits, suffer from quantitative and qualitative post-harvest losses at all stages of production, from harvesting to handling, packaging, transportation, and postharvest

storage and marketing (Paltrinieri, 2014). About 20-25% of guava fruits are damaged and unfit for consumption before reaching consumers (Kanwal *et al*., 2016). However, as shown in Table 2.2, the adoption of proper postharvest practices can help reduce this. Therefore, the development of affordable processing technologies for guava must be adopted (Nikhanj *et al*., 2017). Guava post-harvest losses in Kenya are still unknown. This could be due to the fruit's lack of importance compared to other fruits such as mangoes and avocadoes (HCD, 2014b). Furthermore, compared to other fruit trees, farmers rarely plant guava trees as a source of income due to their neglect by vital Kenyan stakeholders.

Table 2.2: Postharvest losses reduction strategies for fruits

Stage	Recommended handling
Harvesting	Harvesting during cooler hours of the day (e.g., early morning) to avoid bruising, scratching, and punctures; shading crops once harvested to remove field heat
Handling	Pest attacks and physiological and dehydration damage can be reduced by protecting the crops from injury.
Sorting and Cleaning	Sorting and cleaning can significantly extend the shelf life. The risk of fungi or bacteria spreading from damaged crops to other crops is reduced by separating higher and lower quality crops. Using visual charts, quality parameters such as size and color can be determined, allowing the crops to be targeted to the most profitable markets.
Packaging	Freshness deterioration is prevented by proper packaging, which also protects against physical damage during transportation. Containers that are clean, smooth, and ventilated are essential, but the type depends on the crop.
Transportation	Perishable crops should be transported in clean, cool, ventilated, and covered vehicles, with transport during the cooler hours of the day recommended. Excessive vibrations and movement can degrade crop quality, so the smoothness of the road is also essential. Loading and unloading with care is a simple but effective way to reduce loss.
Storage	Only crops that meet specific quality standards (correct maturity, undamaged) should be stored. Temperatures optimal for each commodity should be known and used because the shelf life is extended when stored at these temperatures.
Processing	Processing allows producers to stabilize the product, diversify the food supply for enhanced nutrition throughout the year, and generate employment.

Adapted from Kiaya, 2014 (Kiaya, 2014)

The rate of guava deterioration is influenced by a variety of external environmental factors to which the harvested guavas are exposed to including ambient temperatures, relative humidity, airspeed, and atmospheric air composition (the ratio of carbon dioxide, ethylene, and oxygen), as well as the hygienic conditions of the storage area (Kader, 2005). Fresh guavas last about 3–10 days on average under room temperature (25±5^{o}C), but depending on the varieties and methods used, they can last 2–11 days longer if some of these factors are controlled (Gill, 2018; Pareek *et al*., 2009; Phebe & Ong, 2010; Rana *et al*., 2015).

When guavas are packaged in modified forms, however, the rate of perishability is reduced significantly (Rawan *et al*., 2017). According to Rana *et al*. (2015), storing guavas at 7 ± 3°C after shrinking and cling wrapping with polythene bags (LDPE) increased the shelf life by 15 days. It reduced the shelf life ripening rates and physiological weight losses. Salts like calcium chloride and calcium nitrates have been found to help keep guavas fresh for longer (Kumar *et al*., 2012). This is due to the counteractive effect on ethylene, which reduces ripening rates and extends the guava life by up to 12 days when stored at room temperature. Furthermore, low-concentration salicylic acid has been shown to effectively reduce guava degradation (Biosci *et al*., 2017), while antioxidants like benzyl adenine have similarly increased guava shelf life by up to 14 days during storage (Jayachandran *et al*., 2007).

Freeze-drying of guavas and guava pulp has been used to preserve the fruits (Conceição *et al*., 2016; Mahendran, 2011; Marques & Freire, 2005). The technique is the most appropriate method for drying products, especially fruits and vegetables, susceptible to heat (Marques & Freire, 2005). Unlike conventional drying, freeze-drying is carried out at low temperatures (-20 to -50^{o}C), minimizing the shrinking and degradation reactions resulting in products of superior quality (Conceição *et al*., 2016; Marques & Freire, 2005). However, the technique may be costly considering that the fruit is not a premium product in Kenya.

Postharvest losses in Kenya and sub-Saharan Africa are caused by various factors and manifest themselves in various ways (Kitinoja & Kader, 2015). The primary causes are pre-harvest factors such as disease and insect infestation (Kitinoja *et al*., 2011; Sheahan & Barrett, 2017). Other significant factors affecting post-harvest losses include improper handling of fruits and inappropriate packaging methods, resulting in physical damage and high temperatures, resulting in moisture loss. Additionally, postharvest losses have frequently been linked to delayed marketing and ineffective market distribution strategies that extend the time between harvest and consumption (Kitinoja & Kader, 2015).

There has been little research on postharvest losses of guavas in sub-Saharan Africa, but losses have been as high as 49% due to their status as minor fruits in the region (Hailu & Derbew, 2015). However, postharvest losses of guavas in Kenya may be extremely high due to a lack of documentation and a poorly structured value chain for the locally produced fruits.

2.5 Guava fruit value addition

The guava has excellent processing qualities and the potential for widespread commercial use due to its high nutrient content and ease of processing into various industrial products (Kocher, 2011). Guava processing results in a variety of products, including guava pulp, jam, juice, jelly chocolates, and wine, as well as guava powder (which is primarily used to make yogurt) (Kadam *et al*., 2012a) and spray dried soluble guava extracts with high antioxidant concentrations (Kadam *et al*., 2012a; Kr Chauhan, 2014).

Several commercial products made from guava include the following:

2.5.1 Guava pulp

Guava pulping is a critical unit operation in the fruit's processing because it removes fibers and seeds while providing a critical raw material for subsequent stages of processing (Correa *et al*., 2010; Kumari, 2016; Yadav *et al*., 2017). To avoid nutrient degradation, the guava pulp is best preserved by adding potassium metabisulphite at low concentrations (0.005 - 0.2%) and storing it at low temperatures (2-5^{o}C) (Correa *et al*., 2010). The pulp is readily processed into other products such as juices, ready-to-drink beverages, guava nectars, and guava leather (Correa *et al*., 2010; Kumari, 2016; Yadav *et al*., 2017) and can be stored at a temperature of 2-5^{o}C for up to 90 days (Yadav *et al*., 2017).

The fruit pulp extraction is critical because it determines the final product's quality and yield (Tillett *et al*., 2014). The pulp extraction can be accomplished using cold or hot methods (Kadam *et al*., 2012a; Tillett *et al*., 2014). The hot method begins with a blanching stage in which the fruits are blanched before being extracted with hot water or steam (Tillett *et al*., 2014). While hot methods produce a high extraction yield, they frequently result in browning and off-flavors, which degrade the end product's quality. On the other hand, cold methods involve pulping cleaned fruits without preheating, which results in higher-quality pulp but lower yields than hot methods. The pulp can be made with peeled or unpeeled guavas (Kadam *et al*., 2012a). Guavas can be peeled using lye or diluted sodium hydroxide (NaOH) or by hand. The former is preferable because it results in a more uniform peeling of the product and thus a higher pulp yield (Han *et al*., 2018; Tillett *et al*., 2014). The fruits are then pulped using household blenders or industrial pulpers, followed by sieving or straining to remove the seeds using muslin cloths or 1 mm stainless steel meshes (Bhuvaneswari & Tiwari, 2007; Tillett *et al*., 2014).

2.5.2 Blended ready-to-serve guava beverages

Guava fruit pulp has been used to create a variety of blended, ready-to-drink beverages by combining it with other fruits such as canola, papaya, and pineapples in various ratios (Sarkar & Bulo, 2017). According to Jakhar *et al*. (2013), blending guava pulp with other fruit pulps enhances the appearance and nutritional value of the final product. Additionally, it improves the flavor of the resulting products.

2.5.3 Dehydrated guava products

Drying preserves fruits by lowering their water activity, inhibiting microorganism growth, and enzymatic reactions (María & Acosta, 2014). Numerous drying methods are available, including sun and solar drying, which produce contaminated and low-quality products compared to osmotic dehydration, vacuum, freeze, and spray drying techniques (Sagar & Suresh Kumar, 2010). Guava slices can be dehydrated by drying them in direct sunlight (Ndawula *et al*., 2004). Although this is the least expensive method of preservation, it has been shown to result in up to 84 % loss of heat-labile nutrients such as ascorbic acid and water-soluble vitamins such as thiamine and niacin, limiting its use as a suitable preservation method (Ali *et al*., 2016; Ndawula *et al*., 2004; Wojdyło *et al*., 2014).

Guava slices are osmo-dried after dipping in sugary syrups containing 0.05% potassium metabisulphite and citric acid (Sagar & Suresh Kumar, 2007). These factors result in a decrease in moisture content and an increase in solid and sugar levels, both of which have preservative properties. The method has a negligible effect on the appearance, texture, and flavor of the guava slices.

2.5.4 Guava jams and jellies

Guava jam is made by cooking pulp with sugar, jellifying agents, and other suitable additives until the desired consistency is achieved (Kanwal *et al*., 2017). The jam should have a Brix value of 65-68º before being hot-filled into cleaned and sterilized glass jars (Sidhu, 2006). Guava jellies are made from firm-ripe fruits. The fruits are cut into small pieces and boiled for approximately 45 minutes in an equal amount of water, with the juice extracted using strainers or clean muslin cloths (Kuchi *et al*., 2014). Additional processing involves adding sugars to the extracted juice and boiling it to 105°C or forming a sheet when a small portion is cooled in a spoon (Sidhu, 2006). The amount of sugar used is determined by the pectin content of the extracted juices and varies between 0.5 kg sugar/kg juice and 0.75 kg sugar/kg juice for pectin-rich and low-pectin juices, respectively (Sidhu, 2006). This is followed by hot filling into clean and sterilized jars.

2.5.5 Guava juice and nectars

Guava juices can be made from fresh fruits or guava pulp. Juice is extracted by squeezing guava fruits through a hydraulic filter press or diluting with water and subsequent filtration of the pulp (Kumari *et al*., 2017). The juice is typically cloudy and may require the addition of pectic enzymes to produce clearer, easily filtered juices (Kumari *et al*., 2017). Nectars are made by adding water to guava pulp or freshly squeezed juice (FAO, 2005). Allowable additives or sweeteners, as well as sugar, may be added. Still, the products must have a minimum Brix of 8.5, a minimum of 25.0 % guava puree or juice, and a minimum acidity of 0.15%t at a pH of 3.4 – 4 (FAO, 2005; Kumari *et al*., 2017). Additionally, guava juices or nectars can be blended with other juices to increase their nutritional value. Other researchers Kadam *et al*. (2012a), Kumari (2016), Mehta *et al*. (2018), and Rani & Babu (2015) have developed various blended

guava nectars and reported that blending improves product acceptability, increases nutritional content, and increases product stability, resulting in longer shelf life for the nectars.

2.6 Effects of different processing methods on guava fruit nutrients

The guava's nutrient content is significantly altered during processing into various products (Dweck, 2001). These include reductions in heat-labile nutrients such as vitamin C, which may be reduced by up to more than 50% (Dweck, 2001) depending on the intensity and time of exposure to heat. The carbonyl compounds that give the fruit its characteristic aroma and other phytochemical degeneration have been shown to occur and are attributed to the enzymatic activities due to exposure to light and oxygen (Dweck, 2001; Hussein *et al*., 2000). Additionally, cutting guavas promotes ethylene production, which accelerates senescence processes and increases oxidase and lipoxygenase enzyme activity, resulting in the oxidation of fatty acids and carotenoids. (Hussein *et al*., 2000).

Losses of ascorbic acid have been shown to occur by as much as 20 and 63 % during juice and jam processing, respectively (Jawaheer *et al*., 2003), 63% loss in vitamin C and 62% in lycopene during nectar manufacture (Ordóñez-Santos & Vázquez-Riascos, 2010b). Drying increases the guava shelf life with minimal degradation of the fruit's mineral and antioxidant activities (Patel *et al*., 2016). However, freeze-drying has been shown to have the most negligible effect on guava dehydration as it has minimal effects on the nutrient content levels as well as the fruits' natural color, flavor, and aroma, although the method is costly (Ali *et al*., 2016; Kumar & Sagar, 2014; Marques *et al*., 2006).

There is currently no data on the nutrient content of processed guava products available in Kenyan markets, necessitating further research to determine the extent of nutrient degradation in processed guava products.

2.7 Processing of guava wastes

Wastes such as seeds, stone cells, and fibrous tissues from the skin are produced during the processing of guavas into various products, particularly during pulping. These account for about a quarter of the total processed fruits and are suitable for animal feeds processing and other products. (Augusto *et al*., 2011; El Boushy *et al*., 2000). Guava wastes contain a high concentration of crude fiber (up to 61%), significant amounts of ether extracts (primarily oleic and linoleic acids), and metabolizable energy values ranging from 1,336 kcal/kg to 1,808 kcal/kg (Guimarães, 2007; Pereira *et al*., 2009). Guava seed meal also contains significant minerals such as zinc, iron, potassium, phosphorus, and manganese (Uchoa-Thomaz *et al*., 2014b). Guava wastes can also be processed to produce value-added food products such as pectin, dietary fiber (derived from ground dried wastes), and powder that can be used to increase the dietary fiber content of bakery products and as a substrate for ethanol fermentation. (Sharma & Kaur, 2018).

According to Lira *et al*. (2009), incorporating guava wastes into broiler chicken feeds increases carcass yields, while Farid & Kamel (2016) demonstrated that incorporating about 20% of guava wastes into feeds can be used effectively without compromising the animals' health, performance, or digestibility, and has a negligible effect on carcass quality. Using guava wastes as rabbit feed or inclusion in their diets has reduced feed costs while improving rabbit growth and health with minimal interference indigestion and carcass quality (Kamel *et al*., 2016). While guava wastes could be processed into commercial products, thereby reducing pollution caused by waste disposal, there is a need to promote guava processing, which is currently lacking among Kenyan fruits, and evaluation of their suitability for guava processing into value-added products.

2.8 Recommendations

In Kenya, the nutritional and economic potential of guava fruit has yet to be realized. More research into the factors that limit its full utilization is required. Even though the Kenya Agricultural and Livestock Research Organization (KALRO) has been at the forefront of promoting guava production by providing farmers with guava seedlings (Oyugi, 2018), a multisectoral approach from the other government bodies, policymakers, farmers, processors, and researchers should be established to promote guava production and processing. It is worth noting that guava can be grown in most counties, so farmers may need to be educated about the fruit's potential. Furthermore, just like with other fruits like mangoes, the involved authorities, including the Horticultural crops directorate, the Ministry of Agriculture, should be at the forefront in providing farmers with high-quality guava seedlings, providing extension services on proper agronomic practices for guavas, and establishing marketing channels. Furthermore, farmer education groups can promote simple processing and preservation techniques that can be done at home to reduce postharvest losses. At the same time, the government can intervene to ensure that fruit processors in the country also produce and market guava products made from locally sourced guava fruits.

CHAPTER THREE : TRENDS AND CONSTRAINTS IN GUAVA PRODUCTION, UTILIZATION, PROCESSING AND PRESERVATION IN KENYA

3.1 Abstract

The guava fruit is a highly palatable and nutritious tropical fruit with a pleasant flavor. It is abundant at moderate prices in Kenya. However, limited processing and low market returns result in the crop's high annual fruit losses. The purpose of this study was to evaluate the production, utilization, preservation, and processing of guavas in Kenya's Kitui and Taita Taveta counties. A cross-sectional study was used to collect data from guava farming households (n=417) using a semi-structured questionnaire. At the same time, focus group discussions and key informant interviews were held to gather additional information. Most respondents reported that guavas grew naturally (83.9%), although 37% had planted guava trees. The red-fleshed guavas were the most common variety in the respondents' farms (97.6%), followed by the white (49%) and strawberry (0.2%) varieties. Nearly half of those polled (46.6%) had both white and red-fleshed varieties. Guavas were mainly consumed at home (97.4%), but 30.5% of those polled also sold them. Guava marketability differed significantly ($p<0.05$) between the two counties, with Taita Taveta (($\chi^2=105.3$, $p<0.001$) having more difficult market access than Kitui. Regardless of their level of education or gender, the majority of respondents (60%) did not know of any processed guava products ($p>0.05$). Despite the country's high production of guavas, processing remains extremely low (3.1%) due to a lack of knowledge (74.8%) and appropriate equipment (65.9%), resulting in the fruit's economic under exploitation. In conclusion, the guava value chain remains highly unexploited with high annual on-farm and post-harvest losses despite the fruits' potential and, therefore, a need to adopt good agricultural and postharvest handling practices to increase its utilization for increased economic and nutritional value.

3.2 Introduction

The guava is a hardy, evergreen tree in the Myrtaceae family primarily grown for its edible fruits (Yadav *et al*., 2017). Guava trees are hardy and adapt well to various climatic conditions in tropical and subtropical areas worldwide (Salazar *et al*., 2006). As a result, the crop is highly productive, requires little maintenance, and yields high economic returns (Kadam *et al*., 2012b). Guava fruits are nutrient-dense fruits commonly consumed in fresh and processed forms (Kadam *et al*., 2012b). The fruits are high in vitamin C, minerals, and antioxidants, among others (Kamath *et al*., 2008). Furthermore, the guava tree's leaves, bark, and roots contain numerous phytochemicals, making the crop valuable in ethnomedical practices worldwide for treating various diseases (Das, 2011; Kamath *et al*., 2008). However, because guava fruits are climacteric, they are highly perishable and have high post-harvest losses during glut (Singh & Singh, 2017).

In Kenya, commercialized guava cultivation is limited. Production is primarily from naturalized guava, which typically invades farmlands and uninhabited areas due to seed dispersal by various agents such as birds, mammals, and men (HCD, 2014; Chiveu *et al*., 2016). As a result, different varieties exist with different genetic and morphological characteristics (Chiveu *et al*., 2016). Despite the country's favorable climatic conditions for fruit growth, a lack of suitable varieties, limited research, poor marketing, and a lack of processing techniques have hampered the development of a sustainable guava value chain, resulting in high annual losses (Omayio *et al*., 2019; Wasilwa *et al*., 2018)

Guavas are considered minor crops in most African countries, except for South Africa, Egypt, and Sudan, which have invested in research programs to improve their genetics, propagation, and disease management (Pereira *et al*., 2016). Their high perishability has resulted in low-

income generation in the households where the fruits are grown and underutilization of the fruits' nutrients (Omayio *et al*., 2019).

Kenya produces more than 11,000 tons of guava annually, valued at 1.1 million dollars (HCD, 2014b). According to the Horticultural Crops Directorate, Kenya (HCD., 2016; HCD., 2014), there is a projected increase in yield in the future. Despite the fruits' economic potential, which has been demonstrated in more than 50 countries around the world (Pereira *et al*., 2016), their value in Kenya is almost non-existent due to the lack of industrial processing of the local varieties' pulp into jam, juice, jelly, chocolates, wine, and guava powders, among other commercial products that have been developed and have high consumer acceptance (Kadam *et al*., 2012b; Kr Chauhan, 2014). Furthermore, there are no known widely used guava preservation methods, such as modified atmosphere packaging and chemicals such as calcium chloride, calcium nitrate, and salicylic acids, that effectively extend shelf life (Omayio *et al*., 2019).

There is also a scarcity of data on guava production, consumption, and processing, and these limitations have hampered the development of long-term guava value chains in the country (Omayio *et al*., 2019). This is due to a lack of understanding of guava's importance, poor market returns, low-yielding guava cultivars, and a lack of value-added technologies for preserving surpluses due to their seasonal availability (HCD, 2014; Omayio *et al*., 2019). Due to inefficiencies, the guava marketing channels have also been shown to be relatively ineffective, limiting wider market access, including exports (Mbora *et al*., 2008; HCD, 2014; Chiveu, 2018).

The purpose of this study was to assess trends and constraints in guava production, utilization, marketing, processing, and preservation of the locally produced guava fruits in Kenya's Kitui and Taita Taveta counties.

3.3 Methodology

3.3.1 Study area

The study took place between April and May 2019 in Taita Taveta and Kitui Counties (Figure 3.1), which have a high capacity for guava production. Taita Taveta is located in Kenya's coastal region between the longitudes 37° 36' and 30 ° 14' East and latitudes 2° 46' and 4 ° 10' South (County Government of Taita Taveta, 2018). The county has an estimated 17,084.1km^2 and shares a southern border with five other counties and the Republic of Tanzania. The County is mainly dry, except for Taita Hills, which receives significant rainfall and is ideal for horticultural production (County Government of Taita Taveta, 2018). The county is divided into four sub-counties and has twenty wards with an estimated 347,909 people in 2018, with rain-fed agriculture as the primary economic activity (County Government of Taita Taveta, 2018).

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

Kitui County is located in Kenya's Arid and Semi-Arid (ASAL) region, covering an estimated area of 30,496.4 km^2 (Figure 3.1). The county is located between latitudes 0˚ 10' and 3˚ 0' South and the latitudes 37˚ 50' and 39˚ 0' East (County Government of Kitui, 2018). The County is divided into eight sub-counties and forty wards. As of 2016, the county's population was estimated to be 1.1 million, although most are food insecure and live in poverty (County Government of Kitui, 2018; Kenya Red Cross, 2016). Additionally, the County is divided into eight agricultural zones that support subsistence crop and livestock agriculture, which is a significant economic activity. Guava trees thrive in the county's highlands, with a sub-humid climate (County Government of Kitui, 2018). Two sub-counties in each county with a high guava production rate were purposefully chosen, with two wards in each sub-county randomly chosen as study sites. Before beginning the fieldwork, permission was obtained from the respective County Agricultural offices and Ward heads to conduct the survey.

3.4 Study design

Cross-sectional baseline surveys were conducted to assess trends and constraints in guava production, utilization, marketing, and processing using smartphones with a preloaded questionnaire.

3.4.1 Study population

3.4.1.1 Determination of sample size

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

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

Where;

N - Sample size desired

P- Proportion of the farmers expected to have guavas in their farms (50%)

q - (1-p)- The expected proportion of farmers without guavas in their farms (50%)

d= Level of precision (0.048^{2})

Z- Normal standard variation at 95% confidence level (1.96).

Therefore;

N= (1.96^{*} 0.5*0.5) ÷ ($0.048^{2)}$ = 417 respondents

3.4.2 Sampling procedures

Simple random sampling techniques were employed to select guava farmer households for interviews by randomly selecting households within the study sites, as Umulisa (2012) described.

3.4.2.1 Inclusion and exclusion criteria

The respondents in this study were guava fruit farmers who had produced the crop for at least four years and had either exotic or indigenous guava trees on their farms, the presence of which was verified by enumerators before the start of the interviews. Each household's most responsible head, who was at least 18 years old, was permitted to participate after signing or thumbprinting the consent forms. Farmers were excluded if they were physically, mentally, or emotionally incapable of participating in the study or if their farms lacked guava trees.

3.4.3 Recruitment and training of enumerators

For ease of data collection, enumerators fluent in the local dialect were recruited. The enumerators were trained on the data collection tool and subjected to pilot pretests with randomly selected farmers to ensure the tool's validity. Before being hired, enumerators must have completed at least secondary school, with preference given to tertiary levels, and must have demonstrated proficiency with smartphone or tablet applications.

3.4.4 Data collection tools and methods

The enumerators distributed a semi-structured questionnaire loaded onto a digital open data kit (ODK) mobile application platform. In both counties, focus group discussions (n=15) and key informant interviews (n=4) involving approximately equal numbers of participants of both genders were engaged in discussions on the state of the guava value chains. The tool included information on the respondents' socio-demographics and guava production, postharvest handling, and utilization practices. The survey took 45–60 minutes on average. It involved verifying the presence of guava trees in the respondents' farms to obtain information related to guava production utilization and postharvest handling.

3.4.5 Data quality management

The questionnaire was pre-tested before data collection, with each enumerator conducting at least two interviews with randomly selected guava farmers in each county. To ensure consistency, the enumerators edited the completed questionnaires before uploading them to a password-protected data server (https://ona.io). The collected data was further cleaned by ensuring that no duplicate entries or missing data were included in the analysis, following the procedures established by Jaya *et al*. (2017).

3.5 Data Analysis

The data was downloaded from the server and analyzed with the Statistical Package for Social Science (SPSS) Version 25 software. Descriptive statistics were used to obtain frequencies, percentages, means, and standard deviations for the socio-demographic characteristics and other variables for guava production, handling, utilization, processing, and preservation. The strength of associations and differences among the variables under study were determined using Chi-squared tests (χ^2), Pearson's correlation coefficient (r), and T-test statistics, with the P-value, set at ≤ 0.05.

3.6 Results

3.6.1 Socio-demographics and economic characteristics of guava producing households

The majority of respondents were females (57.6%) compared to the males (42.4%), with an average age of 46.6±15.9 years. The majority (76.3%) of the respondents were married, while 15.1% were single, and the rest were either widowed (5.5%) or divorced (3.1%). The main household income generation activity was farming, as reported by 72.4% of the respondent, given that the respondents were sampled from rural areas where this is the main economic activity. Other households, however, depended on casual labor (11.8%), business (8.4%), and formal employment (5.3%) for household income. The average income for the households in Kitui and Taita Taveta counties were not significantly different ($t(415)=1.10$ $p=0.272$), which averaged $ 85.18 and $ 93.50, respectively. Most of the respondents in both counties had about 50% of their respective household income used on food. Regarding the educational levels of the respondents, only 6% reported having completed tertiary education compared to the majority (58.5%) who had completed primary school education, 26% had completed secondary level education, and the remaining (9%) were illiterate. Although 20% of the respondents did

not know how long guavas have been on their farms, the rest reported having had them for approximately 15.8±11.3 years.

3.6.2 Guava production

Most (62.1%) households had their guava plantations in naturally existing trees, while 14.9 % had planted their guava plantations though 0.5% had bought existing plantations. Others (21.6%) had both natural and had planted the crop, while the remaining (0.9%) had acquired guavas by either naturalized trees, planting their own, or buying existing guava trees. The commercial cultivation of guava was relatively low considering that most respondents' (72.4%) livelihood depended on farming. There were no significant (χ^2= 29.162, p=0.35) differences in the varieties growing in both counties. The main variety was the red/pink-fleshed guava, predominant in 50.8 % of the respondents' farms. The white-fleshed type was common in 2.4% of the households, while the strawberry guava was the least cultivated (0.2%). The other homesteads had both white and red/pink-fleshed varieties (46.6%).

Pests and disease attacks highly impacted guava production, according to 93% of respondents. However, because guavas grow naturally and have a low economic value, only 6.2% of respondents used pesticides. The respondents cited the fruits' meager economic value as a reason for their neglect, attributed to their limited processing and marketability in the country. Surprisingly, 72% of the farmers said they planned to keep farming guavas in the future. Some (45.2%) will allow family members to manage the farms, compared to 12.5% who will cut down the guava trees and use the land for other agricultural purposes.

3.6.3 Guava post-harvest handling, utilization, and storage

In the study area, the maturity indices were primarily used to harvest guavas for domestic consumption. The majority of respondents (95%) observed the change in the color of the fruit

from green to yellowish. Other maturity indices included slightly more than a third (39 %) of respondents harvesting fruits at full ripeness, while 29% did so after changes in fruit sizes. Two-thirds of those polled (66.6%) said they shield harvested fruits from direct sunlight. The precooling practice differed significantly ($\chi^2 = 25.015$, p=0.001), with Kitui county practicing it more than Taita-Taveta. The most common precooling method was holding the harvested fruit under shade or in cold places within the household.

The majority of respondents packaged the harvested fruits in sacks (29%), paper boxes (28.1%), plastic containers (16%), and wooden boxes (6%). Furthermore, manual transportation of the fruits was the most common method (71%) used. In comparison, mechanical means of transporting the fruits were used by only 20% of the respondents, and hand-drawn carts and bicycles were used by 10% and 8% of the respondents, respectively. Depending on maturity level, the time it took for harvested guavas to spoil differed significantly (t(415)=8.389, p=0.001) between the two counties, averaging 4.9±1.8 days in Taita Taveta and 3.4±1.9 days in Kitui. This is because Taita Taveta region is cooler than Kitui, which has slightly warmer temperatures (Kitui County Climate Information Services Strategic Plan, 2015; MoALF, 2016). There were also significant ($p<0.05$) differences in the guava shelf lives in both counties depending on the weather conditions, during the wet periods (t(415)=11.766, p=0.001), guavas in Kitui had a shelf life of 3.3±1.8 days, compared to 5.3±1.7 days in Taita Taveta County. During the drier seasons, the fruits had a shelf life of 3.7±1.6 days and 2.9±1.3 days in Kitui Counties and Taita Taveta, respectively (t(415)= -5.605, p=0.001). However, slightly more than half of the farmers (56%) said they did not store their harvested guavas, indicating that post-harvest storage practices are lacking.

Harvesting was primarily for household consumption because there were no known traditional preservation techniques for the fruits, according to most respondents (97%), with only 30%

selling the fruits. The consumption of guava has increased in 54 % of those polled. However, 37% said they had cut back on their consumption. A further 9% had inconsistent consumption patterns due to a lack of knowledge about the fruit's nutritional value, a link between the fruit and wild animals, primarily monkeys, pests, diseases, and other factors. The vast majority of respondents (83%) ate guavas with their peels, while only 17% did not.

3.6.4 Guava fruits processing and preservation

The majority of respondents (96.6%) had never heard of any guava value addition techniques, and there were no correlations between respondents' educational levels ($r=0.04$, $p=0.441$), gender ($r=0.03$, $p=0.562$), and knowledge of traditional guava processing. As a result, guavas were not processed in 97% of the households. The most popular guava products for those who process the fruits were jams and fresh juices (3%).

Given their lack of processing knowledge, 60% of respondents were unaware of any guava products on the market, regardless of their education levels ($r=0.009$, $p=0.86$) or gender ($r=0.031$, $p=0.53$). Taita Taveta, on the other hand, was more knowledgeable about processed guava products (52%) than Kitui (28%). As a result, postharvest losses from guavas were relatively high, as 76.7% of the respondents reported. These were caused, among other things, by over-ripeness (71%), microbial and fungal attacks (40%), and mechanical injuries (22.8%). Overripe fruits were either left to rot (81%) or used as animal feed (40%) or composted (17.3%). Farmers reduced these losses by harvesting in small quantities (45%), sorting fruits according to their ripening stages (57%), storing fruits in cool conditions (37.6%), and minimizing mechanical injuries during harvesting (15%).

3.6.5 Guava and guava-based products trade and marketing

Guava sales generated an average of $ 23 per season, ranging from $ 0.5 to $400. The sales did

not differ significantly (p>0.05) between the two counties, with only 30.5% of respondents (n=127) selling the fruits during their season. Retailers and consumers were the primary purchasers of guava (Table 3.1).

Table 3.1: Categories of guava fruit buyers in Taita Taveta and Kitui counties of Kenya

Guava buyers	County		% (n=127)
	Taita Taveta (n=68)	Kitui (n=59)	
Retailers	36	31	52.8
Consumers	23	37	47.2**
Wholesalers	8	15	18.1*
Brokers	20	1	16.5**
Processors	14	0	11.0**

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

Between the two counties, there were no significant (p>0.05) differences in guava purchases by retailers and exporters (Table 3.1). However, there were significant differences (p=0.001) between wholesalers, brokers, consumers, and processors. Although fruit sales accounted for up to 25% of household income for respondents who sold their fruits, the majority of respondents (33.5%) were unaware of the revenue generated by guava sales. The remainder provided varying estimates, highlighting the importance of farmers receiving proper record-keeping training. While most respondents (60%) agreed that marketing guava fruits and

processed guava products were challenging, only 15% reported encountering minor barriers to market access.

3.6.6 Constraints in the production, utilization, and processing of guavas

The most constraining factors in the production of guavas were pests and diseases, a lack of relevant extension and technical services, and limited knowledge of guava farming (Table 3.2). The main constraints to guava processing were inadequate knowledge of guava value addition and access to processing equipment. Consumers' low willingness to pay and poor guava consumption, on the other hand, were the major roadblocks to guava marketing (Table 3.2). However, there were significant differences in market access between Taita Taveta and Kitui counties (χ^2= 105.3, P0.001), as market access in Taita Taveta was more difficult. Furthermore, guavas are always sold in Kitui, primarily in the Mwingi market, unlike Taita Taveta, where no known guava market exists. As a result, the post-harvest losses of guavas in the two counties were significantly different (r=0.377, p=0.001).

Table 3.2: Constraints in the production, processing, and marketing of guava and guava-based products in Taita Taveta and Kitui Counties

Constrains	Causes	%(n=417)
Constrains in guava production	Pest and diseases	73.9
	Lack of knowledge on guava farming	56.8
	Lack of technical support and extension services	43.2
	Poor market returns from guavas	40.5
	Lack of good quality seeds/seedlings	31.4
	Lack of garden tools, equipment	17.0
	Theft of guava fruits	2.9
Constrains in the processing of guavas	Lack of knowledge on guava value addition	74.8
	Lack of processing equipment	65.9
	Lack of skilled human resources	35.5
	Lack of capital	35.3
Challenges in the marketing of fresh and processed guava	Low willingness of consumers to pay	79.1
	Poor guava consumption	59.5
	High rates of guava perishability	32.4
	Fluctuation in demand	22.1
	High transportation costs	10.8

3.7 Discussion

3.7.1 Socio-demographics and economic characteristics of guava producing households

The current findings reflect the nature of sub-Saharan Africa's farming activities, primarily carried out by women who are majorly tasked with small-scale farming and household food production (Tian *et al*., 2015). The average age of the respondents was 47, indicating a decline in youth (18-35) interest in agriculture (GOK, 2018), jeopardizing future household food security because their participation is critical in ensuring sustainable agricultural production (Njoroge *et al*., 2014; Yeboah and Jayne 2016). Agriculture and farming are seen as tedious and dirty among the Kenyan youth, resulting in low self-esteem and low earnings compared to other professions (Njeru *et al*., 2015). The revenue spent on household foods is typical of rural areas in Sub-Saharan Africa, according to Mabuza *et al*. (2016), because household income determines the household food security status. Because the study areas rely on rain-fed agriculture, food insecurity is possible during dry spells (WFP, 2016). Increased rural-urban migration and a significant shift of labor from farming to off-farm employment by the highly educated (Njoroge *et al*., 2014; Yeboah & Jayne 2016), or employment and ownership of private businesses, may have impacted agricultural production, as evidenced by participation in nonagricultural-related economic activities in this study (Njoroge *et al*., 2014; Yeboah and Jayne 2016)

3.7.2 Guava production

Guava is a largely uncultivated crop in the two counties. Like other neglected crops, farmers were indifferent to guava farming (Baldermann *et al*., 2016) due to low-income generation from local fruits and a lack of good agricultural practices. Although the fruits may be significantly healthier due to their organic cultivation and their high nutritional content, which remains underutilized (Baldermann *et al*., 2016), they received little attention, which is

consistent with Chiveu (2018), HCD (2014), and Omayio *et al*. (2019). There were few commercial guava plantations, consistent with reports from the Kenya Horticultural Crops Directorate (HCD, 2014) and Omayio *et al*. (2019), limiting the country's guava fruits production capacity. Additionally, guava fruit production records were incomplete at the county levels, indicating the lack of commitment by the relevant government authorities on documenting the guava production and utilization trends.Consequently, none of the counties had documented the fruit's production trends, which made determine the crop's annual productivity. Additionally, limited research on guava has continuously hampered the crop's production maximization. As a result, information on climatic, agronomic, and other best agricultural practices for increasing guava production is non-existent (Omayio *et al*., 2019).

The current study established the dominance of guava trees established through the growth from randomly dispersed seeds which is in agreement with a previous study by Chiveu's (2018) and Kidaha *et al*.'s (2015), who found that guavas in Kenya mostly grow naturally and have a wide range of genetic and morphological characteristics. The study sites were located in highlands with favorable climates and environmental conditions for guava production in both counties. The rainfall ranged between 500 - 1200mm annually with temperature ranges of 18.2-25^{o}C and 14-34^{o}C in Taita Taveta and Kitui counties, respectively (Kitui County Climate Information Services Strategic Plan, 2015; MoALF, 2016).

The guava trees may have also been invasive when uncontrolled in areas that grow (Orwa et al., 2009). The trees have been found to colonize open abandoned areas, forming thickets with more than 100 trees per hectare (Heuzé *et al*., 2015). Guavas were invasive in both regions, particularly in uncultivated lands, due to seed dispersal by animals, birds, and fallen fruits. The respondents agreed that they had been forced to clear their farms of seedlings and trees. Due to their ease of adaptation, their invasion has been shown to transform ecosystems and endanger

local biodiversity (Berens *et al*., 2008; Urqua *et al*., 2019). The Taita Taveta area was particularly affected, where large tracts of land remained idle due to the hilly terrain. Respondents agreed that unchecked guava fruit trees had become a menace (Berens *et al*., 2008; Urquía *et al*., 2019).

Although pests and diseases hampered the guava production in the study area, the application of pesticides and fumigants to prevent these were minimally practiced due to the farmers' indifference to the farming of the crop (HCD, 2014). Nonetheless, research findings support the increased production of underutilized food crops as a component of sustainable agriculture techniques in addressing adaptation, mitigation, and long-term intensification of food production systems (Mizrahi, 2014) that are dynamic as a result of the intensified climate change effects and thus the need for implementation of good agricultural practices in the crop's production.

3.7.3 Guava post-harvest handling, utilization, and storage

Guava fruit harvesting is frequently based on subjective fruit size, skin color, and firmness (Bakshi *et al*., 2015). Similarly, the farmers in this study based their harvesting practices on these. However, a minority ensured that no field heat was generated to help extend the guava's postharvest life by reducing metabolic rates and subsequent deterioration (Rawan *et al*., 2017; Silip & Hajar, 2007). During harvesting, precooling of guava fruits was a common practice, especially among some farmers in Kitui County who produced sold the fruits, necessitating a need for ensuring longer shelf life. As a result, Kitui farmers may have adopted far better preservation techniques than the Taita Taveta farmers. The latter enjoys a relatively cooler climate and may not be keen when the weather is much hotter (Kitui County Climate Information Services, 2015).

Guavas are delicate fruits that require gentle handling to ensure they reach consumers in good condition and acceptable quality (Bakshi *et al*., 2015). To accomplish this, proper storage and transportation conditions are critical. It is recommended that the equipment used is hygienic and protects the fruits from bruising and injury and that it be made of soft and smooth materials such as paper or cardboard (Bakshi *et al*., 2015). However, due to their relative ineffectiveness in protecting fruits, the packaging materials reported in this study are not recommended due to the risk of increased postharvest losses. These findings corroborate those of Idah *et al*. (2007), who demonstrated that sacks, paper boxes, plastic containers, wooden boxes, and oven baskets comparable to the current findings are widely used in developing countries in their studies in Nigeria.

Nonetheless, large-scale harvesting was generally lacking due to the absence of large-scale guava fruit production. Additionally, this demonstrates low fruit consumption, a lack of willingness to purchase the fruit, and a lack of processing facilities (Omayio *et al*., 2019). The absence of traditional preservation and processing techniques corroborates previous research indicating that the guava is economically underutilized in Kenya (Chiveu, 2018; Omayio *et al*., 2019; Wasilwa *et al*., 2018). Additionally, guavas were primarily consumed at the household level. None of the respondents produced commercial guava products, highlighting the importance of farmers receiving training in value addition to generate household income through product commercialization (Omayio *et al*., 2019). The limited processing and existing gaps in processed guava products may contribute to the expansion of the fruits' value chain. Other studies on neglected plants indicate that cooling and processing are necessary strategies for fully exploiting the nutritional benefits of these crops, increasing their marketability, and ensuring stable shelf products long after they are out of season (Baldermann *et al*., 2016; Chivenge *et al*., 2015). As a result, there is a need to promote local guava processing.

The findings regarding guava losses are attributed to the climacteric nature of guava fruits, which exhibit rapid deterioration when exposed to physiological, mechanical, and pathological factors (Rawan *et al*., 2017), which accounts for the high losses experienced by farmers in the current study. However, these can be overcome by harvesting at the optimal stage of maturity while minimizing fruit injuries, sorting damaged and rotting fruits to prevent microbial spread to the undamaged fruits, storing them under optimal conditions, and processing them into value-added products for stability (Kiaya, 2014). Apart from internal factors, the rate of the perishability of guava fruits is influenced by ambient temperatures, humidity, air velocity, and storage conditions (Kader, 2005). As a result, care should be exercised during harvesting and storage to minimize mechanical injuries to the fruits (Bakshi *et al*., 2015). The current findings indicate that guava farmers have poor post-harvest handling practices, consistent with Katumbi *et al*. (2021).

3.7.4 Guava and guava-based products trade and marketing

The key informants and focus group discussions revealed that the farmgate sales in Kitui and Taita Taveta counties occurred at relatively low prices of $ 0.08 and 0.1 per kilogram. The majority of purchases were made by middlemen and retailers who preferred to purchase products at lower prices, resulting in poor financial returns for farmers. Additionally, focus group discussions revealed that guavas have low marketability and low prices compared to other fruits. Due to low consumption, few buyers, and thus a low willingness to pay for the marketed fruits. The constraints raised are similar to those reported by Ibeawuchi *et al*. (2015) and Lambert (2001). They found that developing countries' agro-processing industries face a slew of challenges limiting agricultural value chains' exploitation. Among these, inadequate infrastructure, low marketing and pricing, limited credit access, and inadequate agricultural research funding have been critical factors.

3.7.5 Constraints in the production, utilization, and processing of guavas

Despite the tropical climate in most parts of Kenya, which would favor commercial guava production and processing, the fruits are considered a minor crop chain, limiting their production potential. The current findings are consistent with those of previous studies by Ham *et al*. (2007), Jamnadass *et al*. (2011), and Tschirley *et al*. (2010), which found that exotic and indigenous fruit cultivation in sub-Saharan Africa is still low compared to other parts of the world. Although production requires adequate investment in suitable cultivars and good management practices for high-quality fruits, according to Akinnifesi *et al*. (2006) and Jamnadass *et al*. (2011), little research ensures the development of these crops has been a bottleneck. Guavas are also a neglected crop with low-income potential, resulting in farmers' indifference, extension, and agronomic officers advising farmers to grow other fruit crops, often paying little attention to the crop (Pereira *et al*., 2016).

There was generally a lack of familiarity with traditional guava processing methods, indicating that the fruits were only minimally processed in both communities, which agrees with previous studies (HCD, 2014; Omayio *et al*., 2019). The most limiting factor in establishing processing facilities, often capital intensive, has been the technological challenges (Habwe & Walingo, 2008) and the fact that the fruits are grown in rural areas, which are frequently underdeveloped with few processing facilities and a lack of technical human capacity, in addition to high poverty levels, has resulted in the crop's continued lack of value addition (DESA-UN, 2013; Kabuya, 2015). Furthermore, the low purchasing power, unreliable market demands, and the presence of fruits in nearly all homesteads and uninhabited lands within the community may have contributed to the poor marketing of fresh fruits and processed products, which are frequently sold through supermarkets that are rarely found in rural areas. As a result, marketing channels must be established in urban and peri-urban areas, where a niche market for nutritious

fruits and novel guava products exists.

3.8 Conclusion and recommendation

Although guava production is increasing, the two counties suffer significant annual on-farm and post-harvest losses due to low consumption, limited processing and preservation, and limited marketability. Despite the crop's nutritional and economic potential, its trade is hampered by the lack of a structured value chain. To address this, there is a need for increased research on breeding locally available varieties to improve their processing qualities and for relevant authorities such as county and national agriculture ministries, fruit processors, and researchers to implement much-needed production, postharvest handling, and processing technologies. Farmers, manufacturers, and consumers must also be educated on the large-scale production, processing, and preservation of the local guavas and the consumption of guava-based products made Kenyan from varieties. This will result in the crop making significant nutritional and economic contributions to the rural households for improved livelihoods.

CHAPTER FOUR : PHYSICOCHEMICAL AND PROCESSING QUALITIES OF GUAVA VARIETIES IN KENYA

4.1 Abstract

Guavas are climacteric fruits that are high in nutrients and phytochemicals. White guava, red/pink-fleshed guava, and, to a lesser extent, strawberry varieties that grow in different agroecological zones are the most common Kenyan cultivars. Despite Kenya's favorable climate for exotic and indigenous guavas production, neglect has limited research on these fruits' physicochemical and processing qualities. The purpose of this study was to determine the physicochemical properties and processing qualities of the strawberry, red, and white-fleshed guavas. A completely randomized study design was used to profile the guava fruits' physicochemical composition and processing qualities comparatively. Approximately 500kg of the red and white-fleshed guava fruits and 150 kgs of strawberry guavas were procured in duplicates from randomly selected trees in farms within Taita Taveta and Kitui counties. These were pooled and subjected to triplicate batches for the analysis of physicochemical and processing qualities. The fruit sizes varied significantly ($p<0.0001$), with shapes ranging from oval to round to pear-shaped. The chemical composition of the fruits varied significantly ($p<0.03$), with a PCA biplot explaining approximately 58% of the variability due to intra (61%) and inter (39%) varietal differences according to the dissimilarity dendrogram plot. The strawberry guava's vitamin C levels were significantly ($p=0.0001$) lower than the red and white guavas', at 164.11±11.85, 1365.15±250.56, 1665.56±126.50 $mg100^{-1}g$, respectively. The white-fleshed guavas, on the other hand, were significantly ($p=0.001$) low in β-carotenes (0.04±0.06 $mg100^{-1}g$) in comparison to the red-fleshed and strawberry, which had levels (1.98±0.62 and 1.55±0.30$mg100^{-1}g$ respectively) that were not significantly ($p>0.05$) different. The strawberry guavas had significantly ($p<0.005$) higher mineral and total flavonoids contents, whereas the total phenolics (1649.14±329.70$mgGAE100^{-1}g$) and antioxidant

activities (1989.14±383.47µMTE100^{-1}g) were significantly (p=0.048) higher in the red-fleshed guava. While strawberry production would be a processing constraint, the red-fleshed guavas had significantly (p<0.05) higher beta-carotene, phytochemicals, and minerals than the white, and therefore best suited for processing.

4.2 Introduction

Guava fruits are nutritious fruits that grow in tropical and subtropical climates worldwide (Yousafi *et al*., 2021). Apart from several bioactive compounds and minerals such as calcium, iron, and phosphorus, the fruits are high in vitamin C, exceeding most common fruits such as oranges and lemons by up to four to eight times. The phytochemical composition contains a high concentration of beneficial compounds, including saponins, oleanolic acid, lyxopyranoside, arabopyranoside, guaijavarin, quercetin, phenolic compounds, and flavonoids which are prominent among these (Naseer *et al*., 2018). Besides the free radical scavenging activity, the guavas' antioxidants are equally high (Naseer *et al*., 2018).

In Kenya, the fruits naturally grow from wild cultivars distinguished by various white and red varieties of exotic and indigenous nature (Chiveu, 2018). Despite the fruits' high productivity across several Kenyan agro-ecological zones, few studies on the fruit's value chains have been conducted, with findings indicating high underutilization and negligence. (Omayio *et al*., 2020). Guavas have thus been some of Kenya's orphaned crops, despite their nutritional value and potential for income generation as horticultural produce (Omayio *et al*., 2019)

The guavas have climatic characteristics (Abreu *et al*., 2012) and undergo high metabolic activities, respiration, and low stability at ambient storage temperatures. They also suffer post-harvest losses, which often accelerate the rates of these physiological processes (Yousafi *et al*., 2021). The fruits reach their peak climacteric perishability three to five days after harvest,

depending on the variety, postharvest handling practices, and storage conditions (Katumbi, 2020). However, in domestic and export markets, fruit commercialization is frequently hampered by poor postharvest stability, necessitating processing into shelf-stable products.

The guava fruit is suitable for raw consumption and processing of various commercial products (Kumar, 2016). However, a lack of commercial production and breeding programs, poor post-harvest handling, and insufficient good agricultural practices have contributed to guava farming's lack of strengthened value chains (Chiveu, 2018). Industrially, the locally produced guavas processing has been a significant constraint leading to escalation of the annual losses among more than 75% of the households producing guava (Omayio *et al*., 2020). Due to limited research, there is a scarcity of information on Kenyan guavas' nutritional and processing properties. The current study evaluated the physicochemical characteristics and processing qualities of guava varieties commonly grown in Kenya's fruit-growing regions.

4.3 Materials and methods

4.3.1 Study design

A completely randomized study design was adopted in conducting a comparative analysis of the guava fruits' physicochemical and processing qualities. The guava varieties, strawberry, white and red-fleshed guavas, were randomly procured from farms in Taita Taveta and Kitui counties between March and July 2019.

4.3.2 Procurement and transportation of guava fruit varieties

Approximately 500 kg of mature firm-ripe red and white-fleshed guava fruits were obtained by picking 10 – 15 fruits from randomly selected trees within the study areas in duplicates in the mornings hours of 6- 10 am. A previous study by Katumbi (2021) found no significant differences between the ripe white- and red-fleshed guava fruits sourced from the two

respective counties, so the fruits were pooled into either red or white-fleshed batches. However, a duplicate of only 150 kg of the strawberry variety was found in Taita Taveta county. The fruits were transported to the Department of Food Science and Technology at the University of Nairobi. They were stored in modified atmosphere packaging using hermetically sealed gunny sacks lined with polythene paper and stored in a cold room at 8±2^{o}C until further analysis.

4.3.3 Sample preparation

The guava fruits were sorted to remove overripe, spoilt fruits, and those infested with fruit flies (approximately 10%) before being randomly subdivided into roughly equal triplicate batches of 50 kgs for each respective variety. These were then washed in clean running tap water and stored in perforated crates based on subjective judgment for size, shape, diameter, and length as described by García-Rivera *et al.* (2016) and Diniz *et al.* (2014), until further analysis, where samples were drawn randomly in duplicates

4.3.4 Analytical methods

4.3.4.1 Physical characterization of guava fruits

The fruit weights were determined using the AR3130 KERN® PCB 3500 precision weighing balance (Balingen, Germany) by determining the average weight of 8-10 fruits of varying sizes. The fruit diameter and length were determined using a Mitutoyo digital vernier caliper (Japan). Both flesh and skin color were recorded using the PCE colorimeter as per the manufacturer's manual (PCE Instruments, London, UK). All readings were taken in duplicate.

4.3.4.2 Guava fruit pulp extraction

Approximately 50 kg of each batch were mechanically pressed into purees using a commercial locally fabricated fruit crusher and pulper fitted with a 0.5 mm stainless screen (D. K

Engineering, Kenya). Random samples from the pulper were collected in quadruplicates of 2 kg of each variety and immediately frozen at -20°C for further analysis. The purees were then used to determine the proximate, chemical, and bioactive composition for each variety.

4.3.4.3 Guava fruit proximate composition

The moisture content was determined in duplicates using AOAC (2005) method 930.15 and forced-air oven driers (Memmert 40500-IP20-Schutzart, Germany). Five grams of samples were weighed using the AR3130 KERN® PCB 3500 precision weighing balance (Balingen, Germany) and dried for approximately three hours at 105^{o}C on aluminum dishes. The moisture content was calculated as a percentage of weight loss relative to the initial sample weight. The ash content was determined by weighing approximately 3 g of sample into silica crucibles and charring on hot plates for two hours, followed by 24 hours of ashing in a muffle furnace set to 550 5°C. The lipid content was determined using solvent extraction. Approximately 5 g of sample was weighed into thimbles and placed in a soxhlet extraction apparatus with petroleum ether as the solvent, as specified in AOAC (2005) method 960.39. The crude protein concentration was determined using the Kjeldahl method and a protein conversion factor of 6.25, as specified in method 990.03 AOAC (2006). Carbohydrates were determined using the difference method, where CHO = 100 - (Protein% + Moisture% + Fibre + Fat% + Ash%) (Kr Chauhan, 2014). The total energy Kj/100g was calculated using the Atwater factors for protein, carbohydrate, and fat of 4, 4, and 9, respectively, as Turcket al. (2016) described. Each parameter was determined in duplicate. All the other parameters, except for moisture, were calculated on a dry weighty (d.b) basis.

4.3.4.4 Determination of total soluble solids (TSS)

A handheld refractometer was used to determine the TSS (SK106R.- SATO, Japan). To extract the fruit pulp, randomly selected fruits were pulped using a commercial blender and a sieve to

separate the seeds. A drop of the extract was placed on the refractometer screen, and the reading was directly recorded in degree Brix. Readings were taken in duplicate.

4.3.4.5 Determination of pH and total titratable acidity (TTA)

The pH values of fruit were determined using a digital Five Easy pH meter, model F20 (Mettler, Toledo, USA), calibrated with 4.1, 7.0, and 9.1 pH water. The fruits' total titratable acidity (TTA) was determined using the AOAC method 942.15 (AOAC, 2000) in duplicates. Ten grams of fruit pulp were diluted in 25ml of distilled water and titrated against 0.1 N sodium hydroxide using phenolphthalein indicator. The results were expressed in mg of citric acid per 100 grams of sample. Duplicate readings were recorded

4.3.4.6 Determination of vitamin C content

The vitamin C content in fresh guavas was determined in duplicates using procedures described by Puwastien *et al*. (2011) for reducing 2,6-standardized dichlorophenolindophenol (DCPIP) solution to a colorless dye. Standardization of the DCPIP solution was accomplished through triplicate titrations with a standardized ascorbic acid solution. To remove any remaining solids from the freshly extracted pulp, it was filtered through a cheesecloth. Approximately 40-g of the filtered samples was weighed in a 100 mL volumetric flask and filled to volume with a metaphosphoric acid solution. Two (2mls) of these aliquots were then titrated in triplicates against indophenol solution. The vitamin C content was recorded as mg/100 g of sample dry weight basis.

4.3.4.7 Determination of beta carotene

The beta-carotene concentrations were determined using modified spectrophotometric techniques as described by Mustapha & Babura (2010). A standard curve was constructed using beta-carotene standards with concentrations of 0, 0.4, 0.8,1.2, 1.6, 2.0, and 2.4 µg/ml using a

Hitachi 2900 UV/VIS spectrophotometer (Tokyo, Japan) set to 450nm. Two (2) grams of the sample were placed in a motor and pestle and extracted with acetone in small amounts until a colorless residual was obtained. Following this, approximately 25ml of the extract was transferred to a round-bottomed flask, and the acetone was evaporated at 60^{o}C using a rotary evaporator. The evaporated sample was dissolved in 1 ml petroleum ether, eluted with pet ether utilizing a silica gel column, and collected 25ml volumetric flask. After reading the absorbance at 450 nanometers, the beta-carotene concentrations were determined using a standard curve created with a Hitachi 2900 UV/VIS spectrophotometer (Tokyo, Japan) against pet-ether as a blank. The extraction was performed twice, and the results were expressed as mg per 100g of dry weight sample.

4.3.4.8 Determination of phytochemicals

4.3.4.8.1 Determination of total phenolics

The total phenolics were determined according to the Folin-Ciocalteu method, as Otieno et al. (2016) reported. Approximately 0.5 g dried guavas were combined with 10 ml 80% (v/v) methanol in a falcon tube, followed by vortexing for 15 minutes at 3,000 g centrifugation. After that, the flask was filled to the ten-millilitre mark with 80% methanol. An aliquot (0.5 ml) of each extract was diluted with 2.5 ml of 10% (v/v) Folin reagent and 2.0 ml of 7.5% (w/v) sodium carbonate. After that, the mixture was incubated for 30 minutes at 40^{o}C. Total phenolic compounds in each extract were determined using a UV-VIS spectrophotometer at a wavelength of 765 nm using Hitachi 2900, UV/VIS spectrophotometer (Tokyo, Japan). A standard calibration curve prepared by obtaining readings for concentrations ranging from 0.25 - 2.0 µg/ml was used to measure the samples' phenolics concentration. The total phenolic compounds content of guavas was expressed as mg per gallic acid equivalent (mg.GAE.g-1) per 100 g dry weight

4.3.4.8.2 Determination of antioxidant activity

The antioxidant activity of the guava samples was determined using the 2, 2 diphenyl-1-picrylhydrazyl (DPPH) assay as described by Abon'g *et al*. (2020), with minor modifications. The antioxidant activity was determined from a standard curve (R^2= 0.988) using Trolox standard stock solution (0, 5, 10, 25, and 50 µg/ml) and 1 ml of the methanolic 80 %(v/v) extraction solution. For the sample assay, 0.25g of the sample was mixed with 10ml of 80% (v/v) methanol solution and placed in a continuous shaker (Heto JB SH02, Birkerod Denmark) for overnight extraction at 50 revolutions per minute. One (1) ml of the extract was transferred to boiling tubes, and 1 ml of 0.002% DPPH was added and homogeneously mixed. These were then placed in cuvettes, and spectrophotometric readings at 515 nm were taken using Hitachi 2900, UV/VIS spectrophotometer (Tokyo, Japan). Results were read in duplicates and expressed as µM Trolox Equivalents (TE) per 100 g dry weight.

4.3.4.8.3 Determination of the flavonoid contents

The total flavonoids were quantified using the aluminum chloride colorimetric method described by Otieno *et al*. (2016), with catechin used as the standard. Catechin was dissolved in methanol to make a stock solution (100µg/ml concentration), from which aliquots of 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ml were filled in 10ml volumetric flasks containing 4 ml distilled water for the standard curve (R^2 of 0.995). To this, 0.3mL of Sodium Nitrite (5%w/v) was added. After 5 minutes, 0.3ml Aluminum chloride (10% w/v) was added, followed with 2ml of 1M sodium hydroxide after another 6 minutes. The total volume was then made up to 10ml with distilled water. Absorbance was then read at 510nm using Hitachi 2900, UV/VIS spectrophotometer (Tokyo, Japan) against a blank reagent (distilled water). For the samples, 10mg of each extract were dissolved in 10ml of methanol to yield a solution with a concentration of 1mg/ml. An aliquot (1ml) of each extract was added to 10ml volumetric flasks

containing 4ml distilled water. The same reagents similar to the standards were added in the same manner, resulting in 10ml. The tests were repeated twice, and the flavonoids concentrations in the samples were calculated using extrapolation from the standard calibration curve and expressed as milligrams of catechin equivalents per gram of dry weight (mgCE. g^{-1})

4.3.4.9 Determination of mineral contents

The AOAC (2005) method 2005.08 was used to determine the mineral analysis for zinc, iron, calcium, and phosphorous using Atomic Absorption spectrometry on the Buck Scientific Model 210 VGP (Fort Point, USA). Oven driers were used to dry about 5 grams of samples in triplicates until a constant weight was achieved. The dried samples were then milled using Polymix® PX-MFC 90D (Kinematica, AG, Switzerland), with the ash digested in 36% HCl after heating in a furnace at 600 °C. Before the spectrophotometric reading, these were filtered. The results were expressed in milligrams per 100 grams of dry weight.

4.4 Data analysis

Xlstat (Addinsoft, 2021) Microsoft excel plugin was used to analyze the data for the physical properties, proximate composition, beta-carotene, vitamin C contents, mineral contents, phytochemicals, TSS, TTA, and pH. Tukey's HSD test was used to separate significantly different means ($p<0.05$) in a one-way analysis of variance (ANOVA). The Agglomerative, Hierarchical Clustering (AHC), and parallel coordinates analyses were used to classify the fruits based on their chemical composition differences. A principal component analysis (PCA) analysis based on the various nutritional compositions of the fruit varieties was run to show the relationships between the variables under study.

4.5 Results

4.5.1 Physical characteristics of guava fruits

The strawberry, white-fleshed, and red-fleshed guava fruits had distinct physical characteristics. In contrast to the reddish-purple strawberries, the red and white ripe fruits had a distinctive yellow or green-yellow skin color (Figure 4.1). The oval, round, and pear-shaped appearance of the white and red varieties were typical, whereas the strawberry was distinguished by relatively small-rounded berries (Figure 4.1).

A **B**

Figure 4.1: Guava fruit shapes.

A cross-sectional view of the ripe pear-shaped, round, and ovoid red-fleshed guavas. B-Ovoid, round and pear-shaped whole white-fleshed guavas.

Furthermore, the weight, length, and color of the flesh differed significantly ($p<0.05$) across the fruits (Table 4.1). The red-fleshed weight and length averaged more than 5cm than the whites, whose average lengths were slightly higher than 4.8 cm (Table 4.1). On the other hand, the strawberry guavas were the least, with an average of only 2.8 cm.

Table 4.1: Physical characteristics of the common Kenyan guava varieties

Fruit parameters	Fruit varieties		
	Red/Pink fleshed	**White fleshed**	**Strawberry**
Fruit shapes	Ovoid Pear-shaped Round	Ovoid Pear-shaped Round	Round
Ripe fruit peel color	Yellow Green – Yellow	Yellow Green-Yellow	Red-Purple
Ripe flesh color	Red/pink	White	Creamy- white
Fruit weights (g)	148.92±109.52 [b]	126.64±85.08 [b]	5.68±1.96 [a]
Fruit diameter (cm)	5.00±0.90 [b]	4.83±1.07 [b]	2.10±0.26 [a]
Fruit length (cm)	5.20±0.70 [b]	4.87±1.08 [b]	2.13±0.35 [b]
Seed weight (per 100g)	2.4±0.8[a]	3.9±1.0[ab]	4.9±0.6[c]
Pulp weight (per 100g)	71.3±0.9[c]	65.7±2.1[b]	58.6±2.5[a]
Pulp: seed ratio (g/g)	31.2±8.8[b]	17.8±4.6[ab]	12.1±2.5[a]

Values (means± standard deviation) with different superscripts across the row are statistically different (Tukey's test, $P<0.05$).

The pulp yielded per 100 grams of fresh fruits varied significantly ($p=0.019$) among the three, with the red-fleshed guava yielding the most (Table 4.1). The red guava variety had a high fruit pulp to seed ratio of up to 31, followed by the white at 18, and the strawberry, whose levels were only 12. Despite its relatively small size, the strawberry guava had a significantly ($p=0.034$) high seed weight per 100 gram of fruits, averaging 5g compared to the white guava's 4g and the red guava's 2g making it difficult to process the variety.

4.5.2 Guava fruit flesh and peel color

The guava fruits peel and flesh colors were distinctively differentiated among the three varieties (Figure 4.2). Except for the flesh color, there were no visual differences in the ripe white and

red-fleshed guavas, whose skin color ranged from light green to deep yellow. On the other hand, the ripe strawberry guavas had green-red-purplish skin color creamy flesh color (Figure 4.2). All the fruit varieties had a characteristically high number of seeds within the pericarp, as shown in the cross-sectional image (Figure 4.2).

A **B** **C**

Figure 4.2: Color images of whole and cross-sectional fruits' skin and flesh.

A - red-fleshed, B - white-fleshed, and C -for strawberry guavas. Proximate composition of guava fruits.

The color of the fruit pulp showed significant (p=0.001) variations in all the color parameters on a hunter's CIE scale with significantly high variations in the * (79) as well as the b* (60) indices leading to distinct differentiations among the fruit varieties (Table 4.2). The white-fleshed fruit had the highest lightness averaging 78, yellowness (31), chroma (32), and hue angle of the three fruit varieties (Table 4.1). On the other hand, the redness index showed the most significant (p=0.0001) variation and was highest in the red-fleshed guava at 23. The strawberry guavas had the least readings in all the respective color parameters Table (4.2).

Table 4.2: Guava fruit flesh color for the red, white, and strawberry guava varieties

Guava Varieties	Color parameters				
	L	a*	b*	Chroma*	Hue angle*
Red guava	50.52± 2.43 [a]	22.63±3.93 [c]	17.12±2.66[b]	28.45±4.06 [b]	37.51±3.92 [b]
White	77.87±8.19 [b]	2.46±1.44 [a]	31.21±7.62[c]	31.69±7.27 [b]	86.02±1.83 [c]
Strawberry	44.97±2.81 [a]	9.97±2.29 [b]	4.75±1.19 [a]	11.29±1.82 [a]	24.45±5.66 [a]
Overall Mean (Range)	59.39 (40.64-91.40)	11.90 (0.84-31.53)	19.31 (3.32-41.83)	25.38 (8.04-42.16)	52.44 (18.80-88.18)
Coefficient of variation (%	26.3	78.58	60.1	38.54	51.84
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Color values are expressed as mean ± standard deviation. Values with different superscripts along a column are statistically different (Tukey's test, P<0.05).

4.5.3 Fruit chemical composition

4.5.3.1 Proximate composition

The guava fruits had significantly ($p<0.0001$) different dry matter contents, whereby the strawberry varieties had slightly higher levels of more than a fifth of the fruit (20.30 -23.40g 100^{-1} g) as compared to the white and red varieties (Table 4.3). The white and red varieties whose dry matter ranged from 11.03-18.09 and 15.83-18.78 g 100^{-1} g were not significantly different ($p>0.05$). Consequently, the moisture content of the strawberry guava (76.60-79.70 $g100^{-1}$ g) was significantly ($p<0.001$) lower than that of the other two (81.22 - 88.97$g100^{-1}$ g), whose levels did not differ significantly ($p>0.05$). The levels of ash, crude protein, crude fat,

and energy in the guava varieties were not significantly ($p>0.05$) different (Table 4.3). On the other hand, the protein and ash levels varied the most at 85% and 50%, respectively, ranging from 0.09 to 1.22 mg 100^{-1} g, and 0.35 to 1.94 g 100^{-1}g, respectively. The strawberry guavas had the highest crude protein and ash levels, at 0.37-1.94 and 0.09-1.22 g100^{-1}g compared to the red (0.35-0.61 and 0.09-0.91g 100^{-1}g) and white guavas, which had 0.37-0.61 and 0.09-0.94 g 100^{-1}g, respectively. The crude fibre was significantly ($p=0.046$) higher in the strawberry guavas, averaging 37 g 100^{-1}g, and lowest in red guavas, averaging 33 g 100^{-1}g. The carbohydrates contents, which ranged from 54 to 67 g100^{-1}g, were significantly ($p=0.039$) higher in the red-fleshed guava fruits (Table 4.3)

Table 4.3: Proximate composition of the red, white, and strawberry guava varieties

Guava fruit varieties	Moisture (%)	Dry matter (%)	Parameters (per 100 g dry weight basis)					
			Ash (g)	Crude Protein (g)	Fat (g)	Crude Fibre(g)	Carbohydrates (g)	Energy (Kcal)
Red	84.08±2.32^{b}	15.92±2.32^{a}	0.53±0.12 ^{a}	0.36±0.40 ^{a}	0.47±0.08 ^{a}	32.78±0.72 ^{a}	65.86±0.97^{b}	269.12±2.59^{a}
White	82.77±1.05^{b}	17.23±1.05 ^{a}	0.52±0.11 ^{a}	0.50±0.43 ^{a}	0.46±0.07 ^{a}	33.63±1.79^{ab}	64.89±2.04^{ab}	265.71±7.35^{a}
Strawberry	78.58±1.13 ^{a}	21.42±1.13^{b}	0.70±0.54 ^{a}	0.78±0.44 ^{a}	0.48±0.03 ^{a}	35.69±4.38^{b}	62.35±5.14 ^{a}	256.86±19.30 ^{a}
Mean (Range)	82.21 (76.60-88.97)	17.79 (11.03-23.40)	0.57 (0.35-1.94)	0.52 (0.09 - 1.22)	0.47 (0.22-0.54)	33.83 (32.30-42.77)	64.62 (53.53-66.50)	264.78 (223.86-270.86)
Coefficient of variation (%)	3.32	15.36	50.31	85.06	13.56	7.82	4.83	4.3
P value	<0.0001	<0.0001	0.346	0.110	0.792	0.046	0.039	0.053

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test)

4.5.3.2 Guava fruit chemical, mineral, and phytochemicals compositions

The results of agglomerative hierarchical clustering based on fruit chemical compositions revealed significant intra-class variations (60.7%) compared to inter-class differences with much narrower variances (39.3%), indicating significantly different fruit characteristics ($p<0.05$). The dissimilarity dendrogram plot (Figure 4.3) revealed two broad classifications with three homogeneous groups based on the three fruit varieties under consideration.

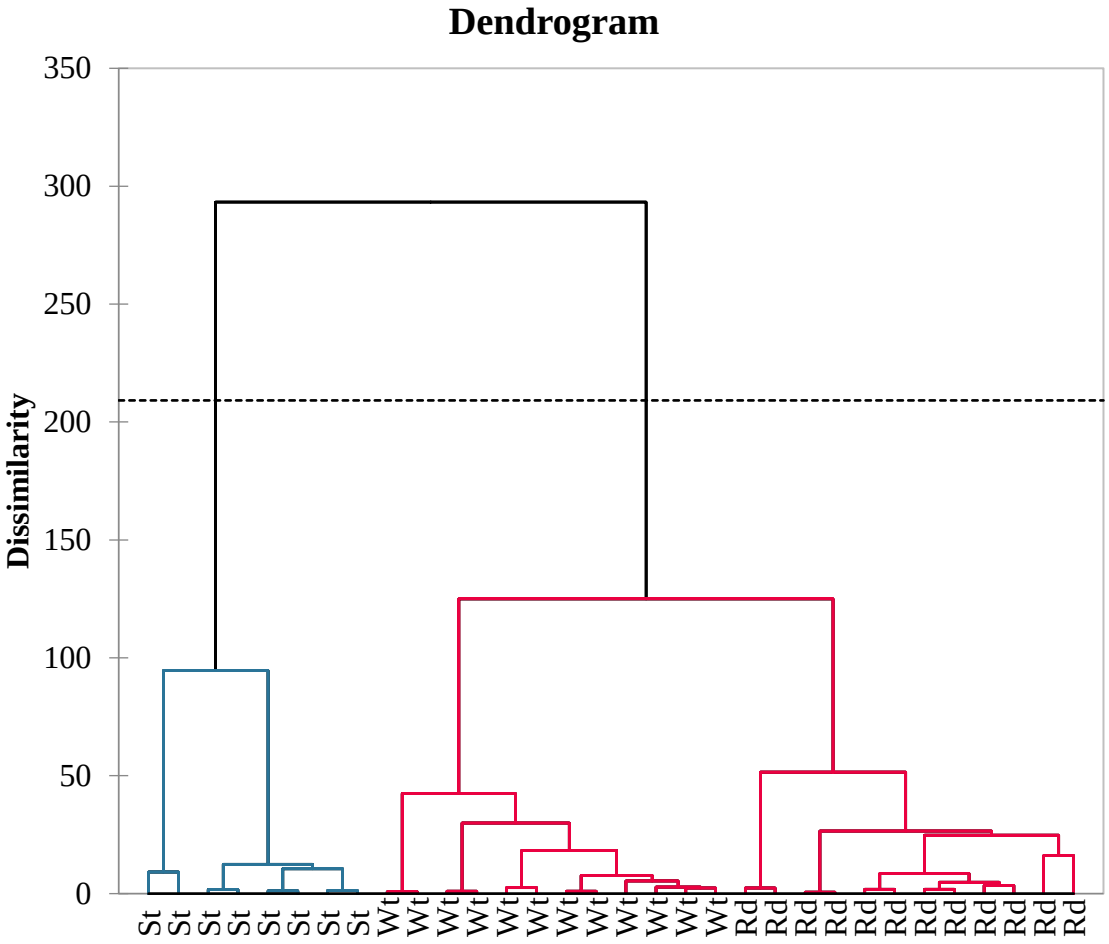


Figure 4.3: Dendrogram dissimilarity plot classification for the strawberry (St), White (Wt), and Red (Rd) guava varieties

The TSS, pH, TA, minerals (zinc, iron, calcium, and potassium), and flavonoid content were all high in group 1, which was made up of the strawberry guavas. On the other hand, the vitamin C, beta-carotene, phenolics, antioxidants, TSS/TTA ratio, and color attributes for lightness (L*), redness (a*), and yellowness (b*), chroma, and hue angles were significantly higher in group 2 (Red and white) fruits (Table 4.4).

Table 4.4.: Class centroid for the AHC fruit composition classification

Fruit parameter	Class centroid	
	1	**2**
Dry matter	16.577	21.419
Moisture	83.423	78.581
Ash	0.523	0.695
Crude Protein	0.431	0.779
Fat	0.465	0.481
Crude Fibre	33.205	35.691
Carbohydrates	65.376	62.354
Energy	267.413	256.861
Tss	10.679	12.950
Ph	3.875	2.913
Titratable acidity	0.677	1.426
TSS/TTA Ratio	16.376	9.128
Vitamin C	1515.354	164.113
β-carotenes	1.008	1.548
Zinc	4.463	6.832
Iron	12.852	32.571
Calcium	11.383	18.840
Potassium	233.096	413.560
Flavonoids	194.332	250.658
Phenolics	1517.844	1410.274
Antioxidant activity	844.148	736.404
L*	64.195	44.973
a*	12.542	9.973
b*	24.166	4.754
Chroma*	30.070	11.290
Hue angle*	61.768	24.445

The correlation between physicochemical properties of guavas in relation to varieties using a PCA analysis biplot shows that the first two components explained up to 57.72% of the variability, according to the principal component analysis (Figure 4.4). Most of the color

parameters, including L*, b*, C*, hue angles, vitamin C, and pH, were attributed to the white in group two. The red guavas had higher phenolics, redness intensity (a*), antioxidants, carbohydrates, energy, and maturity ratio (TSS/TTA) than the white in group 2. Generally, the energy and carbohydrates and the L* and hue angles all had strong positive correlations. The redness of the fruits was inversely related to the yellowness and lightness indices. The vitamin C levels were positively correlated with the fruit's pH and weak positive association with the moisture and maturity ratio but inversely related to the beta carotenes, TSS, beta carotenes, and minerals (Figure 4.4).

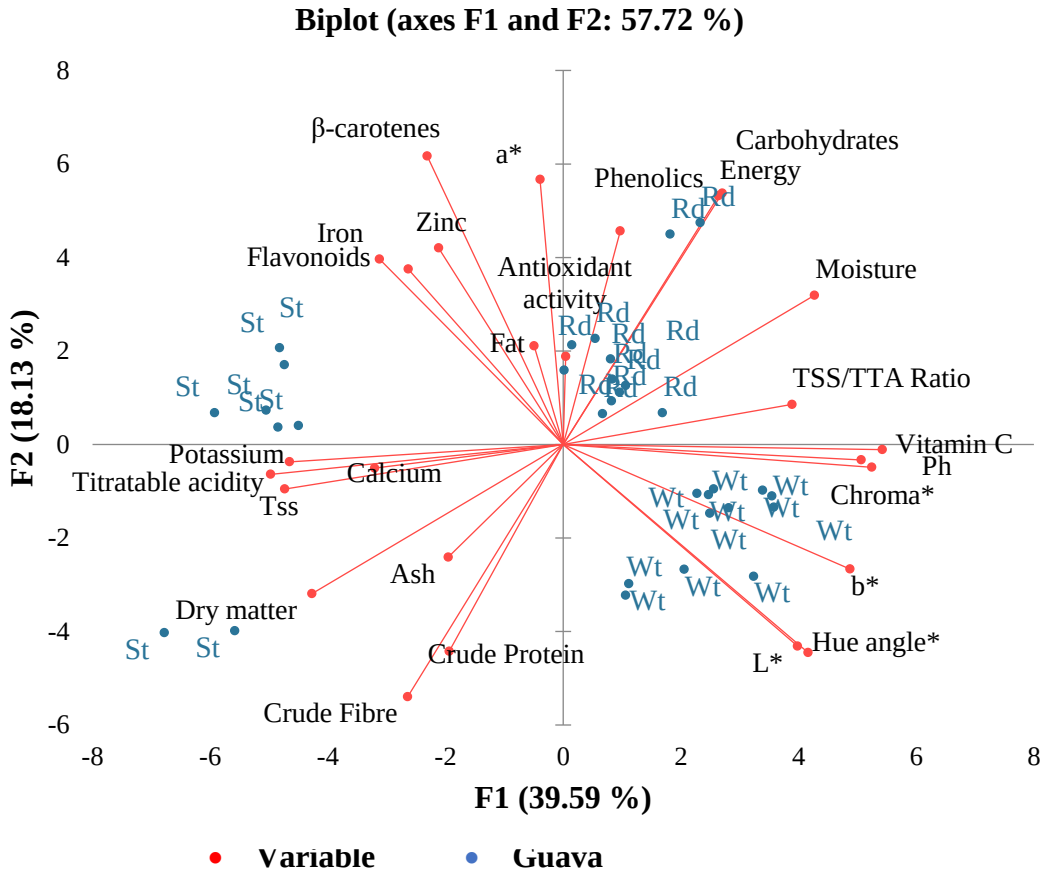


Figure 4.4: The PCA biplot for guava nutrient compositions.

St- strawberry, Wt- White and Rd- Red guava

There were negative correlations between the moisture content and crude protein, fibre, ash and dry matter, calcium, potassium, total soluble solids, and titratable acidity. On the other hand, the zinc, iron, flavonoids, fat, beta carotenes exhibited an orthogonal relationship (Figure 4.4). The beta carotenes, antioxidant activities, and the redness index, however, had positive correlations

The total soluble solids (TSS), pH, and titratable acidity (TTA) of the fruits were all significantly ($p<0.05$) different (Table 4.5). The strawberry guavas had the lowest pH (2.91), which correlated with a much higher TTA (1.4) than the other varieties, with pH values of 3.78-4.10 and 3.60-4.02 for white and red guavas, respectively. They were, however, not statistically significant ($p>0.05$). The strawberry guavas had significantly ($p<0.0001$) lower vitamin C levels, ranging from 149.75-181.65 mg 100^{-1} g, than the highest variety, white guavas, which were approximately ten times less (1371.13-1780.52 mg 100^{-1}g). On the other hand, the latter had the most negligible amounts of beta-carotene (0.00- 0.13mg 100^{-1} g). The red-fleshed (1.32-2.88 mg 100^{-1} g) and strawberry guavas (1.10-1.98mg100^{-1} g), on the other hand, did not differ significantly ($p<0.05$).

The zinc (1.40-9.75 mg 100^{-1} g), iron (3.34-12.18 mg 100^{-1} g), potassium (171.43-413.87 mg 100^{-1} g), and calcium (4.35-12.84 mg 100^{-1} g) levels in white guavas were the lowest, while the strawberry variety had the highest levels, ranging from 6.83 - 1.41, 17.42-46.53, 366.01-467.74, and 13.45-28.01 mg 100^{-1} g respectively. On the other hand, the red guavas had values ranging from 3.30-8.56 mg 100^{-1} g, 4.56-43.94, 168.36-288.45 mg 100^{-1} g, and 2.29-24.58 mg 100^{-1} g. The white-fleshed guavas had the lowest phenolic and antioxidant activities ($p<0.05$). However, the red-fleshed guavas had the highest antioxidant capacity and total phenolics (Table 4.5).

Table 4.5: Chemical, mineral, and phytochemical characterization of red, white and strawberry guava fruits

Parameter	Guava varieties			Mean (Range)	Coefficient of variation (%)	P-value
	Red guava	White	Strawberry			
Total soluble solids (ºBrix f.w.)	10.65±0.62 [a]	10.71±0.91 [a]	12.95±0.17[b]	11.25 (9.30-13.20)	10.64	<0.0001
pH (f.w)	3.82±0.11[b]	3.93±0.10[b]	2.91±0.22 [a]	3.63(2.72-4.10)	12.31	<0.0001
Titratable acidity (%)	0.65±0.13 [a]	0.70±0.15 [a]	1.43±0.12[b]	0.86 (0.53-1.58)	41.07	<0.0001
Vitamin C (mg/100g d.w)	1365.15±250.56[b]	1665.56±126.50[c]	164.11±11.85 [a]	1177.54 (149.75-1948.56)	53.63	<0.0001
Beta carotenes (mg/100g d.w)	1.98±0.62[b]	0.04±0.06 [a]	1.55±0.30[b]	1.14 (0.00-2.88)	84.95	<0.0001
Zinc (mg/100g d.w)	5.35±1.69[ab]	3.76±2.91 [a]	6.83±1.41[b]	5.06 (1.40-9.75)	49.11	0.009
Iron (mg/100g d.w)	17.30±16.28[b]	8.41±3.26 [a]	32.57±14.24[b]	17.78 (3.34-46.53)	3.34	0.001
Potassium (mg/100g d.w)	234.96±37.32 [a]	231.23±85.80 [a]	413.56±41.27 [b]	278.21 (168.36-467.74)	35.58	<0.0001
Calcium (mg/100g d.w)	13.96±8.69[ab]	8.80±2.58 [a]	18.84±5.81[b]	13.25 (2.29-28.01)	54.81	0.005
Total flavonoids (mg CE/100g d.w)	200.41±39.52[a]	188.25±30.33 [a]	250.66±66.04 [b]	208.41 (128.69-333.33)	24.03	0.014
Total phenolic (mg GAE**/100g d.w** d**.w)**	1649.14±329.70 [b]	1386.54±243.07 [a]	1410.27±134.24 [ab]	1490.95 (1036.23-2460.94)	18.87	0.042
Antioxidant activity (µMTE/100g d.w)	989.14± 383.47 [b]	699.15±207.46 [a]	736.40±230.28 [ab]	817.21 (376.07-1970.76)	38.30	0.048

Values (means± standard deviation) with different superscripts across the row are statistically different (Tukey's test, P<0.05).

4.6 Discussion

4.6.1 Physical characterization of guava fruits

The current findings show variations in the physicochemical and processing qualities of inter and intra fruit varieties, indicating the diverse morphological and genetic characteristics of indigenous and exotic Kenyan guava varieties, which varies significantly across the country in various agro-ecological zones (Chiveu, 2018). According to Chiveu (2018), the Kenyan guava fruit morphological and genetic diversity frequently results in variation between the two most common broad white and red-fleshed guava varieties, which is also the case across the world (Ali *et al*., 2014; Flores *et al*., 2015). While the length and diameter of the fruits in this study were consistent with previous research (Kumari, 2016), the sizes were significantly smaller than the 4.3–56.5–42.6, 57.1–44.8, and 65.6–50.4 cm reported in other studies (Kumari, 2016). Furthermore, the fruit diameters were significantly smaller than those reported in other studies, reporting diameters of 4.1-8.6, 3.5-8.4, and 5.8-7.2 cm for various bred guava cultivars by Kumari *et al*. (2020), Pandey *et al*. (2007) and Patel *et al*. (2007). The physical guava fruit variation may be attributed to the interactions between the varieties' phenotypic, genotypic and environmental factors (Ali *et al*., 2014). The findings on the variations in the fruit size, shape, length diameter, flesh, and skin color agree with Yusof's (2003) findings, which show that the physical characteristics result from varietal and environmental factors and prevailing weather conditions. The fruit’s small sizes in this study may also be due to the lack of genetic improvement in indigenous cultivars due to the crop's limited research program (Omayio *et al*., 2020).

While there were no differences in the skin color for the ripe red and white fruits, the flesh colors were distinct, which was consistent with previous research on the genetic and morphological characteristics of the Kenyan guava varieties, as reported by Chiveu (2018). On

the other hand, the strawberry guavas had distinct skin colors that could be attributed to genotypic and morphological differences with the other two varieties. The fat content positively correlated with the carotenoids, particularly the beta carotenes, and the redness intensity of the fruits, both of which are based on the accumulation of fat-soluble pigments (Tian *et al.*, 2015). However, because they are insoluble in water, they had an orthogonal relationship indicating independent occurrence. The lack of colored pigmentation in the white-fleshed guavas which were practically non-existent, resulted in negligible beta carotenes contents, limiting their potential in contributing to vitamin A intake among consumers. Additionally, all the minerals occurrence in the guava fruits would occur independently of the moisture content as these are bound within the fruit flesh (Rojas-Garbanzo *et al*., 2017)

The current study found some mature ripe fruits weighing less than 100g, although the recommended fruits for processing should weigh between 100 and 200g or more, with as few seeds as possible for optimal pulp yield (Yusof, 2003). This was not the case in this study, indicating poor processing qualities as the seed to pulp ratio was also relatively high compared to other findings, indicating somewhat poor processing qualities as these ratios would result in high mass wastes (Devi *et al*., 2018). When compared to the white and strawberry varieties, the red-fleshed guavas had significantly better processing qualities. Furthermore, according to Omayio *et al*. (2020), the variety is widely grown in Kenya and has a relatively long shelf life (Katumbi *et al*., 2020). Although the strawberry guavas were highly nutritious in most of the parameters tested, their production, short shelf-life, and high seed: pulp ratio made them difficult to process.

During the study, fruits were also infected with the fruit fly, which is in line with Katumbi's 2020 (unpublished thesis), stating that the local Kenyan guavas are susceptible to fruit fly infestation thus require fumigation where necessary. As a result, the quality of the processing

is highly affected. Some fruits were also infested with diseases, increasing their susceptibility to losses and resulting in undesirable processing qualities. However, these can be easily disinfected as part of crop husbandry.

4.6.2 Physicochemical qualities of guava fruits

The guava fruits proximate composition, pH, TTA, TSS, and vitamins compositions agree with Chiveu's findings (2018) and Katumbi's (2020), who found the levels to be 3.08 – 4.38, 059-2.79 and 5.9-20.0^{o}Brix, 58 – 2262mg/100g vitamin C and 0.41 -3.0mg/100g of beta carotenes. Their findings of chemical differences were attributed to morphological and genetic variations in Kenyan guava fruit, which may have been the case in the current findings. Because the fruits grow from randomly dispersed seeds of various varieties, the agroecological zones significantly impacted the fruit's qualities and intra morphological differences, which resulted in the intra and inter cultivar variations as shown on the AHC and PCA plots. Furthermore, the fruits' proximate composition was consistent with the findings of Ali *et al.* (2014) and Yousafi *et al*. (2021) on indigenous Sudanese and Pakistani guava cultivars, respectively.

Similar studies on local varieties show that the fruits vitamin C content was within varying levels ranging from 200 to 350 mg/100 g reported by Kaur *et al*. (2009) and Rana *et al*. (2015). However, the strawberry guava's levels were low and consistent with similar varieties, as Adrian et al. (2012) reported. Guava fruits are high in ascorbic acid, containing up to 4-8 times the amount found in other fruits, though the levels vary depending on the variety (Thaipong *et al*., 2005). Even though the white varieties had significantly higher vitamin C, consistent with Ali *et al*. (2014) and Flores *et al*. (2015), the low beta carotenes may have been caused by a lack of coloring carotenoids in the white guavas compared to the other two. Although the levels of beta carotene were lower, they were comparable to those found in white and red guava fruits reported in Western Kenyan varieties (Mutembete, 2020). The fat content positively correlated

with the carotenoids, particularly the beta carotenes, and the redness intensity of the fruits, both of which are based on the accumulation of fat-soluble pigments (Tian *et al*., 2015). However, because they are insoluble in water, they had an orthogonal relationship indicating independent occurrence.

The minerals in the guava fruits in this study varied significantly, just as they had in previous studies on guava fruits by Chiveu *et al*., 2019 and Pereira *et al*. (2014), who found much lower levels of zinc (0 – 5.04 mg/100g), iron (06 -10.62 mg/100g) but many high quantities of potassium (636- 4230 mg/100g) and calcium (30- 222 mg/100g). As Chiveu *et al*. (2019) described, the levels of macro and microminerals evaluated may result from agroecological, genetic, and environmental interactions. Furthermore, the phytochemical composition compounds of the current fruits revealed significant bioactive compounds- the flavonoids, antioxidants, and phenolic, whose levels were comparable to those found in similar studies (Gutiérrez *et al*., 2008; Naseer *et al*., 2018; Youssef *et al*., 2017). Phytochemicals contribute immensely to boosting consumers' immunity by providing antioxidants that scavenge free radicals suspected to cause diseases within the human body besides playing key roles in the plants' flavor, color, and other functions (Acevedo, 2016).

4.7 Conclusion and recommendation

The guava fruits in the current study show wide variations in the physicochemical and processing qualities of the Kenyan guava fruits varieties. However, the guava varieties contained significant quantities of nutrients that could aid in macro and micro intake among consumers. The current fruit varieties, particularly the red-fleshed guavas, that were found to have superior nutritional and processing properties should be strengthened to ensure fruits with high processing qualities. However, it is recommendable that good agricultural practices in

guava fruit production be combined with appropriate post-harvest handling practices, which have historically been the fruit's greatest hindrance.

CHAPTER FIVE : PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITIES OF KENYAN GUAVA JUICES AND NECTARS

5.1 Abstract

The Kenyan fruit juices markets are dominated by both imported and locally processed fruit juices. Among these, the marketed guava juices are majorly formulated using imported guava pulp, concentrate, and flavors, although limited studies documenting their nutritional composition have been conducted. This study sought to characterize and evaluate the physicochemical and microbiological properties of the commonly marketed guava juices and nectars. Mixed methods research design was used to obtain qualitative and quantitative data from randomly sampled guava nectars and juices by procuring and coding the samples (n=30) in duplicates from the supermarkets. The findings indicate that only five major brands are processing guavas sold through supermarkets. The majority of the processors (60%) used white guava pulp compared to red/pink. The fruit concentration ranged from 10-20%, and the products were packaged in tetra packs (60%) and plastic bottles (40%), with the packaging sizes ranging from 250 ml to 1 litre. There were significant ($p<0.05$) differences in the ash (11.7- 15.6 $g100^{-1}$ g d.w), crude fat (0.13-0.70 $g100^{-1}$ g d.w), and the carbohydrate (95.7-98.8 $g100^{-1}$g d.w) among the sampled brands. On the other hand, there were no significant ($p>0.05$) variations in the moisture content, crude proteins, and energy, which averaged 84.4-88.3%, 0.11-0.26 g 100^{-1} g, and 386.5-398.2 Kcal 100^{-1}g d.w respectively. The product's color differed significantly ($p<0.05$) for the L, a*, b*, chroma, and hue angles. Apart from the potassium levels, there were significant ($p<0.05$) differences in the assessed juices and nectars' chemical, mineral, and phytochemical composition. Although significant ($p=0.001$) differences in the levels of yeast and molds (0-5.8 cfu/ml) and the total viable counts (1.5-2.8 cfu/ml) were found among the samples, none of the products exceeded the Kenyan standard's recommended 30 and 100 cfu/ml respectively. Despite declarations on the packaging that no preservatives were

used, significant ($p<0.0001$) levels of residual metabisulphite in the form of free Sulphur dioxide ranging from 0.20 to 6.0 mg/litre were detected in all samples. The levels, however, did not exceed the maximum limits of 10mg/litre set by the Kenya Bureau of Standards. It is recommended that locally processed fruits be traded to maximize the economic and nutritional potential of the Kenyan guava value chains.

5.2 Introduction

Fruit juices are unfermented but potentially fermentable liquids derived from the palatable section of well-ripened matured fresh fruits (FAO, 2005). Juice extraction can be done chemically or mechanically, with subsequent processing involving concentration, reconstitution with water, permitted food-grade ingredients as desired by the processor, and preservation methods (FAO, 2005).

Fruit juices have become an essential part of many countries' modern diets, with the global trend for fruit juices worth more than US$1300 billion expected to rise in the coming years (Sahar *et al*., 2019). This is due to increased urbanization, the expansion of middle-class families with increasing disposable household incomes, and a shift in dietary patterns towards nutritious whole-fruit beverages that provide various natural nutrients found in fruits (Abdo, 2014). Since 2010, the availability of tropical fruit drinks has increased, with average per capita consumption expected to exceed 9.8-12 kg in 2029, up from 5.5 kg in 2007-2009 (OECD/FAO, 2020).

Although various brands of fruit beverages are processed in different ways (Elepu, 2018), consumers prefer natural flavors over synthetic, so minimally processed products with sensory properties similar to fresh fruits' organoleptic properties are in high demand (Włodarska *et al*., 2019). Despite being infiltrated by various fruit-based juices, the Kenyan processed guava

market is still dominated by processed products made from imported fruits, denying local farmers valuable income and exploiting locally produced guava fruits (Omayio *et al*., 2019). According to previous research (Omayio *et al*., 2019), only 3% of local fruits are processed at the household level with non-existent industrial processing, indicating a critical need for locally processed guava fruits and, as a result, an imbalanced trade against local fruit producers.

Like other tropical fruits, guava is suitable for agro-industrial processing (Thongsombat *et al*., 2007). It is rich in unique, pleasant flavors, in addition to high nutritional and phytochemical nutrients, making it ideal for processing into nutritious fruit juices that can meet global beverage demand (de Castro *et al*., 2016). However, despite Kenya's high guava production potential, processing remains low, resulting in imported processed guava juices. This study aimed to determine the physicochemical and microbiological composition of currently traded guava juices and nectars.

5.3 Materials and Methods

5.3.1 Study design

The study employed a mixed-methods approach. A comparative analysis of qualitative and quantitative data was conducted on guava beverages currently traded in the markets. These beverages were identified and randomly procured from retailers for analysis. A qualitative analysis of the guava juices and nectars was packaging type, and ingredient information was documented based on the manufacturer's label information while the quantitative data were obtained through product samples analysis of the physicochemical properties

5.3.2 Sampling

A survey of the guava juices and nectars stocked were assessed among retailers and the major processors identified within Nairobi county using the procedures from studies by Sahar *et al*.,

(2019) and Włodarska *et al*. (2019). The three major supermarkets, Naivas, Tuskys, and Quickmart, were chosen because they stocked and sold the five identified guava ready-to-drink juices and nectars. At least two random branches from each store were selected, and the identified brands were bought in duplicates. This resulted in 30 duplicate samples being transported to the University of Nairobi's food processing pilot plant.

5.3.3 Physical characterization and sample preparation

Samples from similar brands, which included; Afia, Delmonte, Orchid, Fruitville, and Brava were characterized in terms of beverage type (juice or nectar), guava fruit type used, packaging types and unit sizes, ingredients as described on the package, and market segmentation (Włodarska *et al*., 2019). Homogenous mixtures of each brand were then prepared and repackaged into randomly coded analytical glass bottles (A-E) in relation to the brands and stored frozen at -20^{o}C until further analysis. The mixtures were prepared in triplicates.

5.3.4 Analytical methods

The samples were subjected to analysis by assessing the proximate, pH, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, beta-carotene, phytochemical and mineral content in duplicates as outlined in sections 4.3.4.3 - 4.3.4.9. All analyses were conducted in duplicates

5.3.4.1 Determination of residual metabisulphites and alcohol contents

The residual metabisulphite in the form of sulfur dioxide was analyzed iodometrically as described by (Takahashi *et al*., 2015). Generally, 50 ml samples were added to 25 ml of 1N NaOH solution and vortexed for adequate mixing. The mixture was allowed to stand for 15 minutes. To this, 10mls of dilute sulphuric acid (ratio of 1:3) using distilled water was added together with 2-3 drops of starch indicator. This was then back-titrated with 0.05M iodine

solution until a blue color was obtained. The levels of the residual Sulphur dioxide were then calculated based on the amount of iodine used. The alcohol content of the sampled juices was determined by the modified distillation methods as described by Balcerek *et al*.(Balcerek *et al*., 2017). Generally, 100ml of the juices were mixed with an equal amount of distilled water. The mixture evaporated using a horizontal inland revenue condenser system using an Electrothermal mantle (Southend, England), and the distillate was collected using a 100ml volumetric flask. The collected distillate was transferred into a measuring cylinder, and the alcohol level was read using an alcohol meter (Alla, France) at the menisci and expressed as volume per volume (v/v).

5.3.4.2 Determination of microbial qualities

The total viable count (TVC), yeasts/molds, and total coliforms were determined using methods 990.12, 997.02, 991.14, and 975.55, respectively (AOAC, 2002), while *Staphylococcus aureus* was determined using the ISO methods 6888-1:1999, (2003). Serial dilutions (10^1-10^4) for plating on the respective media were prepared by homogenizing 5ml of sample in 50ml of 0.085% sodium chloride diluent solution (0.85%). The media and diluents were autoclaved for 45 minutes using a Fedegari Autoclave (Albuzzano PV, Italy).

5.3.4.2.1 Enumeration of total plate count

The total population counts of the mesophilic bacteria were determined using the total plate count method on a plate count agar. The plates were incubated at 35^{o}C for 48 ± 2 hrs. The number of colonies developed were counted and recorded as colony-forming units per ml of sample (cfu/ml).

5.3.4.2.2 Enumeration of yeasts and molds

Acidified potato dextrose agar was used to determine the yeast and molds. The plates were incubated at 25^{o}C for five days. The number of colonies developed was counted and recorded as colony-forming units per ml of sample (cfu/ml)

5.3.4.2.3 Enumeration of total coliforms

Lauryl Tryptose Broth (pH 6.8) was used to determine the presence of coliforms. Fermentation tubes with inverted Durham tubes were used. The tubes were incubated at 35^{o} C for 48 ± 2 hrs. The presence of gas trapped in the Durham tubes indicated a positive test for coliforms.

5.3.4.2.4 Staphylococcus aureus

Baird Parker agar (pH 7.2) supplemented with egg yolk was used to determine the presence of *Staphylococcus aureus.* The plates were incubated at 37^{o}C for 48 ± 2 hrs. The number of colonies developed was counted and recorded as colony-forming units per ml of sample (cfu/m).

5.4 Data analysis

Xlstat Microsoft Excel plugin (Addinsoft, 2021) was used to analyze the proximate, chemical, phytochemical and microbiological composition data. Turkey's HSD test was used to separate significantly different means ($p<0.05$) in a one-way analysis of variance (ANOVA). Furthermore, a parallel coordinate analysis incorporating the key nutritional composition of the sampled fruits was performed to demonstrate the inter and intra variations in relation to the brands under consideration.

5.5 Results

5.5.1 Physical characterization of guava juices and nectars sold in Kenya

Five major local fruit processors processed most locally sold guava juices, with white guava accounting for the majority (60%). Only one company processed pure red/pink guavas, while the other blended them. The nectars made up 80% of the total, with the remaining 20% processing a fruit blend consisting of pink guava juice, carrot juice, and pineapples. The base ingredient was guava pulp, flavors, and concentrates in concentrations ranging from 10% to 20% (Table 5.1). Compared to the transparent plastic bottles with unit sizes ranging from 250 to 500 mL, Tetra Pak (250 or 1 litre) was the most commonly used packaging (60%). However, none of these brands sold their products through supermarkets.

Table 5.1: Physical characterization of guava juice and nectar brands sold in Kenya

Brands	Type of beverage	Type of Fruit pulp	Fruit level (%)	Forms of fruit	Packaging type	Unit size
A	Nectar	Red	10	Guava juice concentrate	Tetrapak	250 ml, 1 L
B	Nectar	White	20	Guava pulp and pulp concentrate	Plastic	250 ml, 500 ml
C	Juice blend	Red	20	Guava pulp and guava flavors	Tetrapak	250 ml, 1 L
D	Nectar	White	10	Guava pulp and guava flavors	Plastic	500 ml
E	Nectar	White	20	Guava pulp and guava flavors	Tetrapak	1 L

A - E – Coded guava juices and nectars samples representing the five most common guava brands on the Kenyan markets

All color parameters in the sampled beverages had significant ($p<0.05$) differences, with redness (a*) having the highest variation (41%) (Table 5.2), where the highest score (12.2) was observed in the only brand processing pink guava. The rest had no significant ($p>0.05$) differences in the color intensity. The significantly($p=0.002$) different lightness index for the samples ranged from 34 – 46 with an average of approximately 42. Similarly, the yellowness index ($p=0.005$) with values ranging from 1.46-14.90 and 0.75-9.09 was found to be highest in sample B at 8.25.

Table 5.2: The color of guava nectars and juice sold in Kenyan markets

Samples	Color parameters				
	L	**a***	**b***	**Chroma***	**Hue angle***
A	43.20±1.87 ^{b}	12.19±2.51 ^{b}	7.26±1.29 ^{abc}	14.20±2.80 ^{b}	30.97±0.98 ^{a}
B	42.62±1.20 ^{b}	10.74±0.87 ^{ab}	8.00±0.56 ^{bc}	13.41±0.97 ^{ab}	36.84±1.50 ^{c}
C	36.35±3.87 ^{a}	5.30±1.97 ^{a}	3.82±1.46 ^{a}	6.55±2.46 ^{a}	35.74±1.12 ^{bc}
D	44.99±0.68 ^{b}	9.06±0.43 ^{ab}	8.25±0.60 ^{c}	12.26±0.72 ^{ab}	42.28±0.76 ^{d}
E	40.43±3.34 ^{ab}	6.06±4.79 ^{a}	4.10±3.43 ^{ab}	7.32±5.88 ^{ab}	32.37±3.46 ^{ab}
Mean	41.52	8.67	6.29	10.75	35.64
(Range)	(33.51-45.98)	(1.46-14.90)	(0.75-9.09)	(1.64-17.14	(27.37-43.17)
CV (%)	9.09	41.15	40.49	40.08	12.27
P value	0.002	0.008	0.005	0.009	<0.0001

A - E – Coded guava juices and nectars samples represent the five most common brands on the Kenyan markets. Values (means±standard deviation) with different superscripts along a column are statistically different (Tukey's test, $P\leq0.05$).

5.5.2 Chemical and phytochemical composition of guava nectars

The moisture content whose variations among the samples were not significantly (p=0.119) different and ranged from 84-88%. There were minimal variations among the sample's crude proteins (0.11-0.26 g/100g), fibre (0.7-3.52 mg/100g), and energy (386.5-398.2 mg/100g). There were no significant (p>0.05) differences in the protein, fibre, and carbohydrates, with values averaging 0.17g, 2.07g, and 391.4 kcal per 100g (Table 5.3). However, the ash (p<0.001), carbohydrate (p=0.009) and fat (p=0.004) had significant variations with levels of 0.1-2.02, 96.7-98.9 and 0.13-0.7 g per 100g respectively (Table 5.3).

Table 5.3: Proximate composition of guava nectars and juices sold in Kenyan Markets

Sample	MC (%)	DM (%)	Proximate parameter per 100 g dry weight (d.w)					
			Ash (g)	Crude Protein (g)	Crude Fat (g)	Crude Fibre(g)	Carbohydrates (g)	Energy (Kcal)
A	87.71±0.36 [a]	12.29±0.36 [a]	0.26±0.15 [a]	0.18±0.01 [a]	0.26±0.00 [a]	1.55±0.72 [a]	97.76±0.85 [b]	394.08±3.58 [a]
B	86.45±2.01 [a]	13.55±2.01 [a]	0.23±0.14 [a]	0.18±0.07 [a]	0.51±0.19 [b]	2.85±0.65 [b]	96.24±0.64 [ab]	390.23±4.06 [a]
C	86.70±0.49 [a]	13.31±0.49 [a]	0.16±0.04 [a]	0.16±0.02 [a]	0.23±0.02 [a]	2.21±0.43 [ab]	97.24±0.46 [ab]	391.69±1.81 [a]
D	86.35±0.17 [a]	13.65±0.17 [a]	1.34±0.56[b]	0.19±0.02 [a]	0.21±0.06 [a]	1.85±0.40 [ab]	96.41±0.25 [a]	388.29±1.00 [a]
E	85.75±0.53 [a]	14.25± 0.53	0.38±0.15 [a]	0.14±0.01 [a]	0.33±0.07 [ab]	1.88±0.67 [ab]	97.27±0.48 [ab]	392.60±2.49 [a]
Mean	86.59	13.41	0.47	0.17	0.31	2.07	96.98	391.38
(Range)	(84.4-88.3)	(11.7-15.57)	(0.10-2.02)	(0.11-0.26)	(0.13-0.7)	(0.70-3.52)	(95.66-98.75)	(386.5-398.2)
C v (%)	1.25	8.09	108.35	20.92	45.75	33.63	0.8	0.83
P	0.119	0.119	<0.0001	0.313	0.004	0.064	0.009	0.088

A - E – Coded guava juices and nectars samples representing the five most common guava brands on the Kenyan markets Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

The major micronutrients were observed to vary from approximately 52- 385, 0-0.7, 0.2-0.7, 0.35-0.4 mg/100g for the vitamin C, beta-carotene, zinc, iron, 27-41 CE, 821-1590 GAE, and 354-1725 μMTE100^{-1}g for the flavonoids, phenolics and antioxidant respectively (Table 5.4). Similarly, there were significant ($p<0.05$) differences in the other juices' intrinsic compositions for the pH, titratable acidity, and total soluble solids (Table 5.4).

Table 5.4: Chemical, mineral, and phytochemicals compositions of guava juices and nectars traded in Kenyan markets

Products	Chemical parameter (per 100 g d.w.)											
	Tss (f.w)	**Ph (f.w)**	**Titratable acidity (f.w)**	**Vitamin C (mg d.w)**	**β-Carotene (mg d.w)**	**Zinc (mg d.w)**	**Iron (mg d.w)**	**Calcium (mg d.w)**	**Potassium (dw)**	**Flavonoids (mg.CE d,w)**	**Phenolics (mg GAE d.w)**	**Antioxidant Activity (µMTE)**
A	13.00±0.00^{ab}	3.54±0.06^{a}	0.45±0.02^{c}	385.00±6.51^{d}	0.07±0.03^{a}	0.67±0.46^{a}	0.35±0.02^{a}	1.45±0.63^{a}	12.36±0.38	40.54±8.39^{b}	1592.14±528.79^{b}	588.20±140.28^{a}
B	12.18±0.21^{a}	3.70±0.13^{abc}	0.29±0.01^{ab}	95.24±13.37^{a}	0.00±0.00^{a}	0.21±0.03^{a}	1.35±0.14^{a}	1.31±0.03^{a}	12.31±0.22	27.91±4.18^{a}	1079.91±252.96^{ab}	411.12±53.84^{a}
C	14.05±0.10^{b}	3.95±0.22^{c}	0.35±0.02^{b}	153.15±12.61^{c}	0.00±0.00^{a}	0.43±0.19^{a}	0.64±0.32^{a}	1.77±0.10^{a}	14.92±0.20	39.55±4.64^{ab}	1343.91±240.03^{ab}	1725.38±2422.44^{b}
D	13.23±0.17^{ab}	3.89±0.02^{bc}	0.31±0.04^{ab}	281.14±4.13^{c}	0.05±0.01^{a}	0.47±0.10^{a}	0.88±0.07^{a}	4.1±8.16^{a}	12.89±0.44	27.41±6.66^{a}	1243.72±251.53^{ab}	421.7316.63^{a}
E	13.75±1.81^{ab}	3.66±0.12^{ab}	0.28±0.05^{a}	52.11±8.23^{a}	0.07±0.08^{a}	0.54±0.09^{a}	4.04±2.08^{a}	1.42±0.08^{a}	12.45±0.32	36.85±3.34	820.50±282.47^{a}	354.01±40.44^{ab}
Mean (Range)	13.24 (12.00-15.60)	3.75 (3.48-4.08)	0.34 (0.22-0.47)	193.33 (41.01-393.25)	0.04 (0.00-0.14)	0.46 (0.18-1.08)	1.45 (0.32-5.87)	9.30 (0.80-157.80)	12.99 (12.00-15.18)	34.45 (22.09-48.50)	1216.04 (583.89-2110.30)	700.09 (307.87-3357.87)
CV (%)	7.46	5.21	20.76	65.42	124.46	55.68	110.79	375.79	8.11	22.47	32.5	157.35
P	0.047	0.002	<0.0001	<0.0001	0.034	0.126	0.000	<0.0001	0.438	0.010	0.050	0.044

A - E – Coded guava juices and nectars samples represent the Kenyan markets' five most common guava brands.

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

5.5.3 Chemical and microbial contamination

Contrary to the processors' claim that no preservatives were used significantly different ($p<0.0001$), residual metabisulphites in the form of free Sulphur dioxide were detected, with levels ranging from 0.20-6.00 mg/litre were detected (Table 5.5). Sample E had the most negligible levels at 1.3±1.15 compared to the highest of 5.25±0.50 in sample D. On the other hand, none of the samples contained alcohol despite detectable yeast levels in the samples.

Table 5.5: Levels of residual metabisulphites and alcohol contents of guava juice and nectar traded in Kenyan markets

Description	Parameter	
	Residual metabisulphite (mg/litre)	Alcohol (v/v)
A	1.55±1.00 [a]	Nd
B	1.25±0.50 [a]	Nd
C	1.40±0.58 [a]	Nd
D	5.25±0.50[b]	Nd
E	1.3±1.15 [a]	Nd
Mean (Range)	2.17 (0.20-6.00)	0.00
CV (%)	82.72	
P value	<0.0001	

A - E – Coded guava juices and nectars samples represent the Kenyan markets' five most common guava brands. Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, $P\leq0.05$). **Nd**- not detected

While bacteria, yeast, and molds were detected, they were within Kenyan standards (Table 5.6). The levels of yeast and molds levels were significantly different (p=0.001), ranging from 0 - 7 cfu/ml. The TVCs on the other hand varied significantly (p=0.025), averaging 2.2 cfu/ml with levels ranging from 1.1-4.1 cfu/ml. However, there were no statistically significant differences in the levels of *Staphylococcus aureus* (p>0.438) and total coliforms (p>0.158) among the samples, with levels ranging from 0 -2.3 cfu/ml and 0 -1.3 cfu/ml, respectively.

Table 5.6: Microbial qualities of the guava nectars and juices traded in Kenyan markets

Description	Microbial characterization of guava beverages (cfu/ml)			
	TVC	**Yeast and Molds**	**Coliforms**	***Staphylococcus Aureus***
A	3.2±0.7[a]	5.8±1.3 [c]	1.3±2.5 [a]	0.00±0.00 [a]
B	1.6±0.2 [ab]	1.3±1.5 [ab]	0.00±0.00 [a]	0.3±0.50 [a]
C	2.8±0.63 [ab]	3.5±1.3[bc]	0.00±0.00 [a]	2.3±2.63 [a]
D	1.5±0.3 [a]	0.00±0.00 [a]	0.00±0.00 [a]	1.00±1.15 [a]
E	2.1±1.4 [ab]	2.00±2.5[ab]	0.00±0.00 [a]	0.3±0.50 [a]
Mean	2.2	2.5	0.3	0.8
CV (%)	42.93	97.55	447.21	192.85
P value	0.025	0.001	0.438	0.158

A - E – Coded guava juices and nectars samples represent the Kenyan markets' five most common guava brands. Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

The juices were classified using the parallel coordinates analysis package based on key nutritional properties, color, and chemical and microbial contaminants, yielding three distinct groups with inter-and intra-brand variations (Table 5.7). The samples class 1 were made up of

sample A while group 2 composed of which were made up of B, C, and E, and group 3 was composed of samples D

Table 5.7: Class centroids for the parallel coordinates illustrating the classification of guava juices and nectars based on physicochemical properties

Products parameters	Class Centroid		
	1	2	3
Tss	13.00	12.82	**13.59**
Ph	3.54	**3.81**	3.80
TTA	**0.45**	0.31	0.31
Moisture	**87.71**	86.96	85.92
Dry matter	12.29	13.05	**14.08**
Ash	0.26	**1.01**	0.24
Crude Protein	0.18	**0.21**	0.15
Fat	0.26	0.25	**0.36**
Crude Fibre	1.55	**2.36**	2.10
Carbohydrates	**97.76**	96.17	97.16
Energy Kcal	**394.08**	387.78	392.45
Vitamin C	**385.00**	222.91	98.91
Zinc	**0.67**	0.39	0.42
Iron	0.35	1.07	**2.12**
Potassium	12.36	12.76	**13.37**
Calcium	1.45	**27.49**	1.53
Flavonoids	**40.54**	28.15	35.80
Phenolics	**1592.14**	1238.17	1052.31
Antioxidant activity	588.20	428.94	**907.54**
TVC	**3.18**	1.45	2.31
Yeast and Molds	**5.75**	0.33	2.50
Coliforms	**1.25**	0.00	0.00
Staphylococcus	0.00	0.83	**1.00**
Residual metabisulphite	1.55	**4.07**	1.28
L	43.20	**43.89**	39.42
a*	**12.19**	9.37	6.84
b*	7.26	**8.05**	4.84
Chroma*	**14.20**	12.37	8.39
Hue angle*	30.97	**40.72**	34.46

The figures in bold indicate the highest levels of the parameter in the respective centroid

In general, vitamin C levels in group 1 were relatively high (385 mg/100g) compared to class 3, where levels averaged approximately 99 mg/100g. Flavonoids (42 CE), phenolics (1592 GAE), TVCs (3.2 cfu/ml), yeast and molds (5.8 cfu/ml), and coliforms (1.3 cfu/ml) were also high in this class. The samples had the highest redness index in terms of color (12.2). Class 2 samples had the highest calcium levels (28mg), residual metabisulphites (4 mg/litre), and lightness index in the color properties. Iron, zinc, and antioxidant activity levels were highest in the third class (Table 5.7).

5.6 Discussion

5.6.1 Physicochemical composition of sampled guava drinks

The current finding indicated that guava juices and nectars' packaging and physicochemical properties varied according to the formulations used by the respective processors and possibly the source of the primary raw material, guava pulp. However, it was noted that some of the sampled brands might not meet the Kenya Bureau of Standards' minimum recommended level of guava pulp of 25%. The color of the beverages varied equally depending on the raw material, either red or predominantly white guava fruits, which lacked coloring agents compared to pink guava juices. (Flores *et al*., 2015).

The products were sold only through supermarkets, limiting a majority of consumers access to retail products through open and retail markets, which are considered standard retailers (Włodarska *et al*., 2019). Unfortunately, none of the brands processed their beverages from the local fruits as the raw material was mainly imported. This corroborates a similar study in Uganda where Elepu (Elepu, 2018) reports that the East African market for fruit juices is infiltrated with imported fruit juice products with insignificant contributions from the locally produced crops, which in the long run ends up affecting the production and commercialization of the fruits

The proximate chemical compositions of the samples in this study indicated that, despite variations, they compared favorably in terms of mineral, chemical, and other phytochemical compositions to similar products processed elsewhere by Barakat *et al*. (Barakat *et al*., 2017) and Tanwar *et al*. (Tanwar *et al*., 2014). The sampled brands similarly had significantly higher levels of vitamin C and phytochemicals than the other characteristics, which is consistent with Arboleda's (2019) findings that high levels of vitamin C characterize the guava fruit, in addition to a high concentration of phytochemicals and dietary fibre.

The differences in the nutritional composition between the samples maybe because they are processed using different parameters according to the manufacturer's specifications (Bodini *et al*., 2019). However, due to the intensively mechanized processing of the respective brands and the effect of packaging materials used (Youssef *et al*., 2017), some of the nutrients such as vitamin C may have been extremely low due to degradation during the shelf life. This is consistent with studies by Ali *et al*. (2014) and Sanjinez-Argandoña *et al*. (2005), which found that up to 70% of the vitamin may be lost during retail, in addition to losses due to interactions between time, food matrix, light, and high temperatures involved during processing, which may have been the case among the trades samples in this study (Touati *et al*., 2016).

Despite their small market segments, guava beverages could be significant sources of micro and macronutrients and phytochemicals (Arboleda, 2019). However, to increase their consumption, sensory strategies must be implemented in addition to visually appealing packaging for processed fruits while minimizing interference with the functional properties of the beverages during marketing, particularly for non-traditional fruit juices such as guava juices and nectars. Furthermore, not all supermarkets assessed stocked the processed guava juices, implying a possible lack of adequate marketing for the processed guava, which may be due to the low consumption of guava and guava-based products, as reported by Omayio *et al*.

(Omayio *et al*., 2020). This necessitates a need to ensure increased sensitization of the need to consider the consumption of processed guavas among Kenyan consumers.

5.7 Metabisulphites and microbial contamination

Surprisingly, none of the sampled products declared the presence of sulfites, even though the addition of food preservatives to protect foods from microbiological and enzymatic degradation is a common practice worldwide (FAO, 2005). Still, these must be used within the recommended levels to protect the consumer (Román *et al*., 2017). Preservatives aid in the preservation of the color, aroma, and flavor of processed foods by being highly effective against non-enzymatic browning reactions that frequently occur in processed fruits and vegetables, microbial growth for both yeast, molds, and bacteria, as well as acting as antioxidants and reducing agents depending on their functional characteristics (da Silva, Sabino, de Oliveira, *et al*., 2016). Although these were within the recommended Kenyan standards limits, their presence must be declared (KEBS, 2016).

The samples' microbial loads of <10 cfu/ml were low and within the Kenyan Bureau of Standards (KEBS, 2016) requirements. These findings indicated that good hygiene and manufacturing practices were followed, resulting in the safe processing of juices/nectars. The higher levels of yeast and mold detected in the samples than bacteria may be attributed to the juices' low pH and presence of sugars which support their growth and thus promote their growth. On the other hand, the presence of preservatives may have inhibited their growth, making the juices shelf-stable (Lima Tribst *et al*., 2009). The levels of microorganisms were in agreement with a similar study in Nigeria by Oranusi *et al*. (2012), who found 1.1 to 6.0 cfu/ml of yeast and molds, TVCs, coliforms, and *Staphylococcus aureus*

5.8 Conclusion and recommendations

Although major multinationals process and sell their guava-based juices and nectars in the Kenyan markets, none used Kenyan-produced fruits to promote the local guava fruit processing and marketing. Despite variations in the nutritional composition of the traded guava juices, consumers would not experience food safety concerns, although they may undergo qualitative and functional losses if they expire. The current brands were only found in supermarkets. It is recommended that processors also supply their products to other retailers such as shops and kiosks for consumers who do not have access to the supermarkets. It is also critical to conduct a consumer survey to determine consumers' willingness to pay for locally processed guava juices and nectars, particularly in urban and peri-urban areas where consumers' perceptions of local guava fruits are associated with fresh consumption in rural areas. Additionally, a long-term solution should be sought by increasing the processing of produced local guava varieties rather than importing from other countries

CHAPTER SIX : EFFECT OF PULPING METHODS ON THE PHYSICOCHEMICAL PROPERTIES OF KENYAN RED AND WHITE-FLESHED GUAVA PULP

6.1 Abstract

Fruit pulps are among the most traded forms of fruits on an industrial scale. Because of seasonality, bulk storage of pulp is a common practice among fruit processors worldwide. It helps reduce postharvest losses and food waste, maintain the quality and safety of processed fruits, and provide raw materials for continuous manufacturing during the fruits' offseason. The industrial processing of guava remains untapped in Kenya because the crop's value chain has not been commercialized. The current study sought to evaluate the impact of pulping methods on the quality of pulp from white- and red-fleshed guavas using a two by three factorial experiment study design. Both hot and cold extraction methods were tested, with the hot extraction method involving steam and hot water blanching. The pulps were then subjected to yield extraction, physicochemical analysis, and their changes during processing. Results indicate that the pulp yield was highest in the red guava regardless of the method of extraction used ($p<0.001$). The pulp to by-product ratio was significantly ($p=0.026$) high in the red guava 2.58, 2.97, and 3.30 for the cold, hot water, and steam-blanched compared to the white guava's 1.66, 1.95, and 2.03, respectively. There were no significant ($p=0.639$) differences in the moisture loss during the resultant pulps' pasteurization, ranging from 2.59±5.41 –5.1±2.6%. Although hot extraction methods resulted in significantly ($p<0.0001$) higher yields (67 - 77 %) compared to the cold (62 – 73%), the heat-labile nutrients were affected. As much as 60% of the white guava's and 64% of the red guava's vitamin C was lost and leaching of minerals and significant ($p<0.0001$) losses in the antioxidant and total phenolics of the resultant pulps. The steam blanched pulps exhibited significantly ($p<0.0001$) high overall color changes (ΔE) ranging from 21.97±4.51 - 29.69±7.71 in the pasteurized white guava pulp compared to the

red's (-0.24±4.50 - 5.7±0.76). The cold extraction method resulted in significantly ($p<0.05$) better retention of the vitamin β-carotene (1.9±0.4mg), zinc (5.6±2.1mg), iron (20.1±8.6mg), calcium (19.2±4.2 mg), flavonoids (241.3±56 mgCE), phenolics (1548.7±25.8 mg GAE) and antioxidant activities (1998.6±333μMTE) per 100g in the red pulp than the white guava's. In comparison to the white cold-extracted pulp, the cold-extracted red guava pulp was the most suitable for further processing due to its high nutrient retention and its high pulp to by-products ratio.

6.2 Introduction

The most fundamental industrial or small-scale processing method for converting fruits into processed forms is fruit pulping (Silva & Abud, 2017). However, the pulps must be stored so that the finished product does not degrade due to microbial and enzymatic activity (Silva & Abud, 2017). Fruit pulping has several advantages over fresh fruits, including increased shelf stability (as opposed to the short shelf-life of raw fruits), increased monetary value, and, most importantly, the prevention of food loss and waste during the glut. It is also a convenient way to get fruits out of season (Silva & Abud, 2017).

Fruit pulping, like other food processing techniques, involves extracting the flesh from the fruit using either mechanized or small-scale manual operations, followed by a combination of hurdle techniques such as pasteurization, lowering the pH, addition of permitted food-grade preservatives at recommended levels, and packaging in appropriate airtight containers for shelf-life stability (Putnik *et al*., 2020). Several unit operations are included in the pulping process to ensure that the end product meets the minimum specified standards for safety and quality, including sorting for uniformity, cleaning and sanitization to remove all dirt, fruit crushing or flesh extraction, mechanized pulping, and the subsequent process of preservation

through heat treatment, application of food-grade preservatives and freezing among others (Barret *et al*., 2005).

The guava fruit's high rate of perishability poses enormous problems, necessitating processing into significantly shelf-stable products. The pulp is a highly effective global phenomenon used to ensure a constant fruit supply during the offseason (Khan, 2015). However, although several guava products brands use imported guava pulp in Kenya, there is no known commercial production of pulp from local exotic and indigenous fruits due to lack of industrial guava processing (Omayio *et al*., 2020). This is despite the country's relatively high guava production during the glut, the fruits' relatively low cost and their suitability for industrial processing. According to Omayio *et al*. (2020), processing guava as a value-added product allows for alternative revenue streams from the fruit, as the fresh fruit’s market value of the fruit is estimated to be less than $ 0.1 per kg during the annual guava seasons, compared to processed forms, which fetch up to $ 2.5 per kg of processed fruit, resulting in a loss of valuable income.

Although Kenyan guava varieties have been found to have a high seed to pulp ratio and often low processing qualities due to differences in their morphological, genetic, and agro-ecological environments, the annual yield losses are incredibly high, necessitating the adoption of small-scale, low-cost processing techniques by households and MSMEs (HCD, 2014b). Previous studies have also reported low consumption of locally produced Kenyan guava due to constipation caused by the numerous fruits seeds (Chiveu, 2018; Wasilwa *et al*., 2018). Because the pulp is a crucial ingredient in several guava products, there is a need to use mechanized methods for extracting the guava pulp to increase consumption while also reducing the losses that occur during the fruit season (Silva & Abud, 2017). This study investigated the effect of pulping methods on the physicochemical quality of pulp from white and red-fleshed Kenyan guavas.

6.3 Materials and methods

6.3.1 Study design

An experimental factorial design was used, with two factors: guava variety and extraction method assessed. The guava varieties were red and white, and the extraction methods were cold or normal pulping methods, steam blanching (100-120^{o}C, 2 minutes), and hot water blanching (95^{o} C, 2-3 minutes). Before pulp extraction, the fruits were split into triplicates of either white or red-fleshed guava variety using a completely randomized design. The guava fruits were crushed and pulped using a commercial fruit crusher and pulper before being pasteurized and packaged until further analysis. Samples of pulp were drawn before and after pasteurization for a comparative assessment of the effect of pulping and processing on the physicochemical properties of the white and red-fleshed guava pulp

6.3.2 Procurement of guava fruits

Mature firm-ripe red/pink-fleshed, white-fleshed, and strawberry guava fruits were randomly procured from farms in Taita Taveta and Kitui counties between March and July 2019. A total of 1000 Kg of the red and white-fleshed guava fruits were picked from approximately 10 – 15 fruits from randomly selected trees within the study areas in duplicates. The fruits. were transported in hermetically sealed bags to the College of Agriculture, University of Nairobi. To reduce losses and the effects of field heat, fruits were harvested in the early morning hours (6 a.m. - 10 a.m.) and were collected under shade to avoid direct sunlight. The transported fruits were then stored in a cold room with a temperature of 10±2^{o} C and relative humidity of 75% (Huato- HE174 Data loggers Shenzen China) until further processing.

6.3.3 Sample preparation

The guava fruits were sorted according to ripeness and variety, cleaned in continuous tap water, weighed, and pulped as described by Tillett *et al*. (2014). To extract guava pulp, a completely randomized design with two treatments and three replications were used. A previous study by Katumbi (2021) found no significant differences between the ripe white- and red-fleshed guava fruits sourced from the two respective counties and therefore, the fruits were pooled into either red or white-fleshed batches. The fruits were split into triplicates of 50 kg for the respective varieties

6.3.4 Guava pulp extraction

The guava pulp was extracted using either hot or cold extraction methods. The cleaned fruits were mechanically pressed into a puree for the cold extraction using a commercially locally manufactured fruit crusher and a pulper fitted with a 0.5 mm stainless steel screen (D. K Engineering, Kenya). The hot extraction methods involved the use of steam (100-120^{o}C) for 1.5-2 minutes, generated by a commercial firewood-powered boiler, and hot water blanching (95^{o} C) for 1.5-2 minutes. The blanched fruits were immediately immersed in chilled water (10±2^{o}C) for 2 minutes to prevent further cooking, after which they were subjected to crushing and pulping as the cold. The extracted pulps were then pasteurized (85^{o}C, 5 minutes) and preserved using sodium metabisulphites at 300 ppm as recommended by FAO (2005). For the physicochemical analysis, approximately four replications of 1kg pulp were collected in duplicates from random batches of hot and cold extracted pulps filled into airtight containers. To ensure randomization, samples were collected at intervals after adequate homogenization of the pulp. The same was repeated for the pasteurized guava pulps.

6.3.5 Analytical methods

6.3.5.1 Pulp and by-products yield

The pulp and by-products yields and their ratios were determined as described by Dedo *et al*. (2019) and expressed as percentages in respect to the initial fruit weights after weighing the extracted pulp and the resultant wastes composed of peels and seeds. Duplicate analysis was conducted

6.3.5.2 Guava pulp color analysis

Both raw and pasteurized guava pulps were subjected to color analysis using a PCE colorimeter as per the manufacturer's manual (PCE Instruments, London, UK). All readings were taken in duplicate

6.3.5.3 Guava pulp chemical composition

The pulps were subjected to analysis by assessing the proximate, pH, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, beta-carotene, mineral content, and phytochemical analysis in duplicates as outlined in sections 4.3.4.3 - 4.3.4.9. The same procedures were used to determine the changes in these chemicals for pasteurized pulps.

6.3.5.4 Pulp textural analysis

The texture analysis of the guava pulp was conducted using TA. XT-plus Texture Analyzer (Stable Micro Systems, Surrey, UK) as described by Onyango *et al*. (2020). The extracted white and red guava raw and the respective pasteurized pulps were assessed for the cohesiveness, consistency, firmness, and work of cohesion (index of viscosity) in duplicate. The analyzer measurement settings were 50 kg load cell, with the height set at 60mm using a

45 mm disc diameter and a penetration of 30 mm. The pretest and testing speeds were 1 mm/s at a trigger force of 10 g, while the post speed was 10 mm/s. Readings were taken in duplicates.

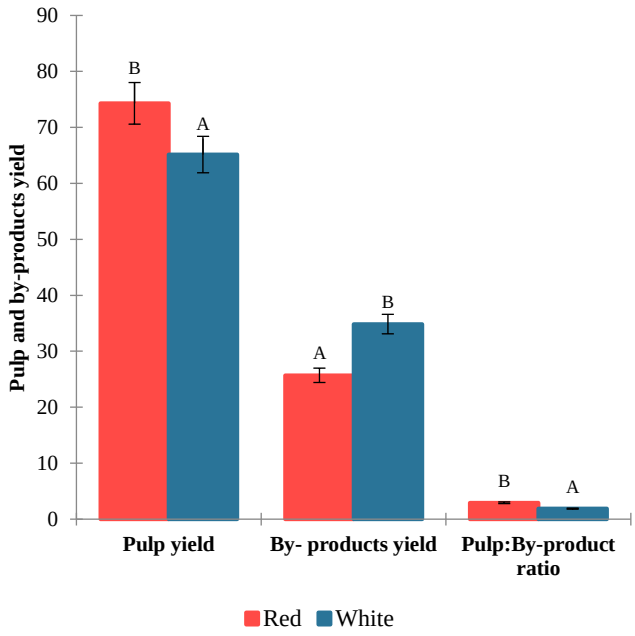
6.4 Data analysis

The pulp and by-products yields, color, proximate composition, chemical, and phytochemical compositions data were analyzed using Xlstat Microsoft Excel plugin (Addinsoft, 2021). A two-way analysis of variance (ANOVA) for the effect of the variety and the extraction method was performed, with Turkey's HSD test used to separate significantly different means ($p<0.05$). The principal component analysis, which included the various nutritional compositions of the sampled fruits, was used to demonstrate the relationships in relation to the varieties under study.

6.5 Results

6.5.1 Pulp and by-products yield

The guava varieties led to significant ($p=0.026$) differences in the pulp yield, by-products, and the ratio of the two (Figure 6.1a). The red-fleshed guava had the largest yield, averaging 75%, compared to white guavas, which had 65%. The red-fleshed guava, on the other hand, exhibited much lower by-product yields ranging from 23 to 28%, whereas white guava yielded 32-38%. As a result, the pulp to byproduct ratio in the red was substantially greater than in white, ranging from 2.6-3.4 to 1.6-2.1, respectively (Figure 6.1a). Regardless of the guava variety, the hot extraction methods resulted in significantly high ($p=0.000$) high pulp yield, with steam extraction having the highest at 66-77%, hot water at 64-76%, and the least in the cold extraction (72-74%). As a result, there were more by-products in the cold extraction (32%) than in hot water (30%), and steam (28%) blanched pulps, resulting in a high pulp to byproduct proportion in the steam blanched pulp (2.7) (Figure 6.1b).



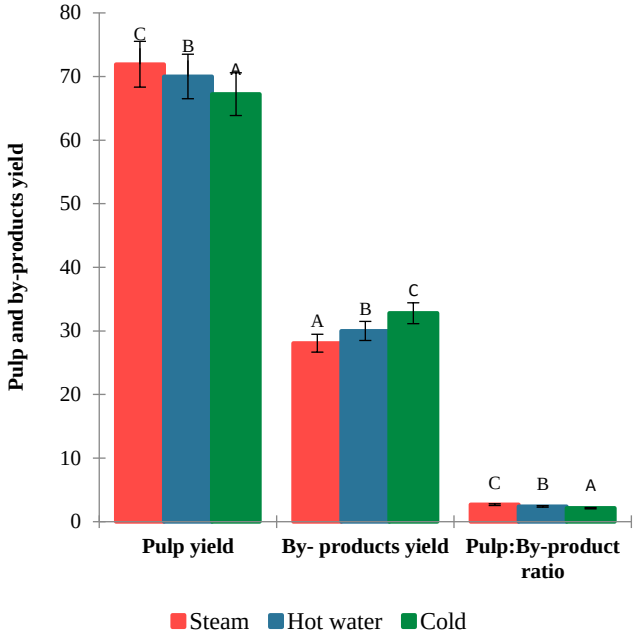


Figure 6.1 a

Figure 6.1 b

Figure 6.1a: Effect of the varieties on the extraction yield, by-products yield, and pulp to by-product ratio. Figure6.1 b: Effect of pulping methods on the pulp yield, by-products yield, and pulp to by-product ratio. The bars indicate the standard error of the means.

The interactions between the extraction methods and the respective variety resulted in significant (p=0.00) differences in the pulp yield, by-products (p=0.00), and pulp to by-products ratios (p=0.00) (Table 6.1). The steam-blanched red-fleshed guavas yielded the most pulp, averaging 77%, compared to the cold extracted pulp, which yielded only 62% (Table 6.1). Regardless of the extraction method used, white guavas produced the highest by-products, ranging from 33.1 to 37.9%, compared to red guavas, which produced the lowest by-products, ranging from 23.4 to 26.8%. As a result, the pulp to by-product ratio of red guavas was approximately 3.0, compared to 1.9 for the white guavas (Table 6.1)

Table 6.1: Effect of guava varieties and pulping methods on the pulp yield, by-products, and pulp to by-products ratio

Interaction between extraction methods and guava variety	Pulp parameters		
	Pulp yield (%)	By-products (%)	Pulp: By-product ratio
Cold x Red	73.19±1.63 [b]	26.81±1.63 [a]	2.74±0.23 [b]
Cold x White	62.11±0.55 [a]	37.89±0.55 [b]	1.64±0.04 [a]
Hot water blanching x Red	74.77±1.27 [b]	25.23±1.27 [a]	2.97±0.20 [b]
Hot water blanching x White	65.70±2.71 [a]	34.30±2.71 [b]	1.92±0.23 [b]
Steam blanching x Red	76.65±0.77 [b]	23.35±0.77 [a]	3.28±0.14 [b]
Steam blanching x White	66.87±1.45 [a]	33.13±1.45 [b]	2.02±0.13 [a]
CV (%)	18.72	18.72	26.35
P value	0.00	0.00	0.00

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

Significant color differences were found across all color parameters, with white guava pulp having significantly ($p<0.0001$) higher lightness of 73 to 84 being and least in the steam blanched pulp and highest in the cold extracted white pulp (Table 6.2). The lightness index for the red flesh guava was varied from 49.7 to 50.9 for the hot water and steam blanching, respectively. The red guava pulp had significantly ($p<0.0001$) higher redness indices (19.6 - 20.2) than the white guavas, which had the least (1.26-2.63) (Table 6.2). White guavas, on the other hand, had significantly ($p<0.0001$) higher yellowness indices (24.01-35.04) than red guava pulp (14.9 – 16.9). Except for the chroma index in the white guava, no significant ($p>0.05$) color changes were observed for the respective variety across all color parameters, regardless of the extraction method used.

Table 6.2: Influence of the extraction methods and guava varieties on the color of white and red-fleshed guava pulp

Extraction method	Guava variety	Color parameters				
		L	a*	b*	Chroma*	Hue*
Cold	Red	49.91±1.73 [a]	20.15±1.02 [b]	14.89±2.01 [a]	25.12±1.86 [a]	37.88±1.42 [a]
	White	83.79±8.28 [b]	2.63± 1.35 [a]	35.04±6.40 [d]	35.05±6.38 [b]	85.87±1.78 [b]
Hot water blanching	Red	49.72±1.56 [a]	20.02±0.93 [b]	15.46±2.16 [a]	25.37±1.70 [a]	38.77±2.34 [a]
	White	77.80±8.96 [b]	2.09±1.43 [a]	26.63±5.19 [c]	27.95±4.48 [ab]	86.55±2.10 [b]
Steam blanching	Red	50.71±1.51 [a]	19.60±0.09[b]	16.78±0.85 [c]	25.80±0.49 [a]	40.57±1.53 [a]
	White	73.01±1.27 [b]	1.26±0.50 [a]	24.01±1.62 [bc]	25.32±2.13 [a]	87.63±0.90 [b]
Mean Range		64.11 (47.49-91.40)	10.98 (0.84-21.68)	22.08 (13.16-39.87)	27.41 (23.50-39.86)	62.8 (36.42-88.18)
CV (%)		24.05	84.11	36.87	17.35	38.95
P value		<0.0001	<0.0001	<0.0001	0.05	<0.0001

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, ($P \leq 0.05$).

6.6 Guava pulp proximate composition

The pulp moisture content was lowest in hot water blanched red guava pulp (84%) and highest in white-hot water blanched white guava pulp (88%). The hot extraction produced significantly ($p=0.04$) less dry matter (9.8 to 15.22%) than the cold methods. The ash content whose levels were significantly ($p=0.023$) different in the guava pup was lowest in the cold extracted red guava (0.37g) and highest in the cold extracted white guava (0.52g). The crude fiber (23.5-33.9 g), proteins (0.37-0.91 g), fat (0.17-0.47g), and carbohydrates (64.4-75.3 g) were also significantly ($p<0.0001$) different. The energy contents were significantly ($p<0.0001$) lower in the cold extracted red guava pulp at 265.4 Kcal compared to the 305.3 Kcal in the steam blanched white guava pulp (Table 6.3).

Table 6.3: Proximate composition of white and red guava pulp extracted using cold and hot methods

Extraction method	Guava variety	Proximate Parameter (mg/100 g d.w)							
		Moisture (%)	Dry matter (%)	Ash (g)	Crude Protein (g)	Fat (g)	Crude Fibre(g)	Carbohydrates (g)	Energy (Kcal)
Cold	**Red**	85.55±2.59 ^{ab}	14.45±2.59^{ab}	0.37±0.04 ^{a}	0.91±0.10^{c}	0.47±0.02 ^{b}	33.88±0.45 ^{b}	64.37±2.12^{a}	265.35±3.02 ^{a}
	White	85.72±1.36 ^{ab}	14.29±1.36 ^{ab}	0.52±0.02 ^{b}	0.47±0.11 ^{ab}	0.19±0.06 ^{a}	23.58±2.88 ^{a}	75.25±2.77^{b}	304.60±11.33 ^{b}
Hot water blanching	**Red**	84.78±1.91 ^{a}	15.22±1.91 ^{b}	0.42±0.11 ^{ab}	0.86±0.11 ^{c}	0.45±0.05 ^{b}	33.01±1.95 ^{ab}	65.26±1.99 ^{b}	268.52±7.09 ^{a}
	White	88.43±1.47 ^{b}	11.57±1.47 ^{a}	0.51±0.01 ^{ab}	0.37±0.01 ^{a}	0.17±0.08 ^{a}	24.87±1.36 ^{a}	74.10±1.42 ^{b}	299.35±5.15 ^{b}
Steam blanching	**Red**	86.46±0.98 ^{ab}	13.54±0.98 ^{ab}	0.47±0.06 ^{ab}	0.62±0.04 ^{b}	0.35±0.09 ^{ab}	26.27±0.72 ^{a}	72.29±0.86 ^{b}	294.77±2.94 ^{b}
	White	87.62±0.34 ^{ab}	12.38±0.34 ^{ab}	0.49±0.05 ^{ab}	0.59±0.03 ^{b}	0.26±0.13 ^{a}	23.52±2.83 ^{a}	75.15±2.91 ^{b}	305.29±10.56 ^{b}
Mean		86.35	13.645	0.318	0.46	0.65	27.8	70.78	288.55
Range		(82.75-90.23)	(9.77-17.25)	(0.10-0.47)	(0.37-0.62)	(0.35-0.91)	(20.45-33.88)	(64.37-78.27)	(265.35-316.88)
Cv		2.28	14.45	16.37	33.13	44.18	17.44	7.19	6.43
P value		0.04	0.04	0.023	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

6.6.1 Guava pulp chemical and phytochemical composition

Except for vitamin C, TTS, pH, and flavonoids, which were significantly higher ($p<0.05$) in the white guava pulp the red guava pulps were characterized by high nutritional contents for the micro nutrients, as shown on the PCA by plot, which explained 56% variability (Figure 6.2). When compared to steam and hot water blanching, which had the main benefit of retaining beta carotene, cold extracted red guava pulp retained more micro and macro nutrients. The cold extracted white guava pulp retained more vitamin C, pH, TTA, and flavonoid in comparison to the hot methods, which had significantly ($0<0.05$) high levels of potassium (Figure 6.2).

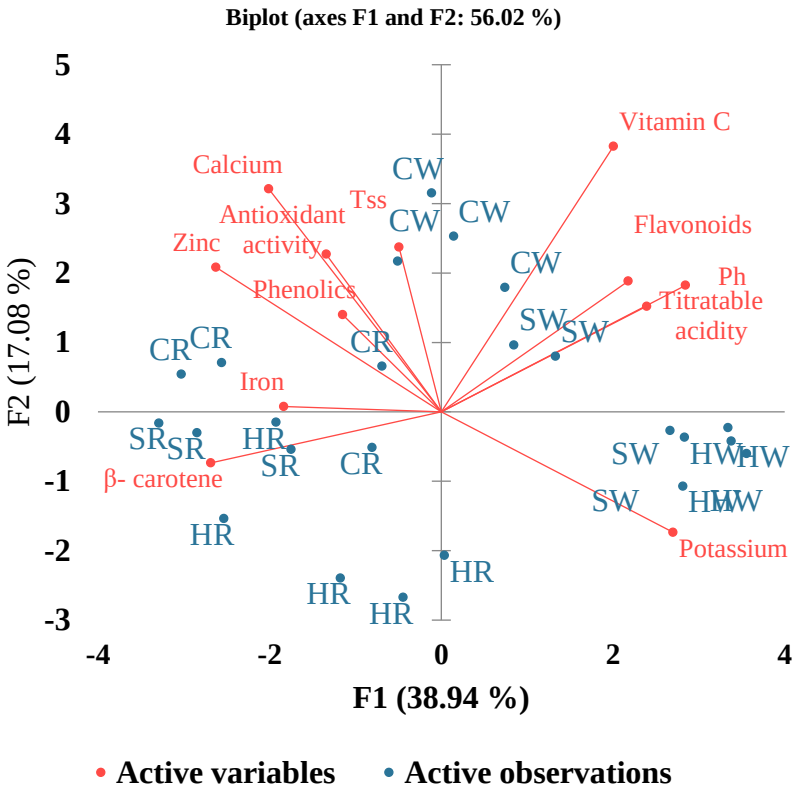


Figure 6.2: The PCA biplot for guava pulp nutrient compositions.
HW- water-blanched white guava, SW- steam-blanched white guava, CW- cold-pulped white guava, HR- water-blanched red guava, SR- steam-blanched red guava CR- cold pulped red guava.

The pH, titratable acidity, antioxidants, and total phenolics were positively correlated (Figure 6.2). Although their levels in the guava pulps were negatively correlated with potassium, zinc,

iron, and calcium had significantly weak positive correlations. In contrast, the beta carotenes negatively correlated with vitamin C, flavonoids, pH, and titratable acidity (Figure 6.2).

There were significant differences in the totals, soluble solids, titratable acidity, and pH of guava pulp, with values ranging from 9-9.9, 0.44-0.62, and 3.8 - 4.1, respectively. There were significant differences in the pulp vitamin C and beta carotene levels ($p<0.0001$) regardless of the extraction method or guava variety extracted ($p<0.0001$) (Table 6.4). The white-fleshed guavas had the highest levels of vitamin C in all methods, with values in the cold extracted pulp at 2378 mg and the lowest in the steam blanched pulp at 1939 mg. Similarly, the cold extracted pulp had the highest concentration of vitamin C in the red guava pulp (1361 – 1571 mg), and the lowest in the steam blanched pulp (1361 – 1571 mg). The concentration of beta carotenes which had the most significant variation was high in red the guava pulp (1.40-2.8 mg) regardless of the extraction method used, as opposed to white guavas, where levels were extremely low (0.03-0.23 mg) (Table 6.4).

The zinc, calcium, and potassium concentrations were significantly ($p<0.05$) higher in white-fleshed guava pulps at 6.09, 55.3, and 440.6 mg, respectively, than in red-fleshed guava pulps, which had the highest iron levels (29.7mg). There were, however, no significant ($p>0.05$) differences in the pulp phenolic and antioxidant activities. Still, there were significant ($p=0.032$) differences in the flavonoid contents, with the concentrations highest (255.5 – 275.6 mgCE) in the white guava pulp compared to the red pulp (201-227.1 mgCE) (Table 6.4).

Table 6.4: Chemical, mineral, and phytochemical composition of white and red guava pulp extracted using cold and hot methods

Extraction method	Guava variety	Chemical parameter (per 100 g d.w)											
		Total soluble solids (f.w)	pH (f.w)	Titratable acidity (f.w)	Vitamin C (mg d.w)	β-Carotene (mg d.w)	Zinc (mg d.w)	Iron (mg d.w)	Calcium (mg d.w)	Potassium (dw)	Flavonoids (mg.CE d,w)	Phenolics (mg GAE d.w)	Antioxidant Activity (µMTE)
Cold	**Red**	9.63±0.21 [b]	3.87±0.02 [a]	0.57±0.03 [bc]	1570.60±262.06[ab]	2.76±1.52 [d]	5.20±1.03 [bc]	25.36±4.63 [a]	33.81±6.18 [bc]	227.12±17.89 [ab]	227.24±26.77 [a]	1999.91±270.22 [a]	2378.99±292.72 [a]
	White	9.45±0.13 [ab]	4.01±0.01 [b]	0.58±0.01 [c]	2378.68±270.81 [c]	0.23±0.05[ab]	6.09±0.00[c]	18.98±9.99 [a]	55.30±13.15 [c]	188.68±26.56 [a]	255.46±22.55 [a]	1733.86±346.52 [a]	2338.70±493.82 [a]
Hot water blanching	**Red**	9.12±0.13 [a]	3.86±0.04 [a]	0.50±0.05[ab]	1267.76±138.48[a]	1.40±0.28[bc]	4.50±1.94[abc]	23.29±6.40 [a]	31.06±8.53 [b]	255.30±59.61 [ab]	215.69±56.7 [a] 2	1566.01±373.78 [a]	2076.98±458.98 [a]
	White	9.45±0.13 [ab]	4.10±0.02 [c]	0.58±0.01 [c]	1993.34±173.52[bc]	0.17±0.03 [ab]	2.48±0.89 [ab]	15.81±1.78 [a]	7.74±2.38 [a]	440.60±29.71 [c]	275.65±26.05 [a]	1452.26±262.62 [a]	1997.45±449.81 [a]
Steam blanching	**Red**	9.57±0.29	3.89±0.03 [a]	0.48±0.02 [a]	1361.41±139.41 [a]	1.96±0.04 [cd]	5.40±0.60 [bc]	29.72±2.85 [a]	39.63±3.80 [bc]	196.22±73.02 [ab]	201.17±26.72 [a]	1907.13±36.74 [a]	2216.07±289.29 [a]
	White	9.38±0.10	4.13±0.02 [c]	0.59±0.04 [c]	1939.46±133.41 [b]	0.03±0.02 [a]	1.94±1.58 [a]	24.90±5.02 [a]	23.20±15.20 [ab]	301.82±44.34 [b]	274.31±20.55	1845.43±251.16 [a]	2099.94±155.63 [a]
Mean		9.41	3.98	0.55	1747.97	1.07	4.23	22.74	31.43	270.75	242.19	1736.55	2178.89
Range		(9.00-9.90)	(3.83-4.14)	(0.44- 0.62)	(1102.9- 2739.0)	(0.01-4.07)	(0.54-6.09)	(10.46-33.75)	(5.68-67.28)	(152.16-468.07)	(145.97-309.99)	(1122.77-2324.94)	(1459.48-2938.19)
Cv		2.41	2.84	9.56	25	110.35	45.2	30.02	54.23	35.14	17.23	18.67	16.99
P value		0.004	<0.0001	0.00	<0.0001	<0.0001	0.001	0.066	<0.0001	<0.0001	0.032	0.118	0.673

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

6.6.2 Effect of processing on the physical properties of guava pulp

Although there were no significant (p=0.639) differences in the pulp yield after pasteurization, there were quantitative yield reductions irrespective of the extraction method, and this averaged 4.3%, with the highest losses (5.8%) being in the hot water blanched white guava pulp (Figure 6.3). In terms of color, the steam-blanched white guava had a significant (p=0.000) increase in lightness index (35) with subsequent redness reduction (-0.9). White guava pulp, on the other hand, had a significantly higher (p=0.004) b* increase and thus a higher yellowness index change (25.8) than the unpasteurized pulp (Figures 6.3). The overall color changes ranged from -5.1 to 37.7 in hot water extracted white guava pulp and were significantly (p<0.0001) higher in the steam blanched red guava pulp (-0.24).

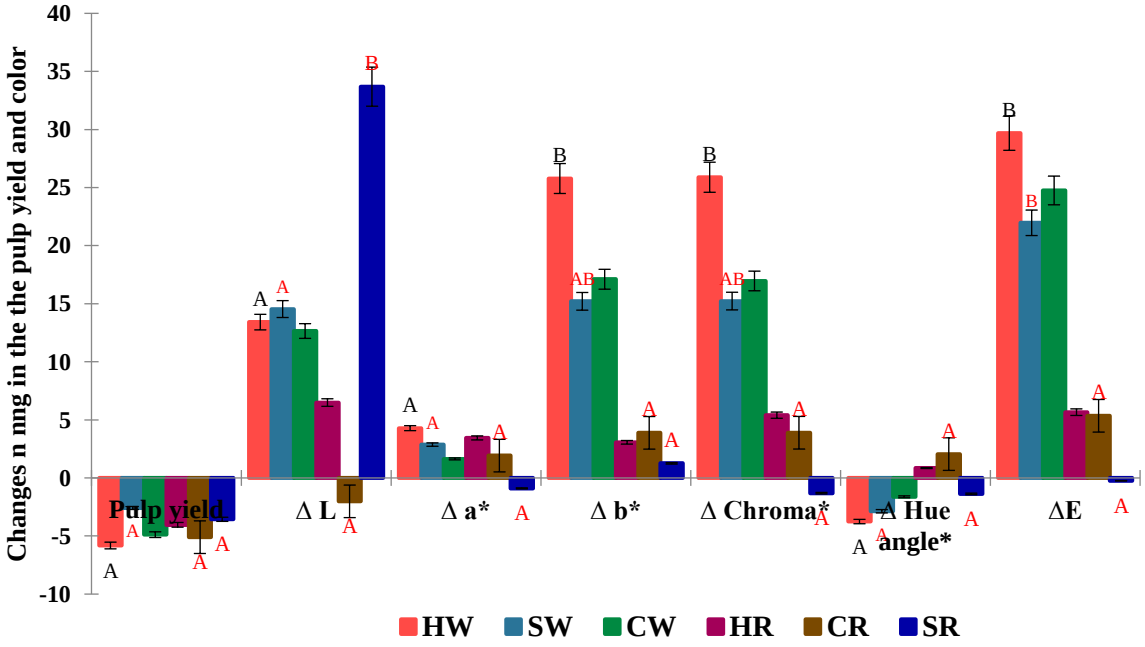


Figure 6.3: Losses/gains in pulp yield and color changes after pulp processing

HW- water-blanched white guava, SW- steam-blanched white guava, CW- cold-pulped white guava, HR- water-blanched red guava, SR- steam-blanched red guava CR- cold pulped red guava. The bars indicate the standard error of the means.

6.6.3 Changes in the proximate composition and chemical composition

All the pulps underwent significant ($p=0.013$) moisture losses, averaging about 4% regardless of extraction method, with hot extraction methods having relatively high losses compared to red guava pulp (Table 6.5). Protein and fat losses were also significant ($p<0.05$), with averages of 0.28 and 0.14 g. The water loss was accompanied by increased carbohydrate and energy content, which did not differ significantly ($p=0.05$) between guava pulps. Pasteurization of the guava pulp had no significant ($p>0.05$) effect on crude fibre and protein changes, though the former showed a decrease compared to the ash, which showed a slight gain (Table 6.5). The changes in total soluble solids, pH, titratable acidity, beta carotene, zinc, and flavonoids gain in pasteurized pulps were significantly higher ($p<0.05$) compared to losses in the vitamin C, iron, calcium, and potassium losses (Table 6.6). The phenolics and antioxidant activities losses of the pasteurized guava pulp, on the other hand, showed no significant ($p>0.05$) differences. The steam blanched red guava pulp had the highest significant ($p=0.001$) loss of vitamin C during pasteurization, at 63.75%, while hot water blanching resulted in a 60.08% loss of vitamin C in the pasteurized white guava pulp (Table 6.6). The cold extraction methods' vitamin C losses were minimal, with no significant ($p>0.05$) loss of red's 26.56% and white's 26.4%.

Table 6.5: Changes in the proximate composition of pasteurized white and red guava pulp extracted using cold and hot methods

Extraction Method	Guava Variety	Moisture (%)	Proximate parameter mg per 100g d.w					
			Ash (g)	Crude Protein (g)	Fat (g)	Crude Fibre(g)	Carbohydrates (g)	Energy (Kcal)
Cold	Red	-1.98±2.36 [a]	0.09±0.04 [a]	-0.55±0.01 [a]	-0.25±0.08 [ab]	-11.55±2.34 [a]	12.26±2.32 [a]	44.60±9.39 [a]
	White	-2.10±1.66 [b]	0.16±0.27 [a]	-0.18±0.02 [c]	0.13±0.21 [c]	-11.37±14.44 [a]	11.27±14.38 [a]	45.49±55.70 [a]
Hot water blanching	Red	-1.47±1.93 [ab]	0.08±0.13 [a]	-0.49±0.13 [ab]	-0.29±0.07 [a]	-8.14±2.28 [a]	8.85±2.32 [a]	30.80±8.42 [a]
	White	-1.77±1.59 [b]	0.00±0.04 [a]	0.06±0.16 [d]	0.00±0.09 [bc]	-1.89±3.50 [a]	1.83±3.37 [a]	7.53±13.58 [a]
Steam blanching	Red	-0.58±0.45 [ab]	0.01±0.06 [a]	-0.29±0.05	-0.23±0.06 [ab]	-1.81±1.27 [a]	2.32±1.35 [a]	6.07±5.05 [a]
	White	-1.00±0.04 [ab]	0.00±0.08 [a]	-0.20±0.06 [c]	-0.16±0.11 [ab]	0.49±3.10 [a]	-0.13±3.16 [a]	-2.77±11.67 [a]
Mean loss/gain		-4.35	0.06	-0.28	-0.14	-5.98	6.34	22.98
P value		0.013	0.546	<0.0001	0.0	0.054	0.048	0.045

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

Table 6.6 Changes in the chemical, mineral and phytochemical composition of pasteurized white and red guava pulp extracted using cold and hot methods

Method	Guava Variety	Chemical parameter (per 100 g d.w.)											
		Total soluble solids (f.w)	pH (f.w)	Titratable acidity (f.w)	Vitamin C (mg d.w)	β-Carotene (mg d.w)	Zinc (mg d.w)	Iron (mg d.w)	Calcium (mg d.w)	Potassium (dw)	Flavonoids (mg.CE d,w)	Phenolics (mg GAE d.w)	Antioxidant Activity (µMTE)
Cold	Red	0.45±0.24 [abc]	0.24±0.01 [c]	0.00±0.02 [a]	-417.140±149.28 [b]	-1.18±1.62 [a]	-1.13±1.24 [a]	-7.92±3.97 [ab]	-11.35±4.63 [ab]	-12.68±42.91 [bc]	76.03±22.97 [b]	-334.62±474.19 [a]	-180.13±166.64 [a]
	White	0.30±0.08 [ab]	0.13±0.02 [b]	0.01±0.01 [a]	-629.16±111.81 [ab]	-0.04±0.06 [ab]	0.07±3.47 [a]	-7.18±11.13 [ab]	-29.32±7.65 [a]	59.00±74.79 [c]	44.80±10.31 [ab]	-96.77±543.29 [a]	-298.70±467.30 [a]
Hot water blanching	Red	0.76±0.22 [c]	0.18±0.02 [b]	0.11±0.06 [a]	-438.14±375.16 [b]	0.62±0.52 [b]	0.39±2.40 [a]	-9.13±6.12 [ab]	-14.18±9.40 [ab]	13.03±93.59 [bc]	-14.65±78.77	-112.12±217.93 [a]	-211.36±256.76 [a]
	White	1.85±0.21 [d]	-0.06±0.03 [a]	0.01±0.00 [a]	-1197.5±168.61 [a]	-0.10±0.09 [ab]	1.21±1.29 [a]	-8.10±2.77 [ab]	25.40±5.82 [c]	-195.46±80.39 [a]	-20.24±47.43 [ab]	-54.05±529.92 [a]	-203.47±367.20 [a]
Steam blanching	Red	0.10±0.36 [a]	0.18±0.04 [b]	0.13±0.03 [a]	-868.2±89.08 [a]	-0.04±0.30 [ab]	3.48±0.72 [a]	3.85±1.90 [b]	-20.86±2.13 [ab]	55.46±46.69 [bc]	24.44±37.12 [ab]	-355.88±236.90 [a]	-262.59±160.02 [a]
	White	0.72±0.05 [bc]	-0.06±0.02 [a]	0.06±0.13 [a]	-1060.57±137.99 [a]	0.84±0.42 [b]	0.84±1.79 [b]	-20.15±5.20 [a]	-1.44±15.25 [b]	-94.07±23.11 [ab]	-49.05±35.60 [a]	-375.48±334.51 [a]	-277.59±549.79 [a]
Mean loss/gain		0.73	0.1	0.05	-768.46	0.05	0.68	-8.64	-8.35	-30.89	8.59	-211.33	-236.84
P value		<0.0001	<0.0001	0.02	0.001	0.02	0.162	0.003	<0.0001	0	0.014	0.764	0.996

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).
Negative values indicate quantitative losses in the respective parameter; positive values indicate quantitative gains in the respective parameter.

6.6.4 Guava pulp textural properties

Except for the work of cohesion, which was not significantly different (p=0.22) for both raw and pasteurized cold extracted pulps, the textural properties of the red guava pulp were superior (p<0.001) to the white guava pulps, both raw and pasteurized. The unpasteurized red guava pulp had the highest firmness (235.2g), with levels ranging from 87.7 to 271.3g. Similarly, the consistency (2175.9 – 7353 g/sec) of the unpasteurized red guava pulp (6295.5 g/sec) was higher. The firmness and consistency of pasteurized red guava pulp were both relatively higher (Table 6.7). The pasteurized guava pulps had higher cohesiveness (-169 to -166 60 g) than the pasteurized pulps (-317.7 to - 258.5g), but no significant differences were found between these and the pasteurized pulps (- 448 to -357 g/sec).

Table 6.7: Textural properties of raw and pasteurized red and white guava pulp extracted using cold and hot methods

Pulp	Variety	Texture			
		Firmness (g)	Consistency (g/sec)	Cohesiveness (g)	Work of Cohesion (g/sec)
Raw	Red	235.18±29.29[b]	6295.50±862.32[b]	-317.76±47.77[a]	-448.09±100.52[a]
	White	195.70±12.08[b]	5232.89±254.41[b]	-258.51±13.30[a]	-340.14±105.14[a]
Pasteurized	Red	129.09±27.67[a]	3409.45±747.46[a]	-166.01±38.30[b]	-357.85±84.98[a]
	White	121.85±34.99[a]	3168.84±1012.59[a]	-168.83±48.31[b]	-357.11±87.27[a]
CV (%)		31.98	33.3	32.91	26.2
P – value		<0.0001	<0.0001	<0.0001	0.222

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

6.7 Discussion

6.7.1 Changes in the physicochemical properties of guava pulp

The high yield of guava pulp extracted using hot methods could be explained by the effect of heat on the cell wall structure of guava fruits. Heat softens the fruit tissues resulting in a much higher output at the pulping stage (Tillett *et al*., 2014). The findings of a much higher yield among red-fleshed guavas are consistent with the results in chapter four. The study reported a relatively high pulp to seed ratio for the Kenyan guava varieties compared to white-fleshed guavas (Chiveu *et al*., 2016). The color of the fruit also determined the color of the resulting pulp. The high L* reading was due to the white-fleshed guava's lack of color components compared to the red's, which has a rich color composition (Ali *et al*., 2014). The increase in total soluble solids and decrease in the dry matter in this study may be attributed to the loss of moisture during the pasteurization step and are similar to the findings of Rossi *et al*. (2003). However, the authors reported that heating inactivates fruit enzymes, responsible for the color loss in the fruit pulp. The net effect is that the color of the fruits improves, which was also the case in the current studies, where L*, a*, b* levels were generally higher in the pasteurized pulp. However, steam blanching may have denatured some of the coloring pigments in the red guava pulp, resulting in a reduction in a* value. The anthocyanins responsible for coloring are sensitive to heat and, therefore, whitening (Najafzadeh *et al*., 2014).

The effect of heat on the changes in guava pulp properties have been studied extensively by authors who have shown that during guava processing, the heat-sensitive vitamin C is lost to as much as 84% as their rate of deterioration through oxidation and denaturation is accelerated during heating (Correa *et al*., 2010; da Silva *et al*., 2016; Jumlah *et al*., 2016; Kumari *et al*., 2017). While the hot extraction method was ideal for extracting the maximum amount of fruit pulp, the detrimental effect of the heat on the nutrients in the guava pulp cannot be overlooked

when compared to the cold extracted guava fruits, which retained significant amounts of desirable nutrients, making it the optimal method for fruit preservation. Similarly, in the current study, as much as the heat and steam blanching led to high extraction, the vitamin C was highly affected and may be attributed to the two-stage heating, which may be unrecommended (Tillett *et al*., 2014).

The pulp proximate, chemical, and phytochemical compositions were least affected in the cold extracted guava pulps as the steam and hot water blanching probably increased the diffusion of the chemicals from the tissues into the heating medium study (Egea & Takeuchi, 2020; SÁnchez *et al*., 2009; Silva & Abud, 2017; Vijaya *et al*., 2020; Youssef *et al*., 2017). Apart from leaching minerals and phytochemicals, the heating process also led to vaporization of the pulp's bound water, affecting the moisture content lost through evaporation, resulting in a reduction in the final pulp. These findings corroborate similar reports by Rossi *et al*. (2003) and Tanwar *et al*. (2014).

The high retention of beta carotenes, phytochemicals, and minerals in cold extracted red guava pulp despite the relatively lower yield in the pulp is consistent with the findings in chapter four of nutritional superiority and higher processing qualities for the Kenya red flesh guava varieties. Similarly, when compared to hot methods, cold extracted white guava pulp retained more nutrients. These findings are consistent with Marques *et al*. (2006), who demonstrated that, despite aiding in the destruction of enzymes and microorganisms responsible for fruit loss, heating causes nutrient degradation (Silva & Abud, 2017). However, nutrient-conserving methods such as freeze-drying are often prohibitively expensive, limiting their use in small-scale processing (Husen *et al*., 2014) (Husen *et al*., 2014) and therefore need for adopting the cold extraction method during the process.

In terms of the functional properties, the guava pulp is pseudoplastic, and as a result, Diniz *et al*. (2014) reported that its viscosity decreases with increasing temperature. Additionally, their findings corroborate the current output that the consistency and firmness of pasteurized pulp decreased significantly between the two varieties. However, when compared to white guava pulp, red guava pulp exhibited significantly superior characteristics as it has been shown to lose consistency when heated, which increases its flow behavior index (SÁnchez *et al*., 2009). This was also observed in this study, implying that the red guava pulp possesses and given its better cohesion and superior rheological properties, it would be much easier to work with during processing than the white. Given the limited processing of guava in Kenya, additional research must be conducted on the fruits' rheological properties, which are critical as a quality control parameter and in the design, evaluation, and operation of processing equipment (SÁnchez *et al*., 2009).

6.8 Conclusion and recommendation

Seeds in the exotic and indigenous white and red guava fruits resulted in a high seed to pulp ratio, impeding optimal extraction. However, regardless of the extraction method used, red guava fleshed guava would yield a significantly higher pulp with superior nutrient retention and rheological properties compared to the white guava pulp. Although the cold extraction method is preferable, hot extraction methods produce higher yields at the expense of heat-labile nutrients, particularly vitamin C, which are severely affected during processing and processors should take care to keep the severity of pulp processing regimes to a minimum while maintaining the required processing standards.

CHAPTER SEVEN : SENSORY ACCEPTABILITY AND PHYSICOCHEMICAL QUALITIES OF GUAVA NECTARS BLENDED WITH *MORINGA OLEIFERA* LEAF EXTRACT

7.1 Abstract

Guavas are perishable fruits found throughout the world's tropical and subtropical regions. The fruits thrive in rural areas with favorable climate conditions in Kenya. However, the fruits are not commercially produced or processed, resulting in extremely high annual losses. This study sought to assess the effect of the blending guavas to maximize nutritional benefits and minimize losses. A completely randomized study design was adopted in the formulation guava nectars which were subjected to organoleptic tests from randomly selected participants (n=35). The unblended guava nectars were made using 25% of cold extracted fruit pulp and other permitted food ingredients specified in the Kenyan standards. The blended nectars were created with similar ingredients using a food-to-food fortification by blending with 12.5 - 20% of *Moringa oleifera* leaf extract into the ameliorated guava nectars to ensure compliance to standards. A comparative analysis was used to assess the effect of blending on the physicochemical properties of guava nectars between the unblended and the most preferred blended nectar. The sensory panelists clearly distinguished the formulated guava nectars with the organoleptic scores among the formulations explaining approximately 70% of the variability on a PCA biplot. The formulations' mouthfeel had the highest discriminating power (test power 3.94, $p=0.00004$) differentiating the nectars. The standardized sensory profile indicated that including moringa leaf extract up to 12.5% resulted in comparable overall acceptability (5.9±0.8) as the unblended nectars' (5.3±0.9). However, increasing the leaf extract beyond 12.5% resulted in significantly ($p=0.0001$) low organoleptic scores. Except for the crude proteins, carbohydrates, and the energy, there were no significant ($p>0.05$) differences in the moisture content, ash, fat, crude fibre, TSS, pH, and the titratable acidity

between the most acceptable blended, unblended formulated nectars and the sampled commercially traded nectars/juices. However, the most acceptable nectars had significantly superior nutritional profiles compared to the commercially traded samples. The *Moringa oleifera* juice extract significantly (p=0.000) resulted in high zinc (4.62±2.14mg), iron (4.62±2.14mg), vitamin C (574.16±116.22), β-carotene (0.34±0.03mg), flavonoids (217.02±18.82mg), phenolics (1934.81±198.33 mgGAE) and antioxidant activity (1934.81±198.33 µMTE 100-1 g) per 100g d.w in the blended nectars compared to the unblended. The inclusion of moringa leaf extract resulted in nutrient-enriched guava nectars. However, studies on the nutrient bioavailability and stability during storage should be evaluated to ensure consumers benefit from the fortificants.

7.2 Introduction

The future fruit consumption projections show a high demand, with research indicating possible unavailability and insufficient supplies as the global food system fails (Mason-D'Croz *et al*., 2019). With rising demand and shifting food systems, developing countries are likely to continue to consume insufficient amounts of the recommended daily fruit intake of 200 grams per person (Keding *et al*., 2017), which is exacerbated by low economic development, population pressure, and changing climatic conditions (Mason-D'Croz *et al*., 2019). However, because they are high in essential micro and macronutrients and are significantly cheaper and more accessible to rural households with limited purchasing power, neglected and underutilized fruits have been among the most recommended to meet nutritional needs, although their consumption to meet the daily fruit consumption target remains a mirage (Baldermann *et al*., 2016). Despite being an orphaned fruit, guava can contribute to daily fruit consumption (Keding *et al*., 2017). On the other hand, the fruits have a very short shelf life

once they reach peak maturity, so proper post-harvest handling and preservation techniques are essential for consumption after the fruits have gone out of season (Singh, 2017).

Guavas are nutritious and readily available during the glut. Still, their low consumption, commercialization, and neglect have resulted in their underutilization in Kenya and consequently high losses necessitating the need for value addition (Omayio *et al*., 2020). Compared to unprocessed forms, processed food valorizes crops through value-added aspects, which often increases consumer appeal and, thus, willingness to pay, in addition to ensuring consistent supply when crops are out of season (Uchôa-thomaz *et al*., 2014). According to studies, guava fruit has a limited shelf life in Kenya and can only be stored for 3-6 days under room temperature (20±5^{o}C) conditions (Omayio *et al*., 2020). However, Katumbi *et al*. (2021) found that fruits stored in modified atmosphere packages under cold storage (10±2^{o}C) had a significantly longer shelf life. The baseline survey on guava production and utilization paints a bleak picture of abundant production, the fate of which more than 70% of the fruits produced in Kenya each year are lost (Omayio *et al*., 2020). This was attributed to low consumption levels, low marketability, and a lack of traditional processing techniques among local varieties (Omayio *et al*., 2020). Guava fruits are nutrient-dense, and as a result, when most fruits go to waste, consumers lose valuable vehicles for micro and micronutrient intake (Vijaya *et al*., 2020).

Lack of knowledge and appropriate processing techniques have been cited as significant constraints affecting the production, processing, and utilization of traditional and indigenous food crops in Kenya, leading to and thus perpetuating losses (Baldermann *et al*., 2016). These issues arise due to continued indifference from key stakeholders such as fruit processors, breeders, extension officers, and consumers who prefer to buy imported guava products.

The Kenyan guava, which is among indigenous food resources, is a foundation for a diversity of food systems (Durst & Bayasgalanbat, 2014), with indigenous varieties dominating the production area (Omayio *et al*., 2019) and limited processing denying farmers and consumers the socioeconomic benefits from these fruits. There have been few studies that have profiled the nutritional characterization of Kenyan processed guava fruits. As a result, the need for market-led demand creates opportunities to exploit the local guava value chain by introducing locally processed guava products into Kenyan markets to balance trade inequalities (da Silva *et al*., 2016).

Fruit nectars have grown in popularity worldwide as consumers perceive them to be more nutritious because they contain whole fruit juices (Krumreich *et al*., 2018). Since industrial processing is non-existent, there are no known locally produced guava nectars or juices (Omayio *et al*., 2019; Omayio *et al*., 2020). Guava fruits are commonly grown in Kenya's rural areas. Marketing the processed fruits in these areas is difficult due to low purchasing power and easy access to fresh fruits in most homesteads when they are in season (Chiveu, 2018). Furthermore, the marketability of guava fruits is frequently hampered by their high perishability, necessitating processing to ensure a consistent supply of processed fruits in the markets (Azzolini *et al*., 2005). Although processed guava nectars have developed a significant economic presence on the market as tropical fruit juices are becoming increasingly popular because they are natural, high in nutrients, and can be substituted for soft drinks (Akesowan & Choonhahirun, 2013), there are limited locally processed guavas distributed to consumers in urban and peri-urban areas of Kenya where access to the fresh fruit is limited (Omayio *et al*., 2020).

The current study sought to develop nutrient-enriched acceptable guava nectars for commercially viable guava products while adopting the local Kenyan standards for processed

fruits, nectars, and juices (KEBS, DKS 2580:2018). The protocols for the processing established in this study target households and MSMEs with small and medium scale processing capacities.

7.3 Materials and methods

7.3.1 Study design

This incorporated multistage study designs. First, a completely randomized design was adopted for the formulation of blended and unblended guava nectars. The *Moringa oleifera* leaf extract was utilized to improve the nutritional content of the guava nectars through a food-to-food fortification by blending the extract in varying ratios while the unblended nectars were formulated without addition of the extract. Organoleptic evaluations of the formulated nectars were then conducted using sensory scores from randomly selected willing panelists. Using discriminatory tests, the most acceptable blended guava nectars were compared to the unblended nectars for their acceptability and physicochemical properties.

7.3.2 Procurement of moringa leaves and guava fruits

Approximately 50kg of fresh moringa leaves were obtained from Voi, Taita Tavaeta County, by plucking from tree branches in the early morning hours of 6 – 9.00 a.m. to avoid field heat. The leaves were immediately packaged in modified atmosphere packages using food-grade hermetically sealed gunny bags and transported to the food pilot plant at the University of Nairobi. Approximately 250 kg of red-fleshed guavas were obtained as described in section 4.3.2 from farms in Kitui and Taita Taveta counties.

7.3.3 Guava pulp and moringa leaf juice extraction

The guava pulp was obtained by use of cold extraction methods as outlined in section 6.3.4. The moringa leaves were sorted for juice extraction as described by Quarcoo (2008) after cleaning with potable water. The leaves were blended using a commercial kitchen blender after adding potable water (200mls per 100g of *Moringa oleifera* leaves) and boiled at 90^{o}C for 10 minutes. The slurry was then filtered using sanitized cheesecloth to obtain the extract, which was hot-filled into 5-litre airtight plastic containers at 55-60 ^{o}C. After cooling, the extract was kept refrigerated at 10 ±2^{o}C for the nectar's product development.

7.3.3.1 Processing of blended and unblended guava nectars

A completely randomized design was used to select pulps from four different batches of pulp for nectar processing. Preparation of nectars made use of 25% guava pulp as required by KEBS (2016) standards for guava fruit nectars, 10% TSS by adding sugar at a rate of 8g/litre, 2.5g/l citric acid, and filling to volume using potable water (Kadam *et al*., 2012a). For the blended nectars, the moringa leaf extract was added in ratios of 12.5, 15.5, 17.5 and 20% relative to the entire nectar batch as described by Quarcoo, (2008) and Rani & Babu, (2015). Amelioration was used to ensure compliance of the total soluble solids (TSS) and acidity to standards. Triplicate samples were prepared from the randomly selected pulp batches. In each, duplicate samples of at least 1 kg were hot-filled at 55-60 ^{o}C into airtight translucent PET plastic bottles and stored frozen at -20^{o}C until further analysis.

7.3.4 Sensory evaluation of formulated guava nectars

Coded samples of the formulated guava nectars were evaluated using a 7-point hedonic scale by an untrained panelist (n=35) for appearance, aroma, taste, mouthfeel, and overall acceptability. The panelists included a relatively equal number of male and female participants

of mixed age categories. The participants were obtained randomly from the University of Nairobi's College of Agriculture. Consent was sought to participate in the evaluation before commencement.

7.3.5 Analytical methods for the preferred guava nectars

Based on the consumer scores, the blended nectars with the highest scores and the unblended nectar samples were subjected to analysis by assessing the proximate, pH, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, beta-carotene, mineral content and phytochemical analysis in duplicates as outlined in sections 4.3.4.3 - 4.3.4.9.

7.3.6 Market testing of guava nectars

Approximately 250 litres of each guava nectars formulation were packaged in 250- and 500-ml plastic bottles, and their commercial viability was assessed through the University of Nairobi's pilot plant sales kiosk. The nectars' sale prices of Ksh. 200 and 250 per litre for the unblended and blended nectars, respectively, were based on the sales price for the commercially traded guava nectars products in the Kenyan markets. During the sales, customers were asked to provide feedback to improve the nectars.

7.4 Data analysis

The data were entered into Microsoft Excel. The sensory packages in XLSTAT for Excel (Addinsoft, 2021) for product characterization, sensory profiling, and statis analysis were used to display consumer organoleptic scores and generate the most preferred samples. The physicochemical compositions of blended and unblended nectars were analyzed using the Xlstat Microsoft Excel plugin (Addinsoft, 2021) with one-way ANOVA and Turkey's HSD test ($p \leq 0.05$) used to separate significantly different means ($p < 0.05$) among the nectars'

variables. Data on the cost of production and revenue generation from the sales of the guava nectars was used to determine the cost-benefits analysis of processed guava nectars.

7.5 Results

7.5.1 Sensory analysis of formulated nectars

The panelists' organoleptic scores indicated that the participants were able to distinguish the five guava nectar formulations, with a biplot PCA for the hedonic scores explaining approximately 72% of the variability between consumer scores for the guava formulations, demonstrating that all formulations were significantly dissimilar except for minor differences in the respective organoleptic properties (Figure 7.1). The mouthfeel of the formulations had the highest discriminating power (test power = 3.935, p = 0.00004) of all the product descriptors, with appearance having the least effect (Figure 7.1).

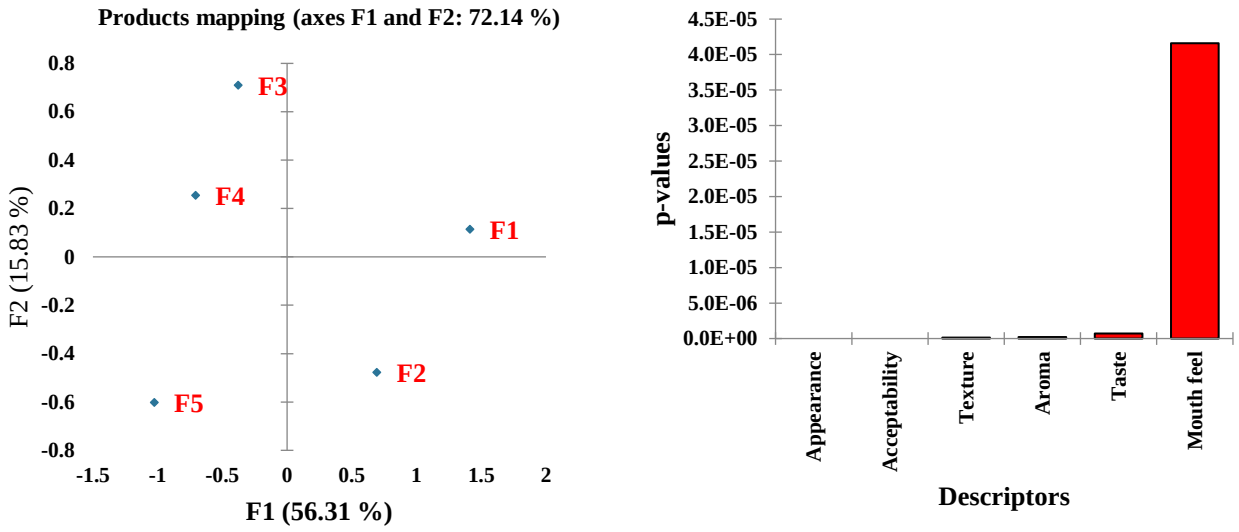


Figure 7.1: Sensory product mapping based on consumers' discriminating scores for the respective formulations' organoleptic parameters and descriptor powers.

F1- Unblended guava nectar, F2- Blended nectars (12.5% MLE), F3- Blended nectars (15% MLE), F4- Blended nectars (17.5% MLE) and F5- Blended nectars (20% MLE).

Generally, the unblended guava nectars (F1) compared favorably with the nectars blended with 12.5% *Moringa oleifera* leaf extract (F2) for all organoleptic parameters. Although the unblended had higher scores for all the respective sensory parameters they were not significantly ($p>0.05$) different from those of formulation 2 (Table 7.1).

Table 7.1 Sensory scores for the formulated guava juices

Product	Organoleptic parameter					
	Appearance	**Aroma**	**Taste**	**Texture**	**Mouth feel**	**Acceptability**
F1	5.9±1.2 [b]	5.4±1.3 [c]	5.8±0.9 [b]	5.3±0.9 [c]	5.4±1.1 [b]	5.9±0.8 [c]
F2	5.0±1.0 [b]	5.0±1.2 [bc]	5.3±0.9 [ab]	4.9±1.0 [bc]	5.0±1.0 [ab]	5.3±0.9 [bc]
F3	4.3±1.4 [a]	4.2±1.6 [ab]	4.8±1.5 [a]	4.7±1.3 [abc]	4.4±1.1 [a]	4.4±1.6 [ab]
F4	4.2±1.2 [a]	4.1±1.6 [ab]	4.5±1.4 [a]	4.6±1.1 [ab]	4.3±1.5 [a]	4.4±1.4 [ab]
F5	4.0±1.6[a]	4.0±1.5 [a]	4.5±1.6 [a]	4.0±1.2 [a]	4.4±1.4 [a]	4.2±1.6 [a]
C v (%)	31.3	33.6	27.9	25.0	27.6	30.1
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.000	<0.0001

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test). F1- Unblended guava nectar, F2- Blended nectars (12.5% MLE), F3- Blended nectars (15% MLE), F4- Blended nectars (17.5% MLE) and F5- Blended nectars (20% MLE).

The mean scores for the sensory profile remained unchanged after adjusting the sensory scores with a PCA biplot of the first two axes explaining 99.6% of the score variability. According to the PCA plot, product F5 with the highest *Moringa oleifera* inclusion at 20% would have the

least score for all parameters, with negative scores on both axes, similar to the unadjusted mean scores) (Figure 7.2). The unblended and 12.5% *Moringa oleifera* inclusion would compare favorably with overlapping ellipses in appearance, aroma, mouthfeel, and acceptability at 95% confidence, as indicated by positive sensory profile coefficients for most of the parameters. However, the scores for formulations with 15% (F3) and 17.5% (F5) would remain unchanged because the 95% confidence ellipses overlapped, indicating similar sensory scores (Figure 7.2).

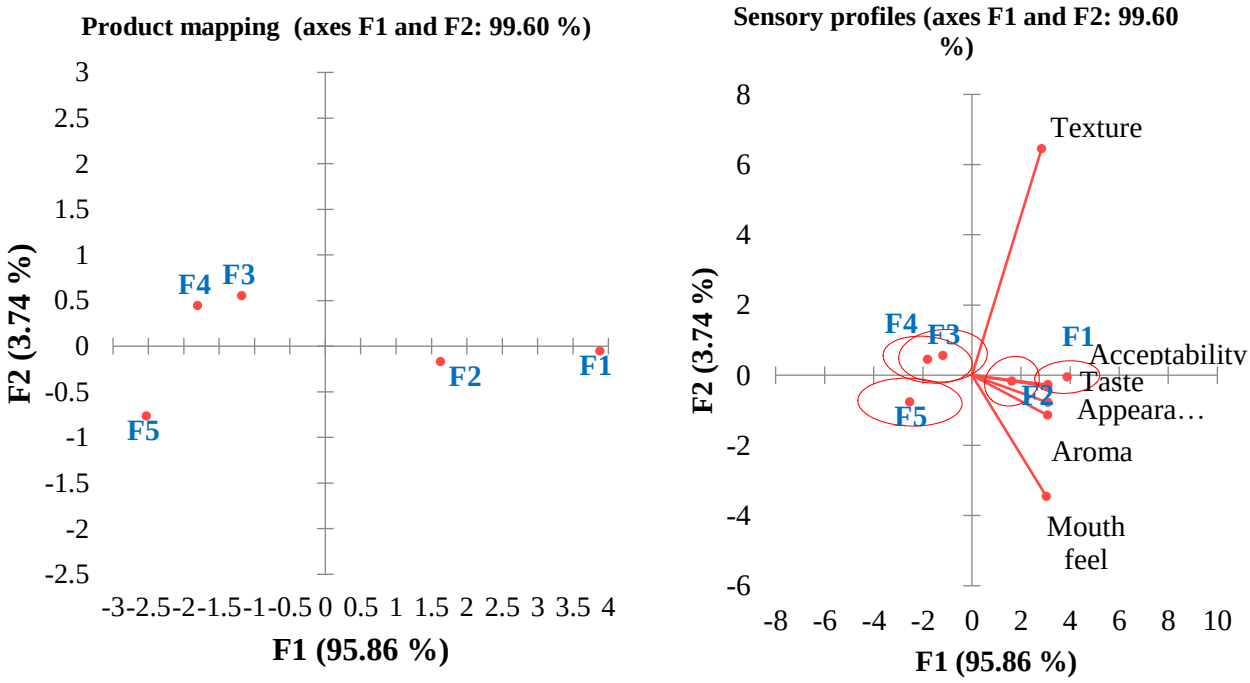
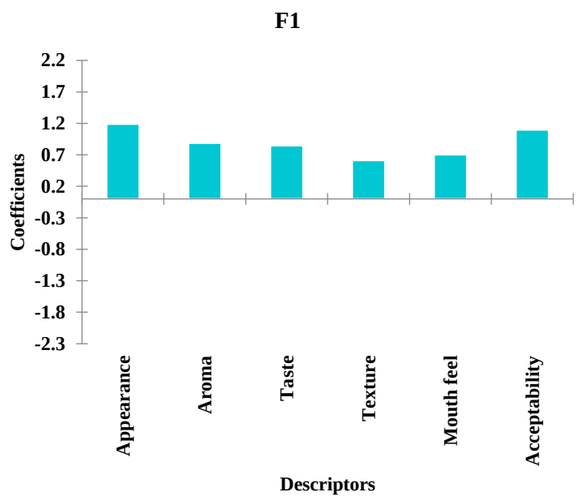
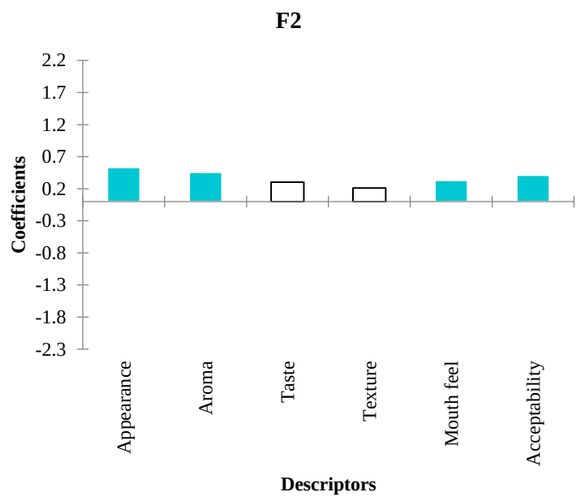
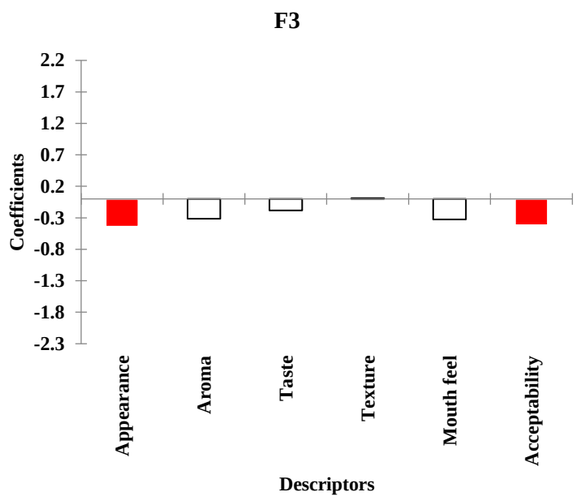


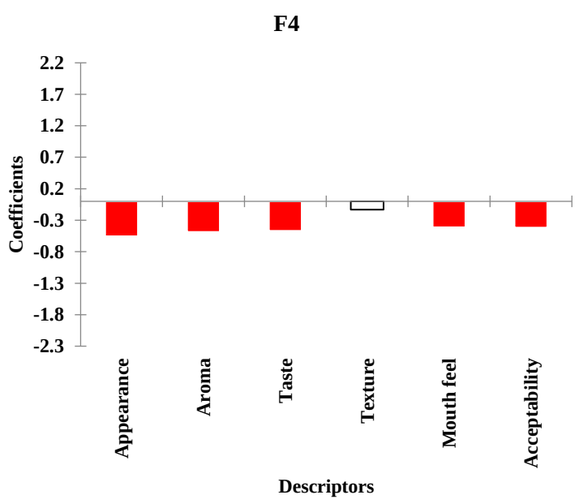
Figure 7.2: PCA plots for product biplot mapping and respective biplots with 95% confidence ellipses for the adjusted means of sensory parameters based on consumers' organoleptic scores.

There were substantial color changes when the leaf extract concentrate was increased above 12.5%. Furthermore, due to the extract's interference with the fruit's natural aroma, flavor, and textural properties, as indicated by the negative coefficients (Figure 7.3), the extract resulted in a declining score for the aroma as the texture.









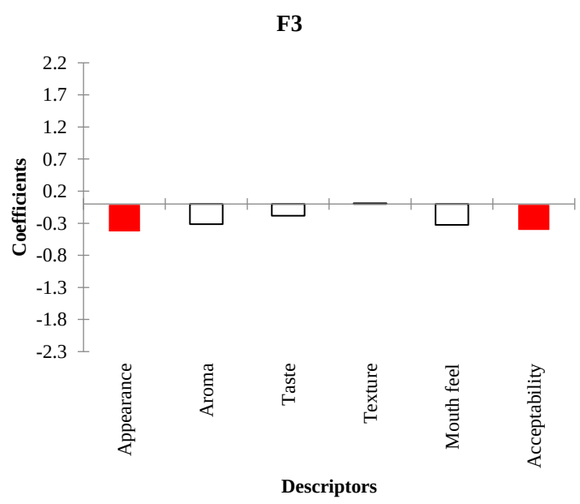


Figure 7.3: Effect of inclusion of the *Moringa oleifera* juice extract on consumer acceptability scores for the guava nectar formulations.
The blue shade denotes acceptance. The red shade denotes decreasing acceptance as the amount of *Moringa oleifera* leaf extract added increases. The noncolored shade denotes that the parameter does not affect the panelists' acceptance of the parameter. F1- Unblended guava nectar, F2- Blended nectars (12.5% MLE), F3- Blended nectars (15% MLE), F4- Blended nectars (17.5% MLE) and F5- Blended nectars (20% MLE).

7.5.2 Physicochemical characterization of the acceptable guava nectars

There were no significant differences in the differences in all the color parameters (Table 7.2). The lightness index was highest in the blended nectar averaging 43.07 compared to the unblended' s 42.83. The blended nectar equally had higher b*, chroma and hue angles of 10.3, 13.3, and 51.3 respectively. However, the redness (a*) of the unblended was the highest at 8.82 (Table 7.2).

Table 7.2: Color of blended and unblended guava nectars

Products	Color parameters				
	L	**a***	**b***	**Chroma***	**Hue angle***
Blended guava nectar	43.07±1.13 [a]	8.31±0.39 [a]	10.30±1.05 [a]	13.18±0.96 [a]	51.29±2.07 [a]
Guava nectar	42.83±1.49 [a]	8.82±0.27 [a]	9.75±0.58 [a]	13.16±0.27 [a]	47.81±2.48 [a]
Cv (%)	2.86	4.79	8.35	4.98	5.69
P value	0.805	0.072	0.392	0.961	0.075

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, $P \leq 0.05$).

7.5.3 Proximate composition of the guava nectars

No significant ($p>0.05$) differences were observed in the proximate composition of the guava nectars with although the moisture contents, crude proteins, carbohydrates and energy were relatively high in the blended nectars whereby with concentrations of 87%, 0.36 g, 97.5g and 394 Kcal per 100g respectively (Table 7.3). The crude fat, ash and fibre, whose levels ranged from 0.32-0.35, 0.26-0.42 and 1.62-1.85 g/100g, were highest in the unblended nectars (Table 7.3).

Table 7.3: Proximate composition of guava nectars

Products	MC (%)	Proximate parameters per 100 g d.w					
		Ash (g)	Crude Protein (g)	Crude Fat (g)	Crude Fibre (g)	Carbohydrates (g)	Energy (Kcal)
Blended guava nectar	87.12±0.53 [a]	0.26±0.16 [a]	0.36±0.17 [a]	0.32±0.16 [a]	1.62±0.23 [a]	97.45±0.09 [a]	394.11±0.89 [a]
Guava nectar	86.86±0.62 [a]	0.42±0.32 [a]	0.24±0.10 [a]	0.35±0.15 [a]	1.85±0.31 [a]	95.43±2.81 [a]	385.87±9.60 [a]
C v (%)	0.63	73.96	48.55	42.14	16.36	2.21	1.97
P value	0.542	0.400	0.308	0.778	0.280	0.201	0.138

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, $P\leq0.05$).

The blending resulted in a significantly ($p<0.0001$) high concentration of the total soluble solids and pH at levels 13 and 3.8 (Table 7.4). However, there were no significant ($p=0.26$) differences in the nectars' titratable acidity, and these were least in the unblended (0.34). Although no significant differences were observed in the vitamin C, phenolics and antioxidant activities, their levels were higher than those in the unblended. They ranged from 564-574 mg, 1777-1935 mgGAE and 1377-1975 µMTE per 100g. The moringa, however, resulted in significantly high levels of zinc (4.62 mg), iron (28 mg), calcium (54.0 mg), potassium (87.4 mg) and flavonoids (217.02 mgCE) compared to the unblended guava nectars (Table 7.4).

Table 7.4: Chemical, mineral and phytochemical composition of guava and guava-moringa blended nectars

Products	Chemical composition (per 100 g d.w.)											
	Tss (f.w)	Ph (f.w)	Titratable acidity (f.w)	Vitamin C (mg d.w)	β-Carotene (mg d.w)	Zinc (mg d.w)	Iron (mg d.w)	Calcium (mg d.w)	Potassium (dw)	Flavonoids (mg.CE d,w)	Phenolics (mg GAE d.w)	Antioxidant Activity (µMTE)
Blended guava nectar	13.03±0.13[b]	3.78±0.01[b]	0.36±.01[a]	574.16±116.22[a]	0.34±0.03[a]	4.62±2.14[b]	28.87±6.21[b]	54.00±5.30[b]	87.35±5.30[b]	217.02±18.82[b]	1934.81±198.33[a]	1975.02±479.73[a]
Guava nectar	12.28±0.10[a]	3.66±0.01[a]	0.34±0.03[a]	563.73±92.13[a]	0.46±0.06[b]	1.81±0.06[a]	12.01±1.54[a]	15.00±2.47[a]	55.82±10.70[a]	132.31±8.86[a]	1776.81±114.34[a]	1377.03±328.01[a]
C v (%)	3.27	1.68	6.96	17.09	18.95	63.74	48.61	61.44	25.95	27.07	9.27	29.65
P value	<0.0001	<0.0001	0.261	0.893	0.012	0.039	0.002	<0.0001	0.002	0.000	0.217	0.085

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05)

7.5.4 Market testing

There was generally high consumer acceptability of the guava nectars with about 60% of return customers. Based on pricing for similar products, market-testing showed that the most consumer suitable guava nectars would fetch between Ksh 200 and 250 per litre for the unblended and blended guava nectars assuming constant pricing for the labor, energy, water, raw materials, packaging materials and other overhead costs which totalled approximately Ksh 93 and 105 per litre respectively. This translated to an average profit of Ksh 106 – 145 per kg of processed fruits compared to the insignificant revenues of Ksh 2- 10 realized from the raw fruits at the farm gate purchases.

7.6 Discussion

7.6.1 Sensory profile of formulated nectars

Increasing the extract resulted in lower acceptability scores for the respective sensory characteristics, which may be associated with the consumers' perceptions of the guava nectar products (Zhong *et al*.,2018). In the current study, the extract's increasing greenness reduced the red color of the guava pulp, resulting in low color scores. Furthermore, the mouthfeel had the higher test power than any other sensory parameter because the flavors from the extract were introduced and were easily picked because they masked the typical guava flavor and taste.

Although the current study may have resulted in a trade-off between taste and improved nutritional quality, the willingness to consume nectars with ratios greater than 15% may have resulted in excessively strong flavors, resulting in the negative scores on the sensory score profile. This is consistent with De Groote *et al*. (2020), who reported that food-to-food fortification does not result in improved sensory acceptability and thus need for less compromise less on taste while ensuring optimal levels of micronutrients.

Given the limited research on food-to-food fortification, particularly in ready-to-drink juices, a comparison with Rani & Babu (2015)'s studies blending guava nectars with aloe vera juice shows that higher levels of the extract would be tolerable, with as much as 30- 40% aloe vera juice inclusion resulting in acceptable fruit nectars. This ratio was higher than that of moringa leaf extract, which could be due to the mild taste and odor of aloe vera compared to moringa extract, which could have introduced stronger flavors. However, masking such flavors through processing additives such a permitted food-grade flavors and colors can aid in boosting the levels of the desirable fortificants (Oyeyinka & Oyeyinka, 2018), although these were not evaluated in the current study.

In contrast to these findings, where the acceptability of blended nectars was much lower, Quarcoo (2008) demonstrated that incorporating up to 50% - 52% moringa leaf extract into pineapple, carrot, and lemon juice blends resulted in acceptable juices. This could be attributed to the intense flavors of the pineapple fruit and lemon juices, which masked the moringa taste instead of the guava fruits, whose flavor and taste intensity may not have been comparable.

7.6.2 Physicochemical composition and marketing of the acceptable nectars

The relatively high levels of all key nutrient composition of both blended and unblended guavas compared to they may be commercial guava juices and nectars may be attributed to the relatively high fruit ratio as per the requirements, whereby it was observed that the majority of the processors whose brands were evaluated used much less fruit pulp and substituted the remainder with flavors.

The addition of moringa to guava nectars had a negligible effect on the proximate composition of guava nectars. Thus the acceptable levels would not result in significant changes in the nectars' macronutrient composition compared to the unblended nectars, making it an ideal fortificant

because it should not interfere with the key food ingredients matrix as recommended by WHO (2006). However, extraction of micronutrients via decoction was effective and compared favorably to fresh leaves or solar-dried milled leaf powder (Kumar, 2004). On the other hand, the extracts had a more appealing color than the solar-dried milled leaves, which have been associated with a dark, unappealing green color when blended into fruit juices, unless consumers have developed acquired organoleptic taste (Naa *et al*., 2013).

Thus, the addition of moringa leaf extracts significantly altered the micronutrient composition of the guava nectars, correlating with similar studies by El-rahim *et al*. (2017) and Naa *et al*. (2013), who found that adding moringa to ready-to-drink fruit beverages increased their micronutrient profile. Thurber and Fahey (2009) report that despite the scarcity of empirical data from clinical trials, there has been widespread evidence-based use of the nutrient-dense *Moringa oleifera*, a micronutrient-dense crop that may aid in the fight against malnutrition which was also true in the current study

Moringa leaves, which are extremely high in vitamins A, C, iron, zinc, calcium, and potassium (Fahey, 2005), resulted in a correlation between the high micronutrient content of the blended nectars, indicating the plant's nutritional potential. The leaf extract resulted in an increase in the iron and zinc micro minerals, which is consistent with previous research by Yang *et al*. (2006), who reported similar properties for moringa leaves, suggesting that affordable and easily accessible moringa leaves may be an effective way to combat micronutrient deficiencies. Additionally, the crop thrives in rain-scarce agroecological zones (Mikore & Mulugeta, 2017), similar to the study sites. Moringa is also a source of numerous bioactive compounds, including phenolics, flavonoids, and antioxidants, which account for the current high concentrations in blended nectars (Affiku, 2011; Gidamis *et al*., 2003; Gopalakrishnan *et al*., 2016b; Oyeyinka &

Oyeyinka, 2018). Due to its high nutritional contents, it thus provides an alternative to improve the nutrient contents of the nectars obtained from the local guava fruits.

Whereas these products were acceptable among consumers, consuming locally processed fruit may impede accessing the local market, as previous studies have shown that guava is commonly consumed fresh in Kenya (Omayio *et al*., 2020). However, the evaluation of guavas' cost-benefit processing indicates that processing shelf-stable nectars would increase revenues as these products were commercially feasible and highly acceptable among consumers. As a result, as much sensitization as possible for consuming processed guava fruit may be required.

7.7 Conclusion and recommendation

While estimated losses of more than 50% of annual production for various fruits and food groups in SSA Africa, combined with high rates of malnutrition, make meeting recommended fruit consumption targets in developing countries difficult, underutilized crops such as guavas have the potential to contribute to nutritional security, the apparent gap in processing and preservation notwithstanding. This study led to the development of acceptable nutritious guava nectar that can be simply processed at the household level, preventing high annual losses and ensuring access to processed fruits. With good manufacturing practices in place, processed Kenyan guavas can generate income to improve the guava value chain. It is recommended that *Moringa oleifera*, a nutritional powerhouse, should be widely promoted as a potential crop for eradicating malnutrition for consumption in alternative forms such as blending into fruit juices.

CHAPTER EIGHT : CHANGES IN PHYSICOCHEMICAL AND MICROBIOLOGICAL PROPERTIES OF GUAVA NECTARS DURING STORAGE

8.1 Abstract

While it is critical to develop new products and conduct consumer organoleptic studies, manufacturers must determine shelf stability as soon as possible. On the other hand, the actual time required is significantly longer, necessitating accelerated shelf studies. A multistage experimental study design was used to formulate blended and unblended guava nectars using a completely randomized design followed by a factorial design to determine the effect of packaging and blending on the changes in the pH, TSS, TTA, and microbial loads of guava nectars during accelerated storage (at 55^{o}C) using Arrhenius Q10model kinetics. Results indicate the nectars would be shelf-stable for at least five months with compliance to good manufacturing practices, regardless of packaging type, blending with *Moringa oleifera* leaf extract, or storage length ($p>0.05$) Although there were significant differences ($p<0.05$) in the nectars' TSS, pH, TTA, and TVCs, the yeast and molds levels did not change significantly ($p>0.05$) during storage. Furthermore, the yeast and mold and the total viable counts did not exceed the maximum allowed levels of 30 and 100 cfu/ml, ensuring the nectars' safety. However, significant ($p>0.05$) color deterioration was observed, particularly in nectars packaged in transparent packages attributed to light and non-enzymatic browning reactions. When compared to the unblended nectars, blended nectars showed the most significant color changes (ΔE) in the fifth month (>6.0). They also had the least lightness (L*) values compared to the unblended nectars, and therefore, the need to stabilize the color of the blended nectar. In conclusion, while processing local guavas would result in shelf-stable guava nectars, additional research is needed into the actual storage period, as well as an assessment of the interactions between food matrices, to ensure that the functional and nutritional qualities, as well as acceptability, of nectars, are not compromised.

8.2 Introduction

The food industry faces an urgent need for data to determine a product's shelf life, allowing it to be stored and sold without significant loss of quality or functional properties (Khasanov & Matveeva, 2020). Shelf life is essential as it significantly impacts handling the products' storage, distribution, and shelf-life dating (Mizrahi, 2014). Realtime stability tests and accelerated stability tests are the two most commonly used testing methods in studying product shelf life. In real-time stability testing, a product is stored at the recommended storage conditions and monitored until it fails the specification. On the other hand, accelerated tests require storage under extreme stress conditions such as high temperatures, humidity, and pH. Degradation at the recommended storage conditions can be predicted using known relationships between the acceleration and degradation rates (Haouet *et al*., 2018).

The widespread adoption of accelerated shelf life in the food industry provides an essential tool for determining the feasibility of extending shelf life through proper product formulation and processing techniques (Khasanov & Matveeva, 2020). Because time delays product development and subsequent launch due to actual long storage, the ASLT's practicality is frequently in demand. As a result, the ASLT helps significantly shorten this time through readily available experimental data (Mizrahi, 2011). ASLT is typically based on deteriorative processes that can be chemical, physical, or microbiological, and these are used to obtain experimental data that is fitted into predictive models in which the respective deterioration markers are quantitatively followed through storage to the point of product failure but under specified conditions such as pre-determined temperature (Dube, 2015). Consequently, the need to meet the growing demand for soft drinks has necessitated accelerated shelf studies to predict the stability and behaviour of new products for the market (Ramalingam *et al*., 2010).

The most commonly used acceleration model for chemicals, pharmaceuticals, and biological products is the Arrhenius model, whose deterioration is temperature-dependent (Haouet *et al*., 2018). Temperature has been widely used in shelf-life studies because of its effect on food products' physical-chemical and biological degradation during storage (Phimolsiripol *et al*., 2016). As a result, the Arrhenius equation explains the relationship between temperature and degradation rates (Bedts *et al*., 2018). This study aimed to determine the shelf life of formulated blended and unblended guava juices to predict their behaviour during shelf life at elevated temperatures (55^{o}C), with a minimum of three months per the Kenyan fruit juice and nectar standards.

8.3 Materials and methods

8.3.1 Study design

A multistage experimental study design was adopted to assess the effect of packaging materials on the physicochemical properties of blended and unblended nectars packaged in translucent and transparent PTE bottles. First, a completely randomized study design was used to formulate the blended and unblended guava nectars with four replications of each, as described in section 7.3.3.1. Hurdle techniques, incorporating adequate pasteurization (85^{o}C, 5 minutes), addition of permitted food-grade preservatives (sodium metabisulphites at rates of 300 ppm), and a low pH aided by the addition of citric acid at a rate of 2.5 g/liter to the final product, were done following FAO (2005) standards. A factorial experimental design was used to assess the effect of interactions between the blended and unblended guava nectars and packaging in either transparent or translucent plastic bottles (Malplast Kenya). The packaged nectars were then subjected to accelerated storage trials in triplicates for each day as described below.

8.3.2 Accelerated Shelf-life studies

The Q10 model was used to evaluate the nectar samples every three days until 15 days, based on the Arrhenius modelling, which states that a rise in temperature of 10^{o}C roughly doubles the rate of a chemical reaction for the zero or first-order kinetics (Levy, 2015; Dube, 2015) where every three days was representative of a month during storage, as described by Hemanth *et al*. (2019) and Ramalingam *et al*. (2010).

$$\text{Accelerated Aging Time Duration (AATD)} = \frac{\text{Desired Real time (RT)}}{Q_{10}^{\left(\frac{Te - Ta}{10}\right)}}$$

Where;

AAR (Accelerated Aging Rate) = $Q_{10}^{(Te - Ta)/10)}$

T^a = Ambient Temperature (23^{o}C)

T^e = Elevated Temperature (55^{o}C)

Q_{10} = Reaction Rate = 2 (Industrial standard)

8.3.2.1 Analytical methods

The nectar samples were subjected to analysis by assessing the proximate, pH, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, beta-carotene, mineral content and phytochemical analysis in duplicates as outlined in sections 4.3.4.3 - 4.3.4.9. The microbial analysis for the TVCs and yeast and molds were evaluated as outlined in sections 5.3.4.2.1 and 5.3.4.2.2, respectively.

8.4 Data analysis

Data were entered into Microsoft Excel and then imported into XLSTAT data analysis software (Addinsoft, 2021) to analyze descriptive and inferential statistics for the changes in the physicochemical properties using a two-way ANOVA. The Tukey's test was used to separate the means, with the P-value set ≤ 0.05.

8.5 Results

8.5.1 Physicochemical properties of guava nectars

Except for the total soluble solids, there were no significant ($p>0.05$) differences in the nectars' physicochemical and microbial at day 0 (Table 8.1). These levels in the nectars were also within the Kenyan Bureau of Standards' criteria for fruit juice (KEBS, 2016). The soluble solids varied significantly (12–13.2^{o}Brix), with the blended nectars having the highest concentration. However, the unblended nectars had significantly higher ($p=0.007$) pH values of 3.69-3.71 and significantly higher ($p=0.39$) titratable acidity than the nectars packaged in transparent packages. There were significant ($p<0.05$) differences in color parameters except for lightness ($p=0.0747$), with the unblended nectars having a higher redness index (8.9-9.96) than blended nectars' green index (11.2 – 11.4). The levels of yeast and molds, and TVCs were not significantly different between samples, ranging between 2.6-3.65 and 0.7–2.9 cfu/ml, respectively (Table 8.1).

Table 8.1: Physicochemical properties of packaged guava nectars

Type	Packaging type	Physicochemical parameter									
		TSS (ºBrix)	pH	TTA (%)	L	a*	b*	Chroma*	Hue angle*	TVC (cfu/ml	Yeast and Molds (cfu/ml)
Blended nectar	Transparent	13.15±0.07^{b}	3.77±0^{b}	4.8±0.42^{ab}	43.34±0.91^{a}	8.19±0.33^{a}	11.35±0.25^{b}	15.11±0.55^{b}	48.79±0.98^{ab}	3.65±0.43^{a}	2.1±1.55^{a}
	Translucent	12.9±0.14^{b}	3.78±0.01^{b}	4.2±0.28^{a}	43.55±0.22^{a}	8.47±0.08^{a}	11.18±0.03^{b}	13.86±0.18^{ab}	53.76±1.2^{c}	2.6±0.35^{a}	2.92±0.81^{a}
Guava nectar	Transparent	12.00±0^{a}	3.71±0.01^{a}	5.6±0.42^{b}	42.86±0.01^{a}	9.96±0.55^{b}	10.83±0.32^{a}	13.75±0.29^{ab}	51.93±0.6^{bc}	3.49±0.42^{a}	1.67±2.37^{a}
	Translucent	11.95±0.21^{a}	3.69±0.02^{a}	4.25±0.07^{ab}	43.28±0.84^{a}	8.9±0.27^{b}	8.98±0.79^{a}	12.55±0.75^{a}	45.63±1.62^{a}	3.33±0.67^{a}	0.67±0.95^{a}
C v (%)		4.63	1.18	13.87	1.26	8.69	10.08	7.51	6.86	17.29	79.03
P value		0.002	0.007	0.039	0.747	0.025	0.018	0.031	0.008	0.278	0.585

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

8.6 Changes in the physicochemical properties during storage

8.6.1 Changes in color

The parallel coordinates analysis for the mean color changes shows that the changes, regardless of product packaging or nectar type, increased with storage days, with the least on day three and the most on day fifteen. (Figure 8.1). The juices lost their lightness as the storage days increased, and the hue angles generally increased.

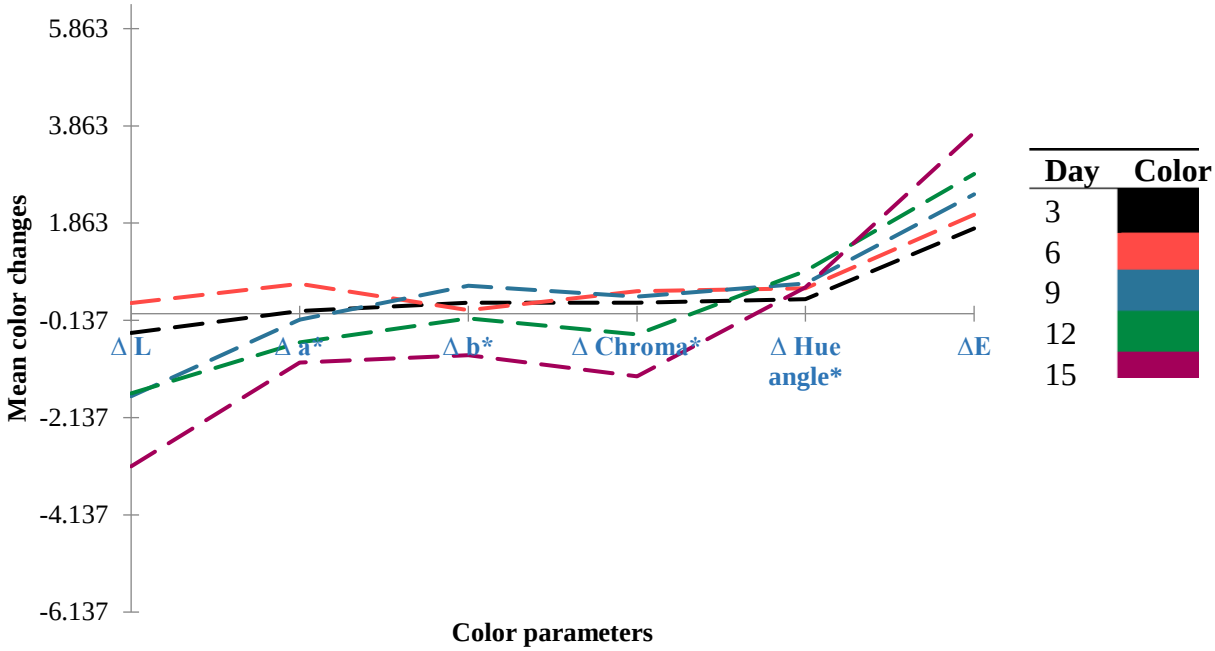


Figure 8.1: A parallel coordinates plot for the changes in color during storage of the guava nectars

All the color parameters changed significantly ($p<0.05$) depending on the type of packaging and the number of days stored (Figure 8.2). Overall, the nectars packaged in transparent bottles showed the most color changes, with the highest overall readings ($\Delta E= 4.7$) on days 15, 12, and 9, compared to the translucent packages on day three, which showed the least overall color changes (($\Delta E= 1.1$).

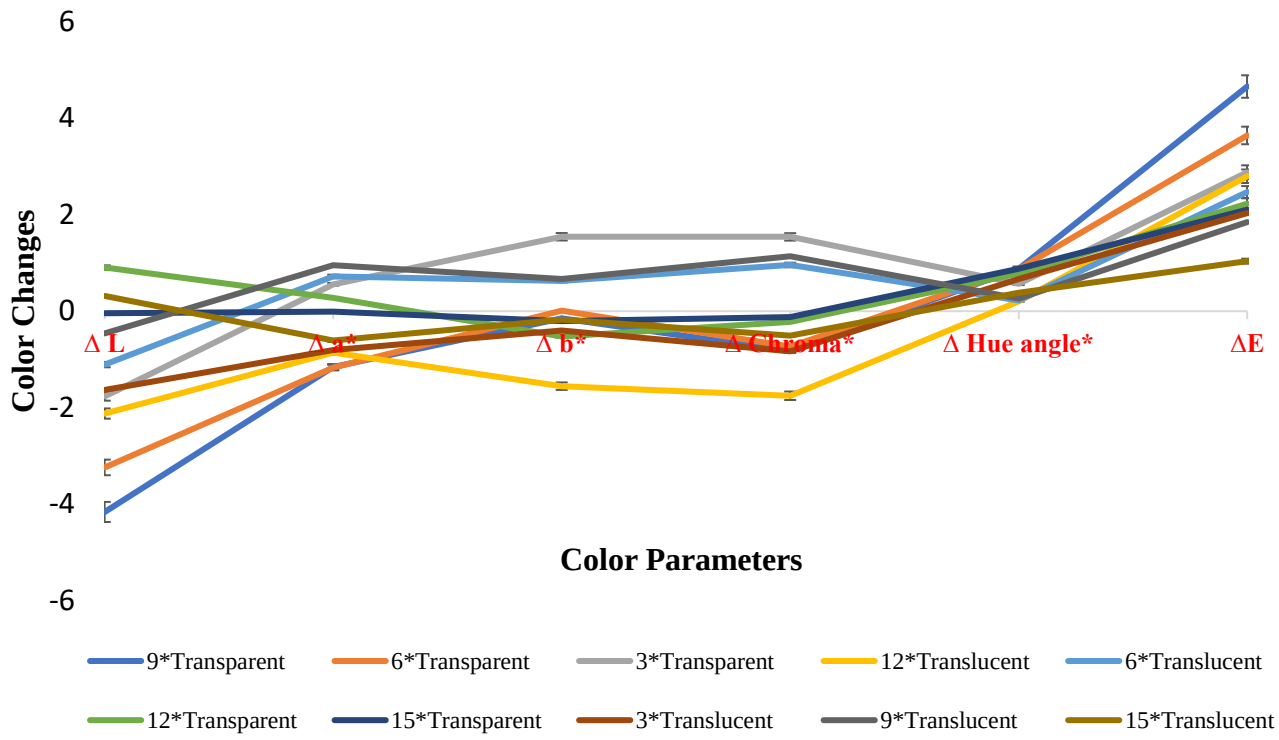


Figure 8.2: Effect of storage days and packaging types on the nectar color changes

The bars indicate the standard error of the means.

In comparison to the unblended guava nectars, the blended guava nectars had significantly higher overall color changes. The blended nectars showed the most overall color changes after 15 days of storage, followed by days 12,9 and 6 for the same blended nectars (Figure 8.3). The L* of these nectars also changed significantly, indicating some degree of darkening. On the other hand, the unblended nectars experienced significantly lower overall color changes, on the order of 12,9,6, and the least on day 3.

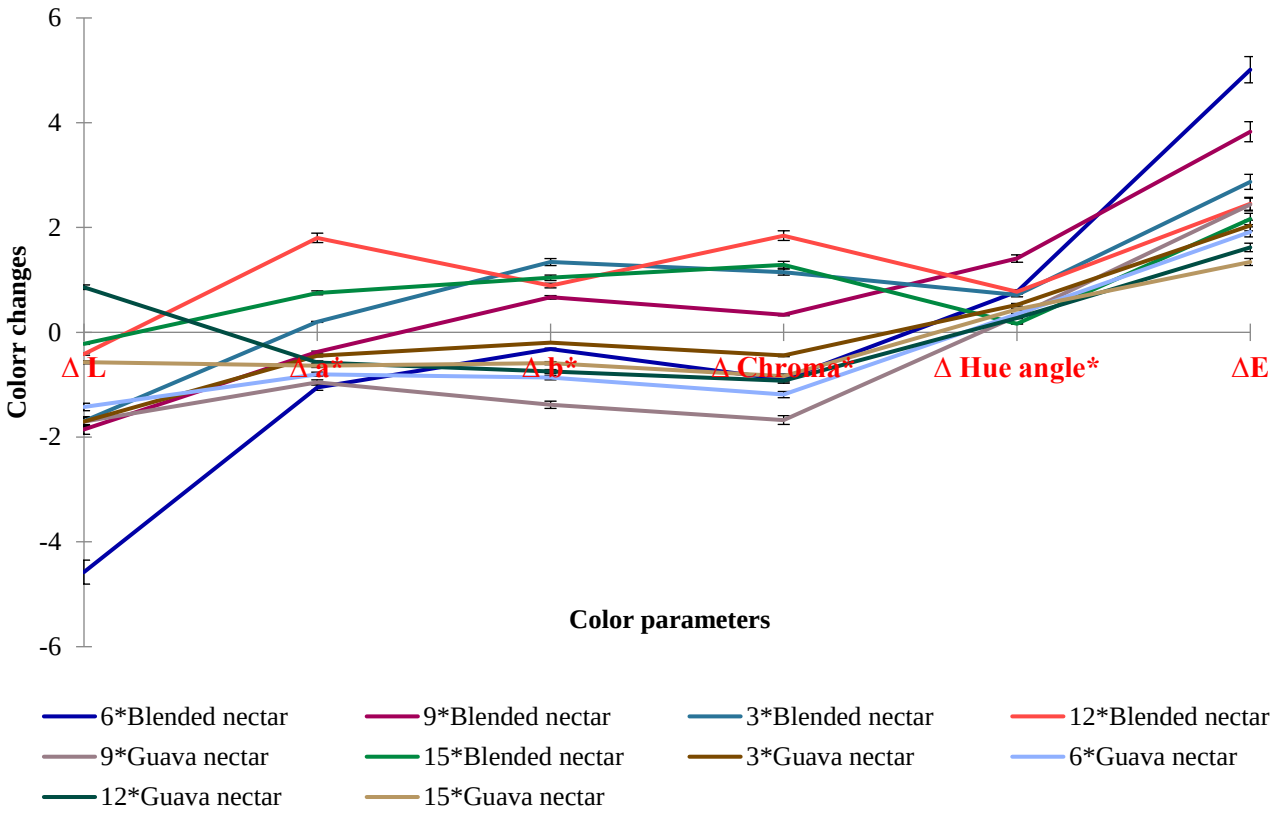


Figure 8.3: Effect of storage days on the nectar color changes

The bars indicate standard error of the means.

The interactions between nectar type, packaging, and storage days also resulted in significant ($p=0.000$) color changes in the nectars, with unblended nectars exhibiting higher color changes on all storage days. Similarly, with storage, the trends for color changes increased gradually (Table 8.2). On day 15, the blended guava nectars packaged in transparent packaging exhibited the highest color change (6.02), compared to the unblended guava nectars, which exhibited a color change of 3.3. On the other hand, translucent packaging experienced significantly ($p<0.0001$) more minor changes, at 4.00 and 1.59 for blended and unblended products, respectively. The most significant loss of color occurred in the lightness index (-6.13), followed by a significant loss of color in the green index (-2.4).

Table 8.2: Color changes for blended and unblended guava nectars in transparent and translucent bottle

Days	Packaging type	Nectar type	Color Parameters					
			Δ L	Δ a*	Δ b*	Δ Chroma*	Δ Hue angle*	ΔE
3	Translucent	Blended	0.75±0.63 ^{def}	-0.48±0.00 ^{abc}	-0.23±0.38 ^{abcd}	-0.47±0.31 ^{abc}	0.23±0.24 ^{ab}	0.97±0.57 ^{a}
		Unblended	-0.12±0.18 ^{cde}	-0.74±1.20 ^{abcd}	-0.12±0.81 ^{abcd}	-0.54±1.36 ^{abc}	0.53±0.46 ^{ab}	1.10±0.91 ^{a}
	Transparent	Blended	-1.19±0.91 ^{cdef}	1.98±0.55 ^{d}	2.31±0.25 ^{e}	3.05±0.55 ^{f}	0.10±0.01 ^{a}	3.36±0.17 ^{abcd}
		Unblended	-1.03±0.22 ^{cdef}	-0.54±0.23 ^{abcd}	-1.06±0.09 ^{abc}	-1.13±0.09 ^{abc}	0.35±0.22 ^{ab}	1.58±0.13 ^{ab}
6	Translucent	Blended	0.46±1.47 ^{def}	1.80±0.39 ^{cd}	0.19±0.04 ^{abcde}	1.29±0.29 ^{cdef}	1.27±0.26 ^{ab}	2.15±0.02 ^{ab}
		Unblended	1.35±1.46 ^{f}	-1.24±0.36 ^{a}	-1.23±1.20 ^{ab}	-1.73±1.18 ^{ab}	0.30±0.40 ^{ab}	2.31±1.69 ^{ab}
	Transparent	Blended	-1.29±0.85 ^{cdef}	1.81±0.65 ^{cd}	1.60±0.31 ^{de}	2.40±0.66 ^{def}	0.28±0.21 ^{ab}	2.76±1.00 ^{abc}
		Unblended	0.37±1.18 ^{def}	0.09±0.00 ^{abcd}	-0.26±0.28 ^{abcd}	-0.12±0.20 ^{abcde}	0.25±0.20 ^{ab}	0.94±0.39
9	Translucent	Blended	-2.09±0.62 ^{bcdef}	-1.21±0.03 ^{a}	0.19±0.67	-0.65±0.54 ^{abc}	1.03±0.43 ^{ab}	2.48±0.49 ^{abc}
		Unblended	-1.2±0.22 ^{cdef}	-0.50±0.05 ^{abcd}	-0.89±0.07 ^{abc}	-1.04±0.09 ^{abc}	0.37±0.01 ^{ab}	1.5±0.22 ^{ab}
	Transparent	Blended	-1.30±0.16 ^{cdef}	1.61±0.14 ^{bcd}	2.50±0.78 ^{e}	2.95±0.68 ^{ef}	0.40±0.33 ^{ab}	3.26±0.60 ^{abc}
		Unblended	-2.23±0.38 ^{bcde}	-0.49±0.38 ^{abcd}	0.59±1.02 ^{bcde}	0.13±0.54 ^{abcde}	0.74±0.96 ^{ab}	2.49±0.02 ^{abc}
12	Translucent	Blended	1.10±2.09 ^{ef}	0.38±2.51 ^{abcd}	0.57±0.15 ^{bcde}	0.76±1.37 ^{bcdef}	1.45±0.12 ^{b}	2.62±0.54 ^{abc}
		Unblended	-1.18±0.22 ^{cdef}	-0.40±0.05 ^{abcd}	-0.98±0.07 ^{abc}	-1.01±0.09 ^{abc}	0.31±0.01 ^{ab}	1.58±0.22 ^{ab}
	Transparent	Blended	-4.80±0.47 ^{ab}	-1.13±0.47 ^{ab}	0.76±0.76 ^{abcd}	-0.10±0.89 ^{abcd}	1.36±0.11 ^{ab}	5.03±0.44 ^{cd}
		Unblended	-1.67±0.61 ^{bcdef}	-1.20±0.40 ^{a}	-0.75±0.13 ^{abcd}	-1.36±0.37 ^{abc}	0.38±0.22 ^{ab}	2.25±0.19 ^{ab}
15	Translucent	Blended	-3.32±0.67 ^{abc}	-1.23±0.11 ^{a}	-1.85±0.14 ^{a}	-2.22±0.18 ^{a}	0.11±0.02 ^{a}	4.00±0.65 ^{bcd}
		Unblended	-0.92±0.28 ^{cdef}	-0.48±0.19 ^{abcd}	-1.25±0.42 ^{ab}	-1.28±0.43 ^{abc}	0.30±0.28 ^{ab}	1.59±0.31 ^{ab}
	Transparent	Blended	-5.83±0.43 ^{a}	-0.88±0.04 ^{abc}	1.22±0.36 ^{cde}	0.42±0.32 ^{abcdef}	1.44±0.19 ^{b}	6.02±0.49 ^{d}
		Unblended	-2.49±0.74 ^{abcd}	-1.43±0.43 ^{a}	-1.51±1.25 ^{ab}	-2.07±1.26 ^{ab}	0.32±0.32 ^{ab}	3.29±1.32 ^{abc}
Mean			-1.330	-0.209	-0.016	-0.135	0.572	2.569
Minimum			-6.137	-1.731	-2.395	-2.957	0.015	0.462
Maximum			2.575	2.368	3.045	3.434	1.572	6.368
P value			<0.0001	0.000	<0.0001	<0.0001	0.002	<0.0001

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05). Negative values indicate a decrease in the respective color parameters, while the positive indicate an increase in the respective values

8.6.2 Changes in the chemical and microbial loads

The interaction between the storage period and the package type had a significant ($p<0.05$) effect on all the chemical parameters. The TSS increased from 12.4 and 12.58 on day zero and peaked on day 12 at 12.95 and 12.75 for the transparent and translucent packages, respectively.

The levels, however decreased on day 15 to 12.58 and 12.70, respectively. As for the pH, the levels decreased with storage time from 3.73 and 3.74 to 3.50 and 3.45 on the last day for the transparent and translucent packaging, respectively. The TTA similarly had a slight increase with the storage days from 0.27 to 0.35, and 0.33 to 0.34 values varied significantly ($p<0.05$) but decreased on the 15th day (Figure 8.4).

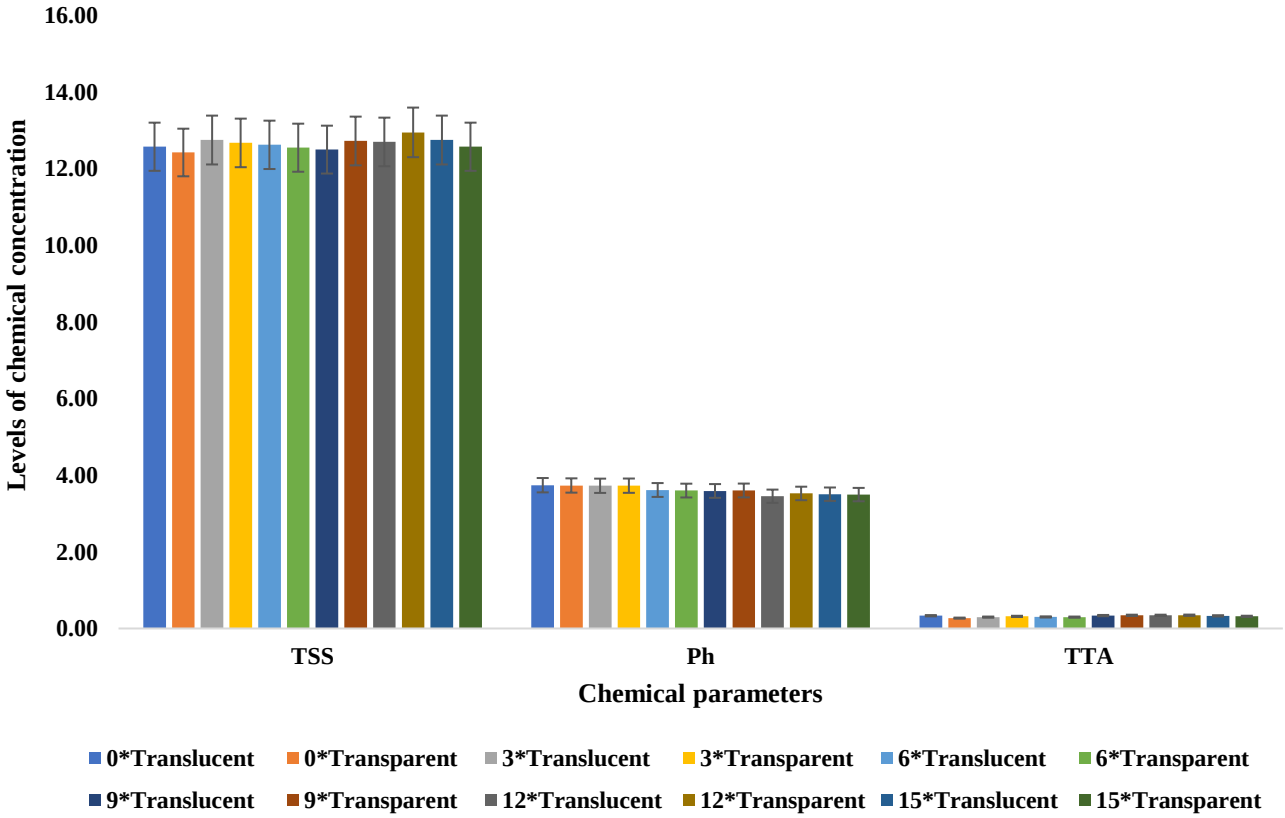


Figure 8.4: Chemical properties of blended and unblended guava nectars in relation to the packaging materials. The bars indicate standard error of the means.

For the microbial loads, the TVC decreased over the storage period from 3.6 to 2.2 and 3.0 to 2.4 cfu/ml on day zero to day 15 for the transparent and translucent packaging materials, respectively. Their levels were highest on the third day of storage at 3.8 cfu/ml. On the other hand, the yeast and molds increased with storage days from 1.9 to 3.9 cfu/ml and 1.8 to 4.4

cfu/ml on day 12 for the transparent and translucent packaging materials. The levels however, declined to 2.2 and 2.8 on the last day (Figure 8.5).

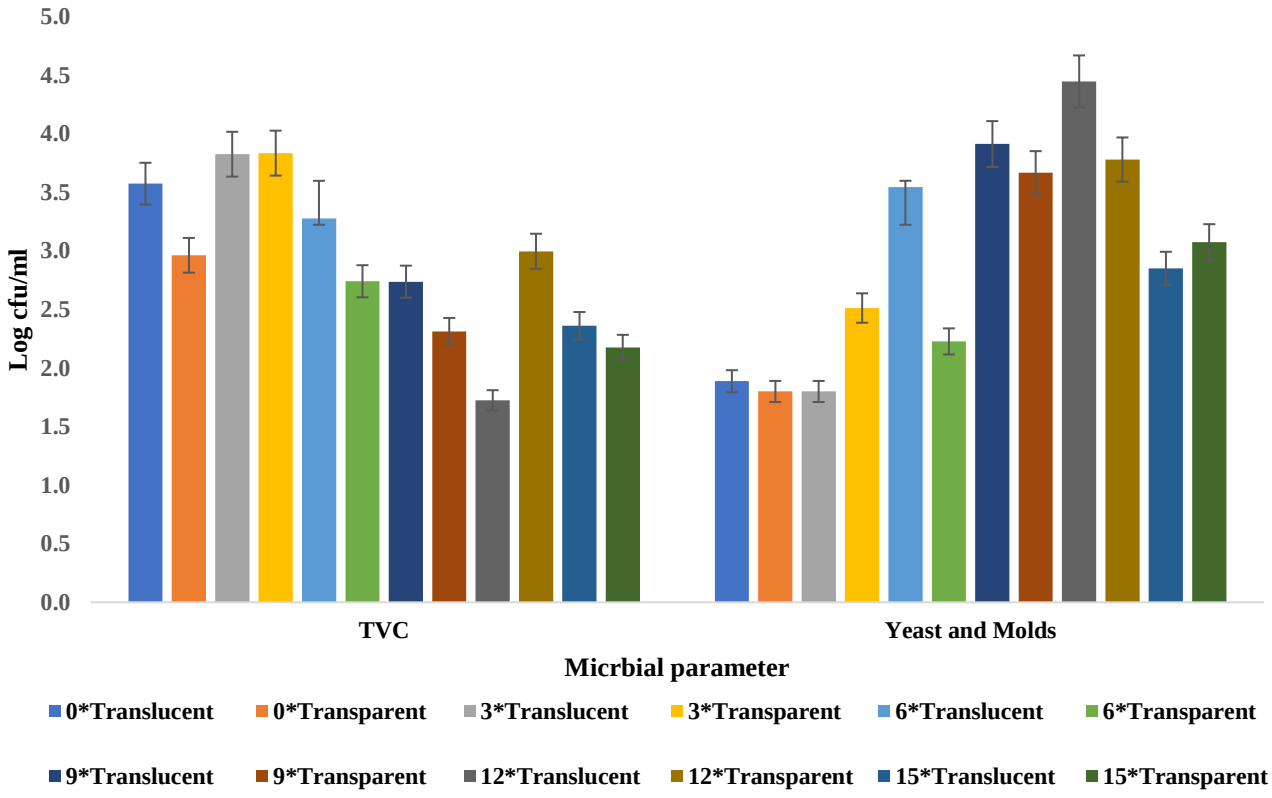


Figure 8.5: Microbiological properties of blended and unblended guava nectars in relation to the packaging materials. The bars indicate standard error of the means.

Significant ($p<0.05$) differences in the nectars' pH, TTA, TSS, and TVC were found due to interactions between the package type, guava nectar type, and storage days. The levels of yeast and molds were not significantly ($p>0.05$) different, indicating that the storage conditions had little effect (Table 9.3). The TSS levels varied significantly ($p<0.0001$) with storage, averaging 12.7 and ranging from 11 to 13.4 in unblended nectars to the highest in blended nectars. Additionally, the pH values were within the Kenyan standards of less than 4, averaging 3.58 with a range of 3.3.9-3.79. On the final day of storage, the titratable acidity varied and stabilized, with no significant differences ($p>0.05$) observed for any of the samples. The yeast

and mold counts, as well as the TVC counts, remained within the recommended limits of 30 and 100 cfu/ml, peaking at 4.9 and 4.5, respectively (Table 8.3).

Table 8.3: Quality and microbial changes in blended and unblended guava nectars packaged in transparent and translucent bottles.

Days	Packaging Type	Nectar type	Quality parameters				
			TSS (°Brix)	pH f.w	TTA (% f.w)	TVC (log cfu/ml)	Yeast and Molds (log cfu/ml)
0	Translucent	Blended	13.15±0.07^{a}	3.77±0.00^{g}	0.31±0.03^{ab}	3.65±0.49^{ab}	2.10±1.55^{a}
		Unblended	12.00±0.00^{a}	3.71±0.01^{fg}	0.36±0.03^{ab}	3.50±0.42^{ab}	1.67±2.37^{a}
	Transparent	Blended	12.90±0.14^{cde}	3.78±0.01^{abcde}	0.27±0.02^{a}	2.55±0.35^{ab}	2.92±0.81^{a}
		Unblended	11.95±0.21^{a}	3.69±0.02^{efg}	0.27±0.00^{a}	3.30±0.71^{ab}	0.67±0.95^{a}
3	Translucent	Blended	13.20±0.14^{de}	3.77±0.04^{g}	0.29±0.03^{ab}	4.07±0.11^{b}	2.17±0.46^{a}
		Unblended	12.25±0.07^{abc}	3.68±0.01^{cdef}	0.32±0.04^{ab}	3.43±0.52^{ab}	1.35±1.91^{a}
	Transparent	Blended	13.25±0.21^{e}	3.78±0.02	0.27±0.01^{ab}	4.22±0.37^{b}	2.25±1.77^{a}
		Unblended	12.15±0.07^{a}	3.69±0.07^{efg}	0.34±0.02^{ab}	3.60±0.14^{ab}	2.85±0.71^{a}
6	Translucent	Blended	13.05±0.21^{de}	3.67±0.04^{cdef}	0.31±0.03^{ab}	2.57±1.60^{ab}	1.60±2.26^{a}
		Unblended	12.30±0.14^{ab}	3.54±0.03^{abcdef}	0.31±0.00^{ab}	3.14±0.79^{ab}	3.09±1.26^{a}
	Transparent	Blended	12.95±0.07^{de}	3.69±0.01^{cdef}	0.29±0.03^{ab}	3.41±0.30^{ab}	4.00±0.18^{a}
		Unblended	12.05±0.07^{a}	3.53±0.17^{abcde}	0.28±0.00^{ab}	2.91±0.46^{ab}	2.85±1.42^{a}
9	Translucent	Blended	13.20±0.00^{de}	3.68±0.01^{cdef}	0.35±0.05^{ab}	2.02±0.25^{ab}	3.53±0.13^{a}
		Unblended	11.90±0.14^{a}	3.54±0.03^{abcde}	0.32±0.02^{ab}	2.04±0.06^{ab}	4.00±0.09^{a}
	Transparent	Blended	13.10±0.14^{de}	3.64±0.01^{bcde}	0.36±0.00^{b}	3.43±0.44^{ab}	3.82±0.21^{a}
		Unblended	12.25±0.07^{ab}	3.53±0.01^{abcd}	0.34±0.03^{ab}	2.60±0.14^{ab}	3.81±0.31^{a}
12	Translucent	Blended	13.20±0.28^{de}	3.54±0.01^{abcde}	0.36±0.00^{b}	2.77±0.81^{ab}	3.74±0.26^{a}
		Unblended	12.40±0.00^{abc}	3.40±0.01^{a}	0.33±0.02^{ab}	1.10±1.55^{a}	4.49±0.51^{a}
	Transparent	Blended	13.00±0.00^{de}	3.51±0.02^{abc}	0.36±0.01^{ab}	2.35±0.71^{ab}	4.40±0.44^{a}
		Unblended	12.70±0.14^{bcd}	3.52±0.02^{abcd}	0.33±0.01^{ab}	3.22±0.52^{ab}	3.82±0.05
15	Translucent	Blended	12.95±0.07^{de}	3.56±0.01^{abcde}	0.32±0.03^{ab}	2.02±0.95^{ab}	3.12±0.33^{a}
		Unblended	12.30±0.14^{ab}	3.52±0.02^{abcd}	0.32±0.04^{ab}	2.10±0.14^{ab}	3.26±0.47^{a}
	Transparent	Blended	13.20±0.00^{de}	3.50±0.01^{ab}	0.34±0.02^{ab}	2.62±0.75^{ab}	2.44±1.92^{a}
		Unblended	12.20±0.00^{ab}	3.44±0.01^{a}	0.31±0.02^{ab}	2.33±1.45^{ab}	3.03±0.24^{a}
Mean			12.680	3.584	0.322	2.798	3.181
Range			11.8-13.40	3.39-3.79	0.262-0.378	0.00-4.477	0.00-4.854
P value			<0.0001	<0.0001	0.005	0.036	0.133

Values (means± standard deviation) with different superscripts along a column are statistically different (Tukey's test, P≤0.05).

8.7 Discussion

While the preservation of nectar was dependent on the product's internal composition and characteristics, the hurdle technology contributed to the longevity and stability of packaged products over time (Putnik *et al*., 2020). Applying the various processing hurdle techniques required for the nectars probably resulted in shelf stability in terms of quality preservation and thus good keeping qualities where good manufacturing practices were used. According to this study, the most significant color changes occurred in transparent packages, indicating that the light for the stored juices had a detrimental effect on the shelved guava nectars (López-nicolás & Carbonell-barrachina, 2007). Additionally, it is worth noting that the moringa juice extract may have significantly contributed to the color loss. Thus, it must be stabilized if long-term processing and commercial supplies are successful. It is also prudent to ensure that the color does not adversely affect consumer purchasing decisions, as it is a significant component of their appeal. Similarly, Bedts *et al*. (2018) found that the color of juices is frequently the limiting physical quality during shelf life analysis. However, apart from appearance degradation, other chemical and biological processes result in degradation, but these are intrinsic and are usually visible after sufficient time to exposure (Mizrahi, 2011).

In their studies, López-nicolás & Carbonell-barrachina (2007) found that using transparent packaging for fruit juices results in shorter shelf life due to qualitative losses compared to opaque packaging materials as tetra paks. Additionally, they reported that oxygen in the headspaces of packaging materials results in vitamin C oxidation and eventual darkening. This study's loss of L* and high color changes are consistent with these findings. Additionally, fruit juices undergo non-enzymatic browning reactions due to the heating process, frequently used as a qualitative loss indicator (Kus *et al*., 2007). The color changes observed during the current storage period may thus be partially attributed to hydroxymethylfurfural (HMFs). However,

fruit-based beverages have been found to undergo organoleptic changes, particularly when stored at high temperatures for extended periods (Jalili & Ansari, 2015; Kus *et al*., 2007). Additionally, the 55^{o}C temperature in this study may have contributed to the color loss (Bedts *et al*., 2018).

The findings on microbial growth changes are consistent with Dube's (2015) findings on the shelf life of apple juices, which showed that higher temperatures associated with a shorter shelf life tend to inhibit microbial growth. Similar patterns were observed in the current study, where viable counts decreased with storage time while yeast and molds levels decreased after the ninth day. The high temperatures may have inhibited the TVCs and yeast and mold growth, which is further exacerbated by pasteurization of the juices, which reduces the microbial counts to insignificant loads (Kaur *et al*., 2019). However, because of the low pH and the presence of metabisulphite, the intrinsic properties of juices may have contributed to the juice's stability during storage (Putnik *et al*., 2020).

The results of the minimal changes in pH, TSS, TTA, and microbial loads are consistent with those of Kaur *et al*. (2019), who reported similar trends. However, it is essential to note that the changes observed in this study did not affect the ready-to-drink juices as defined by the KEBs standard and, therefore, shelf stability of the nectars. Juices are processed in the food industry using a variety of hurdle techniques, such as high temperatures, modified atmosphere packaging, and food grader preservatives, which, when used within good manufacturing levels, ensure that the processed food and safety is assured, as well as improved flavors, ensuring that the quality organoleptically suitable (Leistner & Gould, 2002).

The current study found that good manufacturing practices and hurdle techniques resulted in shelf-stable and high-quality juices, explaining the minimal changes. However, the processing regimes also affect heat-labile nutrients in fruit juices, such as Vitamin C and phenolics, which

were not evaluated. Future studies should assess these changes and changes in micro and macronutrients, especially during actual shelf-life studies. The study does show, however, that if all of the appropriate and minimum processing protocols are followed, the local Kenyan guava can be processed into safe shelf-stable nectars that will provide consumers with access to processed fruits for at least three months which is within the requirements of the Kenyan standard for fruit-based beverages.

Although this study did not evaluate changes in organoleptic properties with increased storage, previous research has demonstrated significant changes in consumer acceptability with increased storage, and it is therefore recommended that nectars be packaged in opaque materials to avoid excessive color loss during storage periods (Jalili & Ansari, 2015; Kus *et al*., 2007).

8.8 Conclusion and recommendations

The current study resulted in the development of shelf-stable guava nectar formulations. However, processed products must be preserved by utilizing various hurdle techniques while minimizing potential nutrient damage. While the shelf study analyzed qualitative parameters, we recommend that additional research be conducted on the effects of storage on key micro and macronutrients in the nectars. Additionally, the study did not compare the impact of actual storage conditions on the juices' physicochemical profile, requiring additional research to ensure that these nutrients reach the consumer. However, it is recommendable that this low-cost technique is adopted at the household level to ensure constant access to nutritious guava-based beverages.

CHAPTER NINE : GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 Discussion

Despite the continued production of guava fruit in recent years in Kenya, the neglect of the fruit has led to the fruit being orphaned, and consequently, its socioeconomic potential and environmental impacts have been overlooked. Furthermore, the fruit thrives in rural areas where significant constraints are technical expertise, value addition, and a lack of necessary infrastructure. Although, the fruit's nutritional potential could contribute to Kenya's daily fruit requirements, as the country is yet to meet the 200 g of fruit consumption per day (Keding *et al*., 2017), the fruit's high perishability, lack of processing, and poor post-harvest handling limit consumer access to the fruit once out of season. The neglect of the guava fruit has also resulted in a lack of robust, reliable empirical data on its value chains. There are very few research programs, policies, and functional frameworks to improve local cultivars.

According to this study's findings, Kenyan guava varieties are nutritious and can serve as food vehicles for macro-and micronutrient intake. The fruits' processing characteristics, on the other hand, may be a limiting factor in processing, as there was significant intra- and inter varietal variations resulting from differences in morphological and genetic interactions. Additionally, all the varieties had a relatively high seed to pulp ratio and significantly smaller fruit sizes, impairing the fruits' processing qualities. Additionally, despite the favorable production climate, there are no known commercial guava cultivars for industrial processing in Kenya; the fruits currently grow in the wild with minimal agronomic practices.

Although numerous guava brands of ready-to-drink guava beverages were found in the Kenyan markets, none of the local processors used Kenyan guava fruits, indicating the existence of an untapped guava value-added products niche that should be capitalized on. However, because

the products are only available in supermarkets, they are inaccessible to most consumers, given that supermarket branches are few and concentrated in major urban areas. The juices and nectars contained a low proportion of fruit pulp, and despite claims of being free of preservatives, detectable residual metabisulphites were found. While the products were microbiologically safe, the micronutrient levels may have been significantly lower due to differences in processing regimes and food ingredients' interactions with environmental heat, light, packaging materials, and storage periods during sales. Nonetheless, the beverages contained significant amounts of phytochemicals that may promote nutritional health.

Pulping guava fruits, a critical step in fruit processing, may require mechanized methods due to the fruits' hardness and numerous tiny seeds. However, the study found that due to the high seed content of the Kenyan varieties, there was a high level of by-product production. While hot extraction methods produced a high pulp yield, they significantly denatured and leached out heat-labile nutrients. However, the red-fleshed guavas, which contained significantly fewer seeds per fruit than white guavas, would be the most suitable for processing. Additionally, the red-fleshed varieties retained more essential micronutrients. Nonetheless, pulping either variety's fruits would ensure access to a critical raw ingredient used in guava-based products.

Moringa leaf extract was found to increase the micronutrient content of guava nectars without affecting the macronutrient properties of the guava nectars. Moringa was effective at relatively low concentrations, consistent with the WHO recommendation for fortificants to be effective at low concentrations without affecting the major food matrices. *Moringa oleifera* leaf extract was also found to be an alternative method of utilising the leaf, as most consumers consume the plant's leaves fresh or powdered after drying. The use of the extract in foods, on the other hand, may require an acquired taste among consumers willing to trade off taste for health

benefits, as the extract introduced additional flavors into the nectars that were unpleasant at higher concentrations.

It was found that adhering to good manufacturing practices aided in the development of shelf-stable, acceptable nectars. A combination of hurdle techniques such as pasteurization, the use of recommended food-grade preservatives, and airtight packaging would result in shelf-stable guava nectars. There were generally few physicochemical and microbiological changes in the guava nectars during storage, but these remained within Kenyan standards, ensuring shelf stability for at least five months. Transparent packaging, on the other hand, maybe undesirable due to color loss.

9.2 Conclusion

Although this study focused on fruits grown in Kitui and Taita Taveta counties, which are among Kenya's most productive, there is sufficient evidence that the Central, Western and Eastern parts of the country are also extremely productive during the guava season, with losses due to poor marketability, low consumption, and, most importantly, a lack of processing (HCD, 2014). The fruit grows naturally and has the potential to be a green crop because it requires minimal natural resources to produce and thus has a high potential for long-term environmental conservation, in line with the Sustainable Development Goals. However, its underutilization obstructs maximization in the sustainable diets of local food systems. The lack of industrial processing for the local varieties despite the fruit’s nutrient-density necessitates a need for the establishment of industrial processing in order to strengthen the Kenyan fruit value chains by ensuring access to fruit when out of season while minimizing the losses during glut and therefore balancing trade through the marketing of processed local guava.

This study established a successful low-cost guava processing method that results in nutritious nectars with high consumer acceptance, shelf stability, and marketability. Pulp processing, a critical unit operation, should always be optimized to obtain the fewest wastes possible during the glut. These can be achieved by strictly adhering to the fruit processing quality standards, which requires that only mature, well-ripened guavas be processed; immature fruits have a high mass and thus produce more waste, while overripe fruits produce products off-flavors. However, processing regimes should always consider the intensity of the parameters used to ensure that heat-labile nutrients such as vitamin C are and the leaching of critical minerals are minimized. Processing would eliminate food waste and losses along the guava value chain while also increasing the fruit's marketability and consumption. Valorization would boost the household income of guava farmers while also ensuring that consumers have access to nutritious, shelf-stable, and safe processed guavas during the offseason.

9.3 Recommendations

To ensure that guava production is commercialized sustainably, farmers must be educated on good agricultural practices and proper post-harvest handling to reduce annual losses among guava farming households. However, the establishment of sustainable value chains would require a multidisciplinary approach involving breeders, researchers, and processors with a critical focus on promoting national and county policies that advocate for the strengthened guava value chains besides other neglected local crops. Farmers are also encouraged to grow seedless guava cultivars because they are much easier to process.

To ensure the successful processing of guavas into shelf-stable products, capacity building in good manufacturing practices is required at the household, micro, small, and medium enterprise levels, particularly for the red-fleshed guava variety, which has superior processing characteristics.

It is also recommended that additional research be conducted on blending with other nutrient-dense fruits and vegetables and processing the fruits into products other than nectars. However, studies on the bioavailability of the micronutrients should be assessed, besides determining their stability during shelf storage. Given the fruit's suitability for processing into various other industrial products, the commercialization of other processed guava pulp products should be investigated. Additionally, the processing of indigenous white guavas should be evaluated, as this study favored the red variety due to its superior nutritional profile.

REFERENCES

Abdo, M. Y. (2014). Safety of Commercial Fruit Juices Available on the Egyptian Markets with Regards to their Heavy Metal and Aflatoxins Residues Content. *Current Science International*, *3*(2).

Abed, S. M., Elbandy, M. A., & Gad, S. S. (2016). Production of guava nectar supplemented with Aloe vera gel. *University of El Arish, Egypt*, 1–19. www.academia.edu/11734365/Production_of_guava_nectar_supplemented_with_Aloe_vera_gel

Abreu, J. R. de, Santos, C. D. dos, Abreu, C. M. P. de, & Castro, E. M. de. (2012). Histochemistry and morphoanatomy study on guava fruit during ripening. *Food Science and Technology (Campinas)*, *32*(1), 179–186. https://doi.org/10.1590/S0101-20612012005000019

Acevedo, O. (2016). *Nutritional and Phytochemical Composition of Moringa oleifera Lam and its Potential Use as Nutraceutical Plant : A Review Nutritional and Phytochemical Composition of Moringa oleifera Lam and its Potential Use as Nutraceutical Plant : A Review*. *April*. https://doi.org/10.3923/pjn.2016.397.405

Addinsoft. (2021). *XLSTAT statistical and data analysis solution.* (23.2.1127.0). XLSTAT. https://www.xlstat.com.

Adrian, J. A. L., Arancon, N. Q., Mathews, B. W., & Carpenter, J. R. (2012). Proximate analysis, in vitro organic matter digestibility, and energy content of common guava (psidium guajava l.) and yellow, strawberry guava (psidium cattleianum var. lucidum) tree parts and fruits as potential forage. *Journal of Agricultural and Food Chemistry*, *60*(42), 10398–10405. https://doi.org/10.1021/jf303617p

Affiku, J. P. (2011). Proximate study, mineral and anti-nutrient composition of Moringa oleifera leaves harvested from Lafia, Nigeria: potential benefits in poultry nutrition and health. *J. Microbiology Biotechnology and Food Sciences*, *1*(3), 296–308.

Akesowan, A., & Choonhahirun, A. (2013). Optimising Enzymatic Production of Guava Juice by Response Surface Methodology. *Journal of Animal & Plant Sciences*, *23*(1), 114–120. http://www.thejaps.org.pk/docs/v-23-1/18.pdf

Akinnifesi, F. K., Kwesiga, F., Mhango, J., Chilanga, T., Mkonda, A., Kadu, C. A., Kadzere, I., Mithofer, D., Saka, J. D. K., Sileshi, G., Ramadhani, T., & Dhliwayo, P. (2006). Towards the development of miombo fruit trees as commercial tree crops in Southern Africa. *Forests Trees and Livelihoods*, *16*(1), 103–121. https://doi.org/10.1080/14728028.2006.9752548

Ali, D. O. M., Ahmed, A. R., & Babikir, E. B. (2014). Physicochemical and nutritional value of red and white guava cultivars grown in Sudan. *Journal of Agri-Food and Applied Sciences*, *2*(2), 27–30.

Ali, M. A., Yusof, Y. A., Chin, N. L., & Ibrahim, M. N. (2016). Effect of different drying treatments on colour quality and ascorbic acid concentration of guava fruit. *International Food Research Journal*, *23*, 155–161.

AOAC. (2000). *Official Methods of Analysis. 17th edn, Official method 942.15, Acidity (Titrable) of fruit products*.

AOAC. (2002). *Official Methods of Analysis* (16th Editi). Association of Official Analytical Chemist.

AOAC. (2005a). *Official Methods of Analysis. 18th edn* (Arlington,).

AOAC. (2005b). *Official Methods of Analysis of AOAC International* (Arlington,). AOAC International.

AOAC. (2006). *Official methods of Proximate Analysis and Calculations*. Reference data: Method 990.03; NITR; NT.

Arboleda, A. M. (2019). Perceptual Density of Guava Juice: The Effect of Image Location and Surface Texture. *Journal of Food Products Marketing*, *25*(3), 340–354. https://doi.org/10.1080/10454446.2018.1555682

Augusto, J., Campos, S. De, Santos, D., Detmann, E., Ferreira, R., Pereira, R., Krish, N., & Fernando, L. (2011). Intake, total digestibility, microbial protein production and the nitrogen balance in diets with fruit by-products for ruminants. *Revista Brasileira de Zootecnia*, *40*(5), 1052–1060.

Azzolini, M., Jacomino, A. P., Bron, I. U., Kluge, R. A., & Schiavinato, M. A. (2005). Ripening of "Pedro Sato" guava: study on its climacteric or non-climacteric nature. *Braz.J.Plant Phsysiol.*, *17*(3), 299–306.

Bakshi, P. (2015). Maturity indices of Guava. In *Agricultural Sciences* (Issue January 2014).

Bakshi, P., Wali, V. K., Sharma, A., Kour, G., & Bhat, D. (2015). Maturity indices of Guava. In Parshant Bakshi (Ed.), *Determination of quality and harvest maturity for commercially grown fruit crops in Jammu Sub-tropics* (First Edit, pp. 1–18). Shree Infomedia Publications Pvt. Ltd,India.

Balcerek, M., Pielech-przybylska, K., & Patelski, P. (2017). *The effect of distillation conditions and alcohol content in ' heart ' fractions on the concentration of aroma volatiles and undesirable compounds in plum brandies*. *September 2016*, 452–463.

https://doi.org/10.1002/jib.441

Baldermann, S., Blagojević, L., Frede, K., Klopsch, R., Neugart, S., Neumann, A., Ngwene, B., Norkeweit, J., Schröter, D., Schröter, A., Schweigert, F. J., Wiesner, M., & Schreiner, M. (2016). Are Neglected Plants the Food for the Future? *Critical Reviews in Plant Sciences*, *35*(2), 106–119. https://doi.org/10.1080/07352689.2016.1201399

Barakat, H., Al-Furaydi, A., Al-Harbi, A., & Al-Shedookhi, A. (2017). Nutritional, Chemical and Organoleptical Characteristics of Low-Calorie Fruit Nectars Incorporating Stevioside as a Natural Sweetener. *Food and Nutrition Sciences*, *08*(01), 126–140. https://doi.org/10.4236/fns.2017.81009

Barret, D. M., Somogyi, L., & Ramaswamy, H. (2005). Processing Fruits: Science and technology. *Processing Fruits:Science and Technology*, 861.

Bedts, T. Van, Haenen, A., Kebede, B., Hendrickx, M., Loey, A. Van, Grauwet, T., & Systems, M. (2018). Shelf-life dating of shelf-stable strawberry juice based on survival analysis of consumer acceptance information. *Journal of the Science of Food & Agriculture*, *9*(98), 3437–3445. https://doi.org/10.1002/jsfa.8856

Berens, D. G., Farwig, N., Schaab, G., & Böhning-Gaese, K. (2008). Exotic guavas are foci of forest regeneration in Kenyan farmland. *Biotropica*, *40*(1), 104–112. https://doi.org/10.1111/j.1744-7429.2007.00338.x

Bhuvaneswari, S., & Tiwari, R. B. (2007). Pilot scale processing of red flesh guava RTS beverage. *J. Hort. Sci*, *2*(1), 50–52.

Biosci, I. J., Amanullah, S., Sajid, M., Qamar, M. B., & Ahmad, S. (2017). *Postharvest treatment of salicylic acid on guava to enhance the shelf life at ambient temperature*.

6655, 92–106. https://doi.org/10.12692/ijb/10.3.92-106

Bodini, R. B., Montini, E. M., Carvalho, C. C. De, Moraes, L. A. B. De, & Meirelles, A. J. D. A. (2019). *Sensory and Composition Analyses of the Aqueous Phases from the Concentration of Guava (Psidium Guava L .) and Mango (Mangifera Indica L .) Juices and the Process-Induced Losses of Vitamin C*. 44–55. https://doi.org/10.2174/1874256401911010044

Boora, R. S. (2012). Improvement in guava - A review. *Agric. Rev*, *33* .(4), 341–349.

Chiari-andréo, B., Trovatti, E., Marto, J., De, M. G., Melero, A., Corrêa, M. A., Chiavacci, L. A., Garrigues, T., Lucia, V., & Isaac, B. (2003). *Guava : phytochemical composition of a potential source of antioxidants for cosmetic and / or dermatological applications*. http://www.agriculturеauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf.

Chiveu, J. (2018). *Assessment of genetic and nutritional diversity, and salinity tolerance of Kenyan guava (Psidium guajava L.): an underutilized naturalized fruit species* [Georg-August-University Göttingen, Germany]. https://ediss.uni-goettingen.de/handle/11858/00-1735-0000-002E-E46B-4

Chiveu, J., Naumann, M., Kehlenbeck, K., & Pawelzik, E. (2019). *Variation in fruit chemical and mineral composition of Kenyan guava (Psidium guajava L .): Inferences from climatic conditions , and fruit morphological traits*. *159*(November 2015), 151–159. https://doi.org/10.5073/JABFQ.2019.092.021

Chiveu, J., Naumann, M., Pawelzik, E., & Kehlenbeck, K. (2016). Morphological Diversity of the Underutilised Fruit Species Guava (Psidium guajava L .) in Kenya. In B. Freyer & E. Tielkes (Eds.), *Tropentag 2016: Solidarity in a competing world - fair use of resources*.

Tropentag. www.tropentag.de/2016/abstracts/posters/1065.pdf%250A%250A

Chiveu, J., Naumann, M., Pawelzik, E., & Kehlenbeck, K. (2019). Nutrient composition of guava (Psidium guajava L .) fruits as influenced by soil nutrients. *Journal of Applied Botany and Food Quality*, *92*(2019), 151–159.

Chopda, C. A., & Barrett, D. M. (2001). Optimization of guava juice and powder production. *Journal of Food Processing Preservation*, *25*(6), 411–430. https://doi.org/10.1111/j.1745-4549.2001.tb00470.x

Conceição, M. C., Fernandes, T. N., & de Resende, J. V. (2016). Stability and microstructure of freeze-dried guava pulp (Psidium guajava L.) with added sucrose and pectin. *Journal of Food Science and Technology*, *53*(6), 2654–2663. https://doi.org/10.1007/s13197-016-2237-5

Correa, M. I. C., Chaves, J. B. P., Jham, G. N., Ramos, A. M., Minim, V. P. R., & Yokota, S. R. C. (2010). Changes in guava (Psidium guajava L. var. Paluma) nectar volatile compounds concentration due to thermal processing and storage. *Ciência e Tecnologia de Alimentos*, *30*(4), 1061–1068. https://doi.org/10.1590/S0101-20612010000400035

County Government of Kitui. (2018). *Kitui County integrated development plan 2018-2022*. County Government of Kitui.

County Government of Taita Taveta. (2018). *Taita Taveta County Integrated Development Plan 2018-2022* (Issue February). County Government of Taita Taveta.

da Silva, N. K. V., Sabino, L. B. de S., de Oliveira, L. S., Torres, L. B. de V., & de Sousa, P. H. M. (2016). Effect of food additives on the antioxidant properties and microbiological quality of red guava juice. *Revista Ciencia Agronomica*, *47*(1), 77–85.

https://doi.org/10.5935/1806-6690.20160009

da Silva, N. K. V., Sabino, L. B. de S., Oliveira, L. S. de, Torres, L. B. de V., & de Sousa, P. H. M. (2016). Effect of food additives on the antioxidant properties and microbiological quality of red guava juice. *Revista Ciencia Agronomica*, *47*(1), 77–85. https://doi.org/10.5935/1806-6690.20160009

Das, A. J. (2011). Review on nutritional, medicinal and pharmacological properties of guava (Psidium guajava Linn). *Journal of Biologically Active Products from Nature*, *1*(4), 216–228. https://doi.org/10.1080/22311866.2011.10719089

De Benoist B, McLean E, Egli I, C. M. (2005). Worldwide prevalence of anaemia. In *WHO global database on anaemia.*

de Castro, D. S., Aires, J. E. F., Aires, K. L. C. A. F., da Silva Junior, A. F., da Silva, W. P., & Gomes, J. P. (2016). Physical and chemical changes in guava raisin (Psidum guajava l.) produced by osmotic dehydration and drying convective. *Australian Journal of Crop Science*, *10*(10), 1449–1454. https://doi.org/10.21475/ajcs.2016.10.10.p7455

De Groote, H., Mugalavai, V., Ferruzzi, M., Onkware, A., Ayua, E., Duodu, K. G., Ndegwa, M., & Hamaker, B. R. (2020). Consumer Acceptance and Willingness to Pay for Instant Cereal Products With Food-to-Food Fortification in Eldoret, Kenya. *Food and Nutrition Bulletin*, *41*(2), 224–243. https://doi.org/10.1177/0379572119876848

Dedo, D., Oduro, I. N., & Tortoe, C. (2019). Physicochemical changes in plantain during normal storage ripening. *Scientific African*, *6*, e00164. https://doi.org/10.1016/j.sciaf.2019.e00164

Deepthi, V. P., Sekhar, R. C., Srihari, D., Sankar, A. S., College, H., Dt, K., & Pradesh, A. (2016). *Guava Fruit Quality and Storability As Influenced By Harvest Maturity and Postharvest Application of Calcium Salts*. *16*(1), 174–182.

DESA-UN. (2013). World Economic and Social Survey 2013: Sustainable Development Challenges. In *United Nations, Department for Economic and Social Affairs (DESA)*. United Nations publication. https://doi.org/10.1016/j.urolonc.2009.06.002

Devi, R., Chawla, S., Devi, R., & Jain, V. (2018). *Changes in physicochemical characteristics of guava fruits due to chitosan and calcium chloride treatments during storage*. *7*(3), 1035–1044.

Diniz, R. S., Coimbra, J. S. D. R., Martins, M. A., De Oliveira Dos Santos, M., Diniz, M. D. M. S., De Souza Santos, E., Santánna, D. D., Da Rocha, R. A., & De Oliveira, E. B. (2014). Physical properties of red guava (Psidium guajava L.) Pulp as affected by soluble solids content and temperature. *International Journal of Food Engineering*, *10*(3), 437–445. https://doi.org/10.1515/ijfe-2012-0250

Durst, P., & Bayasgalanbat, N. (2014). Promotion of underutilized indigenous food resources for food security and nutrition in Asia and the Pacific. In *Www.Fao.Org/Publications*.

Dweck, A. C. (2001). A review of Guava (Psidium guajava). *Malayan Journal of Medical Science*, *8*(1), 27–30.

Egea, M. B., & Takeuchi, K. P. (2020). Bioactive Compounds in Baru Almond (Dipteryx alata Vogel): Nutritional Composition and Health Effects. In *Reference Series in Phytochemistry*. https://doi.org/10.1007/978-3-030-30182-8_17

El Boushy, A. R. Y. and van der Poel, A. F. B. (2000). *Handbook of poultry feed from waste:*

processing and use. Springer-Verlag New York.

Elepu, G. (2018). Market valuation of processed fruit juice attributes in Uganda: What do market prices of processed fruit juice reflect? *African Journal of Food, Agriculture, Nutrition and Development*, *18*(2), 13438–13451. https://doi.org/10.18697/ajfand.82.17075

Fahey, J. W. (2005). Moringa oleifera : A Review of the Medical Evidence for Its Nutritional , Therapeutic , and Prophylactic Properties . Part 1 . *Trees for Life Journal*.

FAO. (2005). *GENERAL STANDARD FOR FRUIT JUICES AND NECTARS*. 1–19. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=16&cad=rja&uact=8&ved=2ahUKEwiBxpzNzN7eAhVJzIUKHSLwB3QQFjAPegQIBBAC&url=http%253A%252F%252Fwww.fao.org%252Ffao-who-codexalimentarius%252Fsh-proxy%252Fzh%252F%253Flnk%253D1%2526url%253Dhttps%2525253A%2525252F%2525252Fworks

FAO. (2011). Intergovernmental group on bananas and tropical fruit. In *Committee on commodity problems* (Issue April). https://doi.org/10.1017/CBO9781107415324.004

Farid, A. S., & Kamel, E. R. (2016). Effect of feeding guava waste on growth performance, diet digestibility, carcass characteristics and production profitability of ossimi lambs. *Egyptian J. Nutrition and Feeds*, *19*(3), 463–475.

Fisher AA; Laing JE; Stoeckel JE; Townsend. (1991). *Handbook for family planning operations research design. 2nd ed. TT* - (2nd ed., Vol. 1991). Population council.

Flores, G., Wu, S. B., Negrin, A., & Kennelly, E. J. (2015). Chemical composition and antioxidant activity of seven cultivars of guava (Psidium guajava) fruits. *Food Chemistry*,

170, 327–335. https://doi.org/10.1016/j.foodchem.2014.08.076

García-Rivera, L. M., Váquiro-Herrera, H. A., & Solanilla-Duque1, J. F. (2016). Physicochemical characterization and nutritional composition analysis of Physicochemical characterization and nutritional composition analysis of pineapple guava at three different ripening stages Caracterización fisicoquímica y análisis de la composición. *Agronomía Colombiana*, *34*(2), 217–227. https://doi.org/10.15446/agron.colomb.v34n2.56030

Gatambia, E. K., Gitonga, J. K., Menza, M. K., Njuguna, J. K., Wanjala, S. B., Karumwa, N., & Wasilwa, L. A. (2010). Situation analysis of guava (Psidium guajava L) production in Eastern Province of Kenya. *Kenya Agricultural Research Institute 12th Biennial Scientific Conference*.

Gautam, N. N., Singh, K., Singh, B., Seal, S., Goel, A., & Goel, V. L. (2010). Studies on clonal multiplication of Guava (Psidium guajava L.) through cutting under controlled conditions. *Australian Journal of Crop Science*, *4*(9), 666–669.

Gidamis, A. B., Panga, J. T., Sarwatt, S. V., Chove, B. E., & Shayo, N. B. (2003). Nutrient and antinutrient contents in raw and cooked young leaves and immature pods of Moringa Oleifera, Lam. *Ecology of Food and Nutrition*, *42*(6), 399–411. https://doi.org/10.1080/03670240390268857

Gill, K. S. (2016). Guavas. In B. Caballero, P. M. Finglas, & F. B. T.-E. of F. and H. Toldrá (Eds.), *Encyclopedia of Food and Health* (pp. 270–277). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-384947-2.00363-9

GOK. (2018). *Kenya Youth Development Policy 2018: Empowering the Youth to Productively Contribute to Sustainable Development Draft 2* (p. 1). Government of Kenya.

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjDy4qTrrLqAhUOLBoKHcqAAPkQFjAAegQIBhAB&url=http%3A%2F%2Fpsyg.go.ke%2Fdocs%2FKenya%2520National%2520Youth%2520Policy.pdf&usg=AOvVaw3NOdItEUQzJb7iqJY9n9Mf

Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016a). Moringa oleifera: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness*, *5*(2), 49–56. https://doi.org/10.1016/j.fshw.2016.04.001

Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016b). Moringa oleifera: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness*, *5*(2), 49–56. https://doi.org/10.1016/j.fshw.2016.04.001

Guimarães, A. A. D. S. (2007). *Utilização do resíduo de goiaba (Psidium guajava L.) na alimentação de poedeiras comerciais* [Universidade Federal Rural de Pernambuco]. https://doi.org/616.89-008.47:616-

Gurvinder Singh Kocher. (2011). Status of wine production from guava (Psidium guajava L.): A traditional fruit of India. *African Journal of Food Science*, *5*(16), 851–860. https://doi.org/10.5897/AJFSX11.008

Gutiérrez, R. M. P., Mitchell, S., & Solis, R. V. (2008). Psidium guajava: A review of its traditional uses, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, *117*(1), 1–27. https://doi.org/10.1016/j.jep.2008.01.025

Habwe, F. O., & Walingo, K. M. (2008). Food Processing and Preparation Technologies for Sustainable Utilization of African Indigenous Vegetables for Nutrition Security and Wealth Creation in Kenya. In G. L. Robertson & J. R. Lupien (Eds.), *Using food science and technology to improve nutrition and development* (pp. 1–8). International Union of

Food Science and Technology.

Hailu, G., & Derbew, B. (2015). Extent, causes and reduction strategies of postharvest losses of fresh fruits and vegetables − A review. *Journal of Biology, Agriculture and Healthcare*, *5*(5), 49–64. http://www.iiste.org/Journals/index.php/JBAH/article/view/20627/21561

Ham, C., Akinnifesi, F. K., Franzel, S., Jordaan, D. D. P. S., Hansmann, C., Ajayi, O. C., & Kock, C. de. (2007). Opportunities for commercialization and enterprise development of indigenous fruits in Southern Africa. In F. K. Aklnnlfesl, R. R. B. Leakey, O. C. Alayl, G. Slieshl, Z. TchoundJeu, P. Matakala, & F. R. Kweslga (Eds.), *Indigenous Fruit Trees in the Tropics: Domestication, Utillization and Commercialization* (pp. 254–272). CAB International Publishing. https://doi.org/10.1079/9781845931100.0254

Han, B., Gu, H., & Liu, S. (2018). Lye Peeling of Fruits and Vegetables. *Shiyou Diqiu Wuli Kantan/Oil Geophysical Prospecting*, *53*(2). https://doi.org/10.13810/j.cnki.issn.1000-7210.2018.02.010

Haouet, M. N., Tommasino, M., Mercuri, M. L., Bella, S. Di, Framboas, M., Pelli, S., & Altissimi, M. S. (2018). *Experimental accelerated shelf life determination of a ready-to-eat processed food*. *7*, 189–192. https://doi.org/10.4081/ijfs.2018.6919

Haque, M. N., Saha, B. K., Karim, M. R., & Bhuiyan, M. N. H. (2009). Evaluation of Nutritional and Physico-Chemical Properties of Several Selected Fruits in Bangladesh. *Bangladesh Journal of Scientific and Industrial Research*, *44*(3), 353–358. https://doi.org/10.3329/bjsir.v44i3.4410

Hassan Khan, S. (2015). Effect of Different Concentration of Guava Pulp, Apple Pulp and Sugar Solution on the Shelf Stability of Blend Leather Storage at Ambient Temperature. *Journal of Food Processing & Technology*, *06*(07). https://doi.org/10.4172/2157-

7110.1000466

HCD. (2014a). *Horticultural Validated Report*. http://www.agricultureauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf

HCD. (2014b). *Horticulture Validated Report*. Agriculture, Fisheries and Food Authority (AFFA), Horticulture Performance Report. http://www.agricultureauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf

Hemanth, K. J., Sinija, V. R., & Hema, V. (2019). *Accelerated shelf-life study on protein-enriched carbonated fruit drink*. *September*, 1–8. https://doi.org/10.1111/jfpe.13311

Heuzé V, Tran G, & Bastianelli D. (2015). *Guava (Psidium guajava)*. Feedipedia Datasheet Citation, a Programme by INRA, CIRAD, AFZ and FAO. http://www.feedipedia.org/node/111

Husen, R., Andou, Y., Ismail, A., Shirai, Y., Hassan, M. A., Sciences, H., Sciences, B., & Putra, U. (2014). Enhanced polyphenol content and antioxidant capacity in the edible portion of avocado dried with superheated-steam. *International Journal of Advanced Research*, *2*(8), 241–248. http://hdl.handle.net/10228/00006668

Hussein, A., Odumeru, J. ., Ayanbadejo, T., Faulkner, H., McNab, W. ., Hager, H., & Szijarto, L. (2000). Effects of processing and packaging on vitamin C and β-carotene content of ready-to-use (RTU) vegetables. *Food Research International*, *33*(2), 131–136. https://doi.org/10.1016/S0963-9969(00)00027-2

Ibeawuchi, I. ., Okoli, N. ., Alagba, R. ., Ofor, M. ., Emma-Okafor, L. ., Peter-Onoh, C. ., & Obiefuna, J. . (2015). Fruit and Vegetable Crop Production in Nigeria : The Gains , Challenges and The Way Forward. *Journal of Botany, Agricultural and Healthcare*, *5*(2),

194–209. https://doi.org/10.1.1.678.6170

Idah, P. A., Ajisegiri, E. S. A., & Yisa, M. G. (2007). Fruits and vegetables handling and transportation in Nigeria. *Australian Journal of Technology*, *10*(3), 176–183.

ISO6888-1:1999. (2003). *Microbiology of food and animal feeding stuffs — Horizontal method for the enumeration of coagulase-positive staphylococci (Staphylococcus aureus and other species)*.

Jakhar M.S., Vaish P.K., P. S. (2013). Studies on the standardization and preservation of guava (Psidium guajava L.) and barbados cherry (Malpighia glabra L.) blended ready-to-serve beverage. *Journal of Progressive Horticulture*, *45*(1), 95–99.

Jalili, M., & Ansari, F. (2015). Identification and Quantification of 5-Hydroxymethylfurfural in Food Products. *Nutrition and Food Sciences Research*, *2*(1), 47–53.

Jamnadass, R. H., Dawson, I. K., Franzel, S., Leakey, R. R. B., Mithöfer, D., Akinnifesi, F. K., & Tchoundjeu, Z. (2011). Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. *International Forestry Review*, *13*(3), 338–354. https://doi.org/10.1505/146554811798293836

Jatinder Singh, K. S. and S. K. S. (2017). Effect of Postharvest treatment of Guava fruits with 1- methylcyclopropene and Gibberellin on storage life and fruit quality Jatinder. *International Archive of Applied Science and Technology*, *8*(2), 35–40.

Jawaheer, B., Goburdhun, D., & Ruggoo, A. (2003). Effect of processing and storage of guava into jam and juice on the ascorbic acid content. *Plant Foods for Human Nutrition*, *58*(3), 1–12. https://doi.org/10.1023/B:QUAL.0000041161.05123.66

Jaya, M. I., Sidi, F., Ishak, I., Affendey, L. S., & Jabar, M. A. (2017). A review of data quality research in achieving high data quality within organization. *Journal of Theoretical and Applied Information Technology*, *95*(12), 2647–2657.

Jayachandran, K. S., Srihari, D., & Reddy, Y. N. (2007). POST-HARVEST APPLICATION OF SELECTED ANTIOXIDANTS TO IMPROVE THE SHELF LIFE OF GUAVA FRUIT. *Acta Horticulturae*, *735*, 627–632. https://doi.org/10.17660/ActaHortic.2007.735.81

Jiménez-Escrig, A., Rincón, M., Pulido, R., & Saura-Calixto, F. (2001). Guava Fruit (Psidium guajava L.) as a New Source of Antioxidant Dietary Fiber. *Journal of Agricultural and Food Chemistry*, *49*(11), 5489–5493. https://doi.org/10.1021/jf010147p

Jumlah, P., Fenolik, K., Antioksidan, A., Buah-Buahan Segar, J., Buah-Buahan Komersial, J., Buah-Buahan, M., Khaw,), Wern, H., Haron, H., & Keng, C. B. (2016). Comparison of Total Phenolic Contents (TPC) and Antioxidant Activities of Fresh Fruit Juices, Commercial 100% Fruit Juices and Fruit Drinks. *Sains Malaysiana*, *45*(9), 1319–1327. http://www.ukm.my/jsm/pdf_files/SM-PDF-45-9-2016/04 Khaw Hui Wern.pdf

Kabuya, F. I. (2015). Fundamental Causes of Poverty in Sub-Saharan Africa. *IOSR Journal Of Humanities And Social Science*, *20*(6), 78–81. https://doi.org/10.9790/0837-20657881

Kadam, M., Kaushik, P., & Kumar, R. (2012a). Evaluation of Guava Products Quality. *International Journal of Food Science and Nutrition Engineering*, *2*(1), 7–11. https://doi.org/10.5923/j.food.20120201.02

Kadam, M., Kaushik, P., & Kumar, R. (2012b). Evaluation of Guava Products Quality. *International Journal of Food Science and Nutrition Engineering*, *2*(1), 7–11. https://doi.org/10.5923/j.food.20120201.02

Kader, A. A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. *Acta Horticulturae*, *682*, 2169–2176. https://doi.org/10.17660/ActaHortic.2005.682.296

Kamath, J., Rahul, N., Kumar, C. A., & Lakshmi, S. (2008). Psidium guajava L: A review. *Int. J. Green Pharm.*, *2*(1), 1–6. https://doi.org/10.22377/IJGP.V2I1.386

Kanwal, N., Randhawa, M. A., & Iqbal, Z. (2017). Influence of processing methods and storage on physico-chemical and antioxidant properties of guava jam. *International Food Research Journal*, *24*(5), 2017–2027. https://doi.org/10.1080/23311932.2016.1176287

Katumbi, J N, Imungi, J. K., Abong, G. O., & Gachuiri, C. K. (2020). *Postharvest handling , hygiene knowledge and practices of guava fruit handlers in Kitui and Taita Taveta* . *16*(1), 29053. https://doi.org/10.17660/ActaHortic.2018.1194.11.Presented

Katumbi, Judith N, Imungi, J. K., Abong, G. O., Gachuiri, C. K., Agnes, W., Omayio, D. G., & Owade, J. O. (2021). Harvesting , postharvest handling , hygiene knowledge and practices of guava fruit farmers : A comparative study of two counties of Kenya. *African Journal of Food Science*, *15*(May), 177–189. https://doi.org/10.5897/AJFS2021.2079

Katumbi, Judith Ndeme. (2020). Harvesting, postharvest handling, and the physicochemical changes during storage of guavas in two counties of Kenya [University of Nairobi]. In *Dissertation*. http://erepository.uonbi.ac.ke/bitstream/handle/11295/153876/Ndeme J_Harvesting%2C Postharvest Handling and the Physiochemical Changes During Storage of Guavas in Two Counties of Kenya.pdf?sequence=1&isAllowed=y

Kaur, G., Kumar, V., Sangma, C., Kaur, J., Kaur, J., & Suri, S. (2019). Preservation of spiced radish juice using hurdle technology. *International Food Research Journal*, *26*(June), 1095–1102.

KEBS. (2016). Fruit juices and nectars - Specification. *Kenya Standards*.

Keding, G. B., Kehlenbeck, K., Kennedy, G., & Mcmullin, S. (2017). *Fruit production and consumption : practices , preferences and attitudes of women in rural western Kenya*. https://doi.org/10.1007/s12571-017-0677-z

Khasanov, A., & Matveeva, N. (2020). *Determination of the shelf life of a functional beverage by accelerated testing*. *01003*, 0–4.

Kiaya, V. (2014). Post-harvest losses and strategies to reduce them. *The Journal of Agricultural Science*, *149*(3–4), 49–57. https://doi.org/10.13031/aim.20152189434

Kidaha, L., Alakonya, A., & Nyende, A. (2015). Morphological Characters of Guava landraces in Western and Coastal Kenya. *American Journal of Experimental Agriculture*, *9*(6), 1–11. https://doi.org/10.9734/AJEA/2015/12674

Kitinoja, L., & Kader, A. A. (2015). *Measuring postharvest losses of fresh fruits and vegetables in developing countries*. The Postharvest Education Foundation. https://doi.org/10.13140/RG.2.1.3921.6402

Kitinoja, L., Saran, S., Roy, S. K., & Kader, A. A. (2011). Postharvest technology for developing countries: Challenges and opportunities in research, outreach and advocacy. *Journal of the Science of Food and Agriculture*, *91*(4), 597–603. https://doi.org/10.1002/jsfa.4295

Kitui County Climate Information Services Strategic Plan. (2015). *Kitui County Climate Information Services Strategic Plan* (Ipp. 1–37). The Adaptation (ADA) consortium.https://www.adaconsortium.org/index.php/ component/k2/item/downlo ad/ 5 1_c1737bfaf1145e f5fcf15dd148e6b742

Krumreich, F. D., Corrêa, A. P. A., Nachtigal, J. C., Buss, G. L., Rutz, J. K., Crizel-Cardozo, M. M., Jansen, C., & Zambiazi, R. C. (2018). Stabilization of guava nectar with hydrocolloids and pectinases. *Polímeros*, *28*(1), 53–60. https://doi.org/10.1590/0104-1428.04916

Kuchi, V. S., Gupta, R., Gupta, R., & Tamang, S. (2014). Standardization of recipe for preparation of guava jelly bar. *Journal of Crop and Weed*, *10*(2), 77–81.

Kumar, P. S., & Sagar, V. R. (2014). Drying kinetics and physico-chemical characteristics of osmo- dehydrated mango, guava and aonla under different drying conditions. *Journal of Food Science and Technology*, *51*(8), 1540–1546. https://doi.org/10.1007/s13197-012-0658-3

Kumar, R., Lal, S., & Misra, K. K. (2012). Effect of post harvest calcium treatments on shelf life of guava cv. Sardar. *HortFlora Research Spectrum*, *1*(4), 344–347.

Kumar, V. (2016). *Fruit nectar as a refreshing beverage an overall review*. *18*(August), 1163–1169.

Kumari, K. U., Rishitha, G., Prasad, K. R., & Kumar, P. S. (2017). Value added products of guava. *Agriculture Update*, *12*, 2171–2177. https://doi.org/10.15740/HAS/AU/12.TECHSEAR(8)2017/2270-2276.K

Kumari, P., Mankar, A., Karuna, K., Homa, F., Meiramkulova, K., & Wasim, M. (2020). Mineral composition , pigments , and postharvest quality of guava cultivars commercially grown in India. *Journal of Agriculture and Food Research*, *2*(July), 100061. https://doi.org/10.1016/j.jafr.2020.100061

Kumari, Y. (2016). *Studies on effect of blending impact of guava (Psidium guajava L.) and*

papaya (Carica papaya L.) pulp on recipe standardization of blended nectar and rts (ready to serve) beverages.

Kus, S., Gogus, F., & Eren, S. (2007). *Hydroxymethyl Furfural Content of Concentrated Food Products*. *2912*. https://doi.org/10.1081/JFP-200060257

Lambert, I. (2001). Problems and Constraints to the Development of the Agro Processing Sector. *Dominica Country Conference*.

Leistner, L., & Gould, G. W. (2002). *Hurdle Technologies: Combination Treatments for Food Stability, Safety and Quality* (Gustavo V. Barbosa-Canovas (ed.)). Springer Science and Business Media.

Levy, S. (2015). *Accelerated Age Testing*. 40. http://www.testedandproven.com/wp-content/uploads/2015/01/Accelerated_Aging_Webinar_by_Scott_Levy.pdf

Lima Tribst, A. A., De Souza Sanťana, A., & De Massaguer, P. R. (2009). Review: Microbiological quality and safety of fruit juices - past, present and future perspectives. *Critical Reviews in Microbiology*, *35*(4), 310–339. https://doi.org/10.3109/10408410903241428

López-nicolás, J. M., & Carbonell-barrachina, Á. A. (2007). Effect of packaging materials on color, vitamin C and sensory quality of refrigerated mandarin juice. *Effect of Packaging Materials on Color, Vitamin C and Sensory Quality of Refrigerated Mandarin Juice*, *31*(2008), 596–611.

Mabuza, M. L., Ortmann, G. F., Wale, E., & Mutenje, M. J. (2016). The effect of major income sources on rural household food (in)security: Evidence from Swaziland and implications for policy. *Ecology of Food and Nutrition*, *55*(2), 209–230.

https://doi.org/10.1080/03670244.2015.1121482

Madrid, M. (2011). *Reducing postharvest losses and improving fruit quality worldwide: the one-billion-dollar untapped business opportunity*. https://fruitprofits.com/new/reducing-postharvest-losses-and-improving-fruit-qualitworldwide:-the-one-billion-dollar-untapped-business-opportunity/12

Mahendran, T. (2011). Physico-Chemical Properties and Sensory Characteristics of Dehydrated Guava Concentrate: Effect of Drying Method and Maltodextrin Concentration. *Tropical Agricultural Research and Extension*, *13*(2), 48. https://doi.org/10.4038/tare.v13i2.3138

María, L., & Acosta, V. (2014). *Analysis of Nutritional and Functional Properties of Dry Guava 1 Análisis de las propiedades nutricionales y funcionales*. *18*(1), 159–175. https://doi.org/10.11144/Javeriana.IYU18-1.apnf

Marques, L. G., & Freire, J. T. (2005). Analysis of freeze-drying of tropical fruits. *Drying Technology*, *23*(9–11), 2169–2184. https://doi.org/10.1080/07373930500212438

Marques, Luanda G., Silveira, A. M., & Freire, J. T. (2006). Freeze-drying characteristics of tropical fruits. *Drying Technology*, *24*(4), 457–463. https://doi.org/10.1080/07373930600611919

Mason-D'Croz, D., Bogard, J. R., Sulser, T. B., Cenacchi, N., Dunston, S., Herrero, M., & Wiebe, K. (2019). Gaps between fruit and vegetable production, demand, and recommended consumption at global and national levels: an integrated modelling study. *The Lancet Planetary Health*, *3*(7), e318–e329. https://doi.org/10.1016/S2542-5196(19)30095-6

Mbora, A., Jamnadass, R., & Lillesø, J. B. (2008). *Growing high priority fruits and nuts in Kenya:Uses and Management*. The World Agroforestry Centre.

McMullin, S., Ngethe, E., Gachuiri, A., Njogu, K., & Jamnadass, R. (2016). Fruit tree portfolios for improved diets and nutrition in Machakos. *Www.Worldagroforestry.Org*, 1–15. https://doi.org/978-92-9059-381-2

Mikore, D., & Mulugeta, E. (2017). *Determination of proximate and mineral compositions of Moringa oleifera and Moringa stenopetala leaves cultivated in Arbaminch Zuria and Konso , Ethiopia*. *16*(15), 808–818. https://doi.org/10.5897/AJB2017.15919

Mitchel Otieno, O., James Mucunu, M., Laetitia Wakonyu, K., Daniel Waweru, G., Stephen Gitahi, K., Francis Okumu, O., & Okumu Mitchel Otieno, C. (2016). Phytochemical profile and antioxidant capacity of leaves of Moringa oleifera (Lam) extracted using different solvent systems. *Journal of Pharmacognosy and Phytochemistry JPP*, *5*(4), 302–308.

Mizrahi, S. (2011). Accelerated shelf life testing of foods. In D. K. and P. Subramaniam (Ed.), *Food and beverage stability and shelf life*. Woodhead Publishing Limited. https://doi.org/10.1533/9780857092540.2.482

Mizrahi, S. (2014). Accelerated shelf-life tests. In *Understanding and measuring the shelf-life of food*. Woodhead Publishing Limited. https://doi.org/10.1533/9781855739024.2.317

MoALF. (2016). *Climate Risk Profile for Taita Taveta County*. https://cgspace.cgiar.org/bitstream/handle/10568/80445/Taita Taveta_Climate Risk Profile.pdf

Morais-Braga, M. F. B., Carneiro, J. N. P., Machado, A. J. T., dos Santos, A. T. L., Sales, D. L., Lima, L. F., Figueredo, F. G., & Coutinho, H. D. M. (2016). Psidium guajava L., from ethnobiology to scientific evaluation: Elucidating bioactivity against pathogenic microorganisms. *Journal of Ethnopharmacology*, *194*(November), 1140–1152. https://doi.org/10.1016/j.jep.2016.11.017

Mpho, M. (2012). Assessment of post harvest losses of fruits at Tshakhuma fruit market in Limpopo Province, South Africa. *African Journal of Agricultural Research*, *7*(29), 4145–4150. https://doi.org/10.5897/AJAR12.392

Musita, C. N., Okoth, M. W., Abong, G. O., & Omayio, D. G. (2020). *Glycoalkaloids in commercial potato varieties traded in Nairobi , Kenya [version 2 ; peer review : awaiting peer review]*. *May*.

Mustapha, Y., & Babura, S. (2010). Determination of carbohydrate and β-carotene content of some vegetables consumed in Kano metropolis, Nigeria. *Bayero Journal of Pure and Applied Sciences*, *2*(1), 119–121. https://doi.org/10.4314/bajopas.v2i1.58515

Mutembete, R. W. R. (2020). *Assessment of selected essential micronutrients in some indigenous fruits in Kakamega County, Kenya*. Kenyatta University.

Mutsuura, F. C. A. U., Folegatti, M. I. da S., Cardoso, R. L., & Ferreira, D. C. (2004). Sensory Acceptance of Mixed Nectar of Papaya , Passion Fruit and Acerola. *Scientia Agricola*, *61*, 604–608. https://doi.org/10.1590/S0103-90162004000600007

Najafzadeh, R., Arzani, K., Bouzari, N., & Hashemi, J. (2014). Identification of new Iranian sour cherry genotypes with enhanced fruit quality parameters and high antioxidant properties. *New Zealand Journal of Crop and Horticultural Science*, *42*(4), 275–287. https://doi.org/10.1080/01140671.2014.918044

Naseer, S., Rahman, M., Pervaiz, M., Naeem, N., & Hussain, S. (2018). The phytochemistry and medicinal value of Psidium guajava (guava). *Clinical Phytoscience*, *4*(1). https://doi.org/10.1186/s40816-018-0093-8

Ndawula, J., Kabasa, J. D., & Byaruhanga, Y. B. (2004). Alterations in fruit and vegetable beta-carotene and vitamin C content caused by open-sun drying, visqueen-covered and polyethylene-covered solar-dryers. *African Health Sciences*, *4*(2), 125–130.

Ndemo, B. (2016). *The tragedy of buying fruit at the roadside*. Daily Nation. https://www.nation.co.ke/oped/blogs/dot9/ndemo/2274486-3087408-p1p6aqz/index.html

Nikhanj, P., Kocher, G. S., & Boora, R. S. (2017). Fermentative production of guava wine from pectinase treated and untreated juice of 'punjab pink' cultivar of *Psidium guajava* L. *Agricultural Research Journal*, *54*(2), 244. https://doi.org/10.5958/2395-146X.2017.00044.8

Njoroge, D., Gowland Mwangi, P. J., & O. Udoto, D. M. (2014). Influence Of Young Farmers' Club Of Kenya Activities On Secondary School Students' Performance In Kenya Certificate Of Secondary Education Agriculture in Rongai Sub-County Of Nakuru County, Kenya. *IOSR Journal of Research & Method in Education (IOSRJRME)*, *4*(6), 15–35. https://doi.org/10.9790/7388-04611535

OECD/FAO. (2020). *OECD-FAO Agricultural Outlook 2020-2029*. OECD Publishing, Paris. https://doi.org/10.1787/1112c23b-en

Omayio, D., Abong', G., Okoth, M., Gachuiri, C., & Mwang'ombe, A. (2020). Trends and Constraints in Guava (Psidium guajava L.) production, utilization, processing and preservation in Kenya. *International Journal of Fruit Science*.

https://doi.org/10.1080/15538362.2020.1791304

Omayio, Duke G, Abong', G. O., Okoth, M. W., Gachuiri, C. K., & Mwang'ombe, A. W. (2019). Current Status of Guava (Psidium Guajava L) Production , Utilization , Processing and Preservation in Kenya : A Review. *Current Agriculture Research Journal*, *7*(3). https://bit.ly/36ob1BZ

Omayio, Duke Gekonge, Abong', G. O., Okoth, M. W., Gachuiri, C. K., & Mwang'ombe, A. W. (2020). Trends and Constraints in Guava (Psidium Guajava L.) Production, Utilization, Processing and Preservation in Kenya. *International Journal of Fruit Science*, *00*(00), 1–12. https://doi.org/10.1080/15538362.2020.1791304

Omurungi, S. M. (2012). *Guavas: Common in homesteads but hardly on the market - Daily Monitor*. Daily Monotor. https://www.monitor.co.ug/Magazines/Farming/Guavas--Common-in-homesteads-but-hardly-on-the-market/689860-1402522-1jr0bcz/index.html

Onyango, C., Luvitaa, S. K., Unbehend, G., & Haase, N. (2020). Nutrient composition, sensory attributes and starch digestibility of cassava porridge modified with hydrothermally-treated finger millet. *Journal of Agriculture and Food Research*, *2*(December 2019), 100021. https://doi.org/10.1016/j.jafr.2020.100021

Ooko Abong', G., Muzhingi, T., Wandayi Okoth, M., Ng'Ang'A, F., Ochieng', P. E., Mahuga Mbogo, D., Malavi, D., Akhwale, M., & Ghimire, S. (2020). Phytochemicals in Leaves and Roots of Selected Kenyan Orange Fleshed Sweet Potato (OFSP) Varieties. *International Journal of Food Science*, *2020*. https://doi.org/10.1155/2020/3567972

Oranusi, U. S., Braide, W., & Nezianya, H. O. (2012). Microbiological and chemical quality assessment of some commercially packed fruit juices sold in Nigeria . *Greener Journal of Biological Sciences*, *2*(September), 1–6. https://doi.org/10.4236/jct.2011.24069

Ordóñez-Santos, L. E., & Vázquez-Riascos, A. (2010a). Effect of processing and storage time on the vitamin C and lycopene contents of nectar of pink guava (Psidium guajava L.). *Archivos Latinoamericanos de Nutricion*, *60*(3), 280–284.

Ordóñez-Santos, L. E., & Vázquez-Riascos, A. (2010b). Effect of processing and storage time on the vitamin C and lycopene contents of nectar of pink guava (Psidium guajava L.). *Archivos Latinoamericanos de Nutricion*, *60*(3), 280–284.

Orwa, C., Mutua, A., Kindt, R., Jamnadas, R., & Anthony, S. (2009). *Psidium guajava Myrtaceae L*. Agroforestree Database: A Tree Reference and Selection Guide Version 4.0. World Agroforestry Centre, Kenya. http://www.worldagrofo restry.org/treedb /AFTPDFS/Psidium_guajava.PDF

Otieno, M. O., James Mucunu, M., Laetitia Wakonyu, K., Daniel Waweru, G., Stephen Gitahi, K., Francis Okumu, O., & Okumu Mitchel Otieno, C. (2016). Phytochemical profile and antioxidant capacity of leaves of Moringa oleifera (Lam) extracted using different solvent systems. *Journal of Pharmacognosy and Phytochemistry JPP*, *5*(4), 302–308.

Oyeyinka, A. T., & Oyeyinka, S. A. (2018). Moringa oleifera as a food fortificant: Recent trends and prospects. *Journal of the Saudi Society of Agricultural Sciences*, *17*(2), 127–136. https://doi.org/10.1016/j.jssas.2016.02.002

Oyugi, Z. (2018). *KALRO gives Busia farmers 55,000 free guava, gooseberry and jack fruit seedlings*. http://farmbizafrica.com/advertise/10-profit-boosters/2054-kalro-givers-busia-farmers-55-000-free-guava-gooseberry-and-jack-fruit-seedlings

Paltrinieri, G. (2014). Handling of fresh fruits, vegetables and root crops. *Food and Agriculture Organization of United Nations (FAO)*, 35–39. http://www.fao.org/3/a-au186e.pdf

Pandey, D., Shukla, S. K., Yadav, R. C., & Nagar, A. K. (2007). *Promising Guava (Psidium guajava L .) Cultivars for North Indian Conditions*. *1943*, 91–94.

Patel, P., Sunkara, R., Walker, L. T., Verghese, M., & Patel, P. (2016). Effect of Drying Techniques on Antioxidant Capacity of Guava Fruit. *Food and Nutrition Sciences*, *7*(7), 544–554. https://doi.org/10.4236/fns.2016.77056

Patel, R. K., Maiti, C. S., Deka, B. C., Deshmukh, N. A., & Roy, D. (2011). Variability Studies in Guava (Psidium guajava L .) Genotypes for Growth , Yield and Quality Attributes at Mid-hills of Meghalaya. *Indian Journal of Hill Farming*, *24*(1), 25–29.

Patel, R. K., Yadav, D. S., Babu, K. D., Singh, A., & Yadav, R. M. (2007). Growth , Yield and Quality of Various Guava (Psidium guajava L .) Hybrids / Cultivars under Mid Hills of Meghalaya. *Acta Hortic.*, *2*, 57–60.

PCE Instruments. (2014). *Colour quality control system-CQCS3 user manual*. PCE Instruments.

Pereira, E., Arabutan, D., Bôa-viagem, C., Lima, R. B., Lima, M. B., & Ludke, J. V. (2009). Physicochemical composition and energy and nutritional characteristics of guava and tomato residues for free range broilers. *Revista Brasileira de Zootecnia*, *38*(6), 1051–1058.

Pereira, F. M., Usman, M., Mayer, N. A., Jair, C. N., Oscar, R. M., & Salomie, W. (2016). Advances in guava propagation. *Rev. Bras. Frutic*, *39*(4), 1–24. https://doi.org/10.1590/0100-29452017

Pereira, M. C., Boschetti, W., Rampazzo, R., Celso, P. G., Hertz, P. F., Rios, A. D. O., Vizzotto, M., & Flores, S. H. (2014). *Mineral characterization of native fruits from the southern*

region of Brazil. *34*(June), 258–266.

Phani Deepthi, V., Chandra Sekhar, R., Srihari, D., & Siva Sankar, A. (2016). Guava fruit quality and storability as influenced by harvest maturity and postharvest application of calcium salts. *Plant Archives*, *16*(1), 174–182.

Phebe, D., & Ong, P. T. (2010). Extending "Kampuchea" guava shelf-life at 27oC using 1-methylcyclopropene. *International Food Research Journal*, *17*, 63–69.

Phimolsiripol, Y., Agro-industry, F., Mai, C., & Innovation, F. (2016). Techniques in Shelf Life Evaluation of Food Products. In *Reference Module in Food Science* (Issue 1). Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.03293-5

Prapasri Puwastien, Tee E Siong, Julia Kantasubrata, Graham Craven, Rafael Ryan Feliciano, K. J. (2011). The ASEAN Manual of Food Analysis. *Institute of Nutrition, Mahidol University*, 188. www.inmu.mahidol.ac.th/aseanfoods

Putnik, P., Pavli, B., Šoji, B., Kao, L., & Kitoni, D. (2020). *Innovative Hurdle Technologies for the Preservation of Functional Fruit Juices*. 1–36.

Quarcoo, P. (2008). *Development of Moringa Oleifera leaf beverage*. Kwame Nkrumah University of Science and Technology.

Ramadan Kamel, E., Abdel-Fattah, F., Samy El-Qaliouby, H., & Eaa, M. (2016). Response of New Zealand rabbits to diet containing guava waste (Psidium guaijava L.): Effect on growth performance, diet digestibility and economic efficiency. *Alexandria Journal of Veterinary Sciences*, *50*(1), 24–35. https://doi.org/10.5455/ajvs.232098

Ramalingam, C., I, P. M., Rai, S., & Gupta, S. (2010). Development of Tropical Fruit Bars and Assessment of its Shelf Life. *Journal of Experimental Sciences*, *1*(7), 26–32.

Rana, S., Siddiqui, S., & Goyal, A. (2015). Extension of the shelf life of guava by individual packaging with cling and shrink films. *Journal of Food Science and Technology*, *52*(12), 8148–8155. https://doi.org/10.1007/s13197-015-1881-5

Rani, T. B., & Babu, J. D. (2015). Acceptability and storage studies of guava - Aloe nectar blends. *The Asian Journal of Horticulture*, *10*(1), 80–85. https://doi.org/10.15740/HAS/TAJH/10.1/80-85

Ravani, A., Prasad, R. V, Gajera, R. R., Joshi, D. C., & Pterygosperma, L. S. M. (2017). *Potentiality of Moringa oleifera for food and nutritional security - A review*. *38*(3), 228–232. https://doi.org/10.18805/ag.v38i03.8983

Rawan, S., Bibi, F., Khan, N., Khattak, A. M., Shah, Z., Iqbal, A., Haq, S. U., Kamal, A., Shah, F. A., Naeem, A., & Ali, W. (2017). Postharvest Life of Guava (Psidium guajava L.) varieties as affected by storage intervals at room temperature. *Pakistan Journal of Agricultural Research*, *30*(2), 155–161.

Río Segade, S., Soto Vázquez, E., & Díaz Losada, E. (2008). Influence of ripeness grade on accumulation and extractability of grape skin anthocyanins in different cultivars. *Journal of Food Composition and Analysis*, *21*(8), 599–607. https://doi.org/10.1016/j.jfca.2008.04.006

Rojas-Garbanzo, C., Gleichenhagen, M., Heller, A., Esquivel, P., Schulze-Kaysers, N., & Schieber, A. (2017). Carotenoid Profile, Antioxidant Capacity, and Chromoplasts of Pink Guava (Psidium guajava L. Cv. 'Criolla') during Fruit Ripening. *Journal of Agricultural and Food Chemistry*, *65*(18), 3737–3747. https://doi.org/10.1021/acs.jafc.6b04560

Rojas-Garbanzo, C., Zimmermann, B. F., Schulze-Kaysers, N., & Schieber, A. (2017). Characterization of phenolic and other polar compounds in peel and flesh of pink guava

(Psidium guajava L. cv. ‘Criolla’) by ultra-high performance liquid chromatography with diode array and mass spectrometric detection. *Food Research International*, *100*, 445–453. https://doi.org/10.1016/j.foodres.2016.12.004

Román, S., Sánchez-Siles, L. M., & Siegrist, M. (2017). The importance of food naturalness for consumers: Results of a systematic review. *Trends in Food Science and Technology*, *67*, 44–57. https://doi.org/10.1016/j.tifs.2017.06.010

Rossi, M., Giussani, E., Morelli, R., Lo Scalzo, R., Nanic, R. C., & Torreggiani, D. (2003). Effect of fruit blanching on phenolics and radical scavenging activity of highbush blueberry juice. *Food Research International*, *36*(9–10), 999–1005. https://doi.org/10.1016/j.foodres.2003.07.002

Sagar, V. R., & Suresh Kumar, P. (2010). Recent advances in drying and dehydration of fruits and vegetables: A review. *Journal of Food Science and Technology*, *47*(1), 15–26. https://doi.org/10.1007/s13197-010-0010-8

Sahar, A., Rahman, U., Ishaq, A., Munir, M. S., & Aadil, R. M. (2019). Health-Promoting Perspectives of Fruit-Based Functional Energy Beverages. In *Sports and energy drinks*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-815851-7.00012-7

Salazar, D. M., Melgarejo, P., Martínez, R., Martínez, J. J., Hernández, F., & Burguera, M. (2006). Phenological stages of the guava tree (Psidium guajava L.). *Scientia Horticulturae*, *108*(2), 157–161. https://doi.org/10.1016/J.SCIENTA.2006.01.022

SÁnchez, C., Blanco, D., Oria, R., & SÁnchez-Gimeno, A. C. (2009). White guava fruit and purees: Textural and rheological properties and effect of the temperature. *Journal of Texture Studies*, *40*(3), 334–345. https://doi.org/10.1111/j.1745-4603.2009.00185.x

Sandhu, K. S., Singh, M., & Ahluwalia, P. (2001). Studies on processing of guava into pulp and guava leather. *Journal of Food Science and Technology (Mysore)*, *38*(6), 622–624. http://www.refdoc.fr/Detailnotice?idarticle=10504054

Sanjinez-Argandoña, E., Cunha, R., Menegalli, F. C., & Hubinger, M. (2005). Evaluation of total carotenoids and ascorbic acid in osmotic pretreated guavas during convective drying. *Italian Journal of Food Science*, *17*, 305–314.

Sarkar, A., & Bulo, J. (2017). Standardization of Blending of Guava Pulp with Pineapple Juice for Preparation of Ready-To-Serve (RTS). *International Journal of Current Microbiology and Applied Sciences*, *6*(11), 395–401.

Shahzad, Z., Rouached, H., & Rakha, A. (2014). Combating Mineral Malnutrition through Iron and Zinc Biofortification of Cereals. *Comprehensive Reviews in Food Science and Food Safety*, *13*, 329–346. https://doi.org/10.1111/1541-4337.12063

Sharma, H. K., & Kaur, M. (2018). Utilization of Waste from Tropical Fruits. In A. K. Anal (Ed.), *Food Processing By-Products and their Utilization* (First Edit, pp. 27–51).

Sheahan, M., & Barrett, C. B. (2017). Food loss and waste in Sub-Saharan Africa: A critical review. *Food Policy*, *70*, 1–12. https://doi.org/10.1016/j.foodpol.2017.03.012

Sidhu, J. S. (2006). Tropical Fruits : Guava , Lychee , and Papaya. In *Handbook of Fruits and Fruit Processing* (pp. 597–634).

Silip, J. J., & Hajar, S. A. (2007). Relationship between precooling, storage temperature and storage duration to the quality characteristics of guava (Psidium guajava L. cv. Kampuchea). *Acta Horticulturae*, *735*(March), 535–545. https://doi.org/10.17660/actahortic.2007.735.70

Silva, C. E. de F., & Abud, A. K. de S. (2017). Tropical Fruit pulps: Processing, product standardization and main control parameters for quality assurance. *Brazilian Archives of Biology and Technology*, *60*(December), 1–19. https://doi.org/10.1590/1678-4324-2017160209

Singh, E., & Puyo, A. (2014). Wine production process from guava (Psidium guajava L .). *International Journal of Enology and Viticulture*, *1*(8), 89–97.

Singh, J., Prasad, N., & Singh, S. K. (2017). Postharvest Treatment of Guava (Psidium guajava L.) Fruits with Boric Acid and NAA for Quality Regulation during Ambient Storage. *International Journal of Bio-Resource and Stress Management*, *8*(2), 201–206. https://doi.org/10.23910/IJBSM/2017.8.2.1633a

Siphiwe Dube. (2015). Effect of accelerated storage temperatures on the shelf life limiting factors of apple juice concentrate. In *MSc Thesis*. University of Pretoria.

Takahashi, A. A., Martins, M. S., Carvalho, J., Della, D. M., Oliveira, C. C. De, & Granato, D. (2015). Influence of distillation time and sample mass on sulfur dioxide analysis in passion fruit juice through Monier-Williams method. *Food Science and Technology*, *35*(3), 434–437.

Tanwar, B., Andallu, B., & Chandel, S. (2014). Influence of Processing on Physicochemical and Nutritional Composition of Psidium Guajava L. (Guava) Products. *International Journal of Agriculture and Food Science Technology*, *5*(2), 47–54. http://www.ripublication.com

Thaipong, K., Boonprakob, U., Cisneros-Zevallos, L., & Byrne, D. H. (2005). Hydrophilic and lipophilic antioxidant activities of guava fruits. *The Southeast Asian Journal of Tropical Medicine and Public Health.*, *36 Suppl 4*(suppl 4), 254–257.

https://doi.org/10.1002/1521-3803(20020901)46:5<353::AID-FOOD353>3.0.CO;2-B

Thongsombat, W., Sirichote, A., & Chanthachum, S. (2007). The production of guava juice fortified with dietary fiber. *Songklanakarin Journal of Science and Technology*, *29*(SUPPL. 1), 187–196. https://doi.org/10.1038/ncomms4449

Tian, H., Lu, C., Yang, J., Banger, K., Huntzinger, D. N., Schwalm, C. R., Michalak, A. M., Cook, R., Ciais, P., Hayes, D., Huang, M., Ito, A., Jain, A. K., Lei, H., Mao, J., Pan, S., Post, W. M., Peng, S., Poulter, B., … Zeng, N. (2015). Global patterns and controls of soil organic carbon dynamics as simulated by multiple terrestrial biosphere models: Current status and future directions. *Global Biogeochemical Cycles*, *29*(6), 775–792. https://doi.org/10.1002/2014GB005021

Tian, S. L., Li, L., Shah, S. N. M., & Gong, Z. H. (2015). The relationship between red fruit colour formation and key genes of capsanthin biosynthesis pathway in Capsicum annuum. *Biologia Plantarum*, *59*(3), 507–513. https://doi.org/10.1007/s10535-015-0529-7

Tillett, A., Kim, D., & Madison, O. M. A. (2014). Fruit nectar as a refreshing beverage an overall review. *Library Resources & Technical Services*, *7654185763*(July), 47906. https://doi.org/10.1111/j.1469-0691.2011.03558.x/pdf

Touati, N., Barba, F. J., Louaileche, H., Frigola, A., & Jose Esteve, M. (2016). Effect of storage time and temperature on the quality of fruit nectars: Determination of nutritional loss indicators. *Journal of Food Quality*, *39*(3), 209–217. https://doi.org/10.1111/jfq.12189

Tschirley, D., Ayieko, M., Hichaambwa, M., Goeb, J., & Loescher, W. (2010). Modernizing Africa's Fresh Produce Supply Chains without Rapid Supermarket Takeover: Towards a Definition of Research and Investment Priorities. In *Food Security International Development Working Papers* (No. 106; International Development).

https://doi.org/10.22004/ag.econ.9303

Turck, D., Bresson, J., Burlingame, B., Fairweather-Tait, S., Heinonen, M., Hirsch-Ernst, K. I., Mangelsdorf, I., McArdle, H. J., Naska, A., Nowicka, G., Pentieva, K., Sanz, Y., Siani, A., Sjödin, A., Stern, M., Tomé, D., Van Loveren, H., Vinceti, M., Willatts, P., & Neuhäuser-Berthold, M. (2016). Scientific Opinion on the energy conversion factor of d-tagatose for labelling purposes. *EFSA Journal*, *14*(11). https://doi.org/10.2903/j.efsa.2016.4630

Uchoa-thomaz, A. M. A., Sousa, E. C., Carioca, J. O. B., Morais, S. M. De, Lima, A. De, Martins, C. G., Alexandrino, C. D., Ferreira, P. A. T., Rodrigues, A. L. M., Rodrigues, S. P., Thomaz, J. C. D. A., Silva, J. D. N., & Rodrigues, L. L. (2014a). Chemical composition, fatty acid profile and bioactive compounds of guava seeds (Psidium guajava L.). *Ciencia e Tecnologia de Alimentos*, *34*(3), 485–492. https://doi.org/10.1590/1678-457x.6339

Uchoa-thomaz, A. M. A., Sousa, E. C., Carioca, J. O. B., Morais, S. M. De, Lima, A. De, Martins, C. G., Alexandrino, C. D., Ferreira, P. A. T., Rodrigues, A. L. M., Rodrigues, S. P., Thomaz, J. C. D. A., Silva, J. D. N., & Rodrigues, L. L. (2014b). Chemical composition, fatty acid profile and bioactive compounds of guava seeds (Psidium guajava L.). *Food Science and Technology*, *34*(3), 485–492. https://doi.org/10.1590/1678-457x.6339

Uchôa-thomaz, A. M. A., Sousa, E. C., Carioca, J. O. B., Morais, S. M. De, Lima, A. De, Martins, C. G., Alexandrino, C. D., Ferreira, P. A. T., Rodrigues, A. L. M., Rodrigues, S. P., Thomaz, J. C. D. A., Silva, J. D. N., & Rodrigues, L. L. (2014). Chemical composition, fatty acid profile and bioactive compounds of guava seeds (Psidium guajava L.). *Food Science and Technology*, *34*(3), 485–492. https://doi.org/10.1590/1678-457x.6339

Umulisa, C. (2012). Sampling Methods and Sample Size Calculation for the SMART Methodology. In *ULAP* (Vol. 2).

Urquía, D., Gutierrez, B., Pozo, G., Pozo, M. J., Espín, A., & De Lourdes Torres, M. (2019). Psidium guajava in the Galapagos Islands: Population genetics and history of an invasive species. *PLoS ONE*, *14*(3), 1–21. https://doi.org/10.1371/journal.pone.0203737

USDA. (2018). *National Nutrient Database for Standard Reference Release Legacy April , 2018 full report (All nutrients) 09139,Guavas, common, raw*. National Nutrient Database. https://ndb.nal.usda.gov/ndb/foods/show/09140

Verma, A. K., Rajkumar, V., Banerjee, R., Biswas, S., & Das, A. K. (2013). Guava (Psidium guajava L.) powder as an antioxidant dietary fibre in sheep meat nuggets. *Asian-Australasian Journal of Animal Sciences*, *26*(6), 886–895. https://doi.org/10.5713/ajas.2012.12671

Vijaya Anand, A., Velayuthaprabhu, S., Rengarajan, R. L., Sampathkumar, P., & Radhakrishnan, R. (2020). Bioactive Compounds of Guava (Psidium guajava L.). In H. N. Murthy & V. A. Bapat (Eds.), *Bioactive Compounds in Underutilized Fruits and Nuts* (pp. 503–527). Springer International Publishing. https://doi.org/10.1007/978-3-030-30182-8_37

Wasilwa, L. A., Wayua, F., Wasilwa, T., Wasike, V. W., Omari, F., & Ndungu, J. (2018). *Preferences of Guava (Psidium guajava L.) types amongst school Children in Western Kenya*. https://www.academia.edu/38251467/Wasilwa_et_al_Guava_Sensory_Analysis_PAPER_Jan_2018-3_REVISED_FW_9-4-2018.pdf

WFP. (2016). Comprehensive Food Security and Vulnerability Survey: Summary report Kenya

2016. *World Food Programme*, 1–12.

WHO. (2006). Fortificants: physical characteristics, selection and use with specific food vehicles. *Guidelines on Food Fortification with Micronutrients*, 341. http://www.who.int/nutrition/publications/micronutrients/GFF_Part_3_en.pdf

Williams, J. T., & Haq, N. (2000). *Global Research on Underutilised Crops: An Assessment of Current Activities and Proposals for Enhanced Cooperation*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwi3iZuNi5viAhVBzBoKHYGsD-0QFjAAegQIAxAC&url=http%253A%252F%252Fwww.fao.org%252Fdocs%252Feims%252Fupload%252F216780%252Fuoc_assessment_current_activities.pdf&usg=AOvVaw00fv1rlrrDxi9tLEzXVpX7

Włodarska, K., Pawlak-Lemańska, K., Górecki, T., & Sikorska, E. (2019). Factors influencing consumers' perceptions of food: A study of apple juice using sensory and visual attention methods. *Foods*, *8*(11). https://doi.org/10.3390/foods8110545

Wojdyło, A., Figiel, A., Lech, K., Nowicka, P., & Oszmiański, J. (2014). Effect of Convective and Vacuum-Microwave Drying on the Bioactive Compounds, Color, and Antioxidant Capacity of Sour Cherries. *Food and Bioprocess Technology*, *7*(3), 829–841. https://doi.org/10.1007/s11947-013-1130-8

Yadav, S. K., Sarolia, D. K., Pilania, S., Meena, H. R., & Mahawer, L. N. (2017). Studies on Keeping Quality of Preserved Guava Pulp during Storage. *International Journal of Current Microbiology and Applied Sciences*, *6*(3), 1235–1242.

Yan, L. Y. (2006). Antioxidant Properties of Guava Fruit: Comparison With Some Local Fruits. *Sunway Academic Journal*, *3*, 9–20. http://eprints.sunway.edu.my/28/1/lim3.pdf

Yousafi, A. A., AbbasiI, K. S., Ahmad, A., Hassan, I., Sohail, A., Qayyum, A., & Akram, M. A. (2021). Physico-chemical and Nutraceutical Characterization of Selected Indigenous Guava (Psidium guajava L.) Cultivars. *Food Science and Technology*, *41*(1), 47–58. https://doi.org/10.1590/fst.35319

Youssef, M. (2016). Molecular markers associated with high Vitamin-c content in guava. *J.Agric.Chem.and Biotechn., Mansoura Univ*, *7*(3), 49–55.

Youssef, M. A., Khafar, E., Khafar, A., & El Kady, A. (2017). *Studying the adulteration consequences of Guava Juice on vitamin - C loss at different packaging materials*. 570–577.

Yusof, S. (2003). Guavas. In *Encyclopedia of Food Sciences and Nutrition* (2nd ed., pp. 2985–2992). Elsevier Science Ltd. https://doi.org/https://doi.org/10.1016/B0-12-227055-X/00572-1

Zhong, Y., Wu, L., Chen, X., Huang, Z., & Hu, W. (2018). *Effects of Food-Additive-Information on Consumers ' Willingness to Accept Food with Additives*. https://doi.org/10.3390/ijerph15112394

APPENDICES

Appendix 1: Baseline Questionnaire

Survey on post-harvest handling and consumption of guava and guava products

This study aims to assess the current trends and constraints in utilizing guava and the traditional preservation and processing techniques of guava and processed guava products in Kenya. Your honest responses were used for this research purpose only and shall be treated with the utmost confidentiality. Your cooperation and participation are highly appreciated.

Thank you for accepting to take part in this study.

Enumerator's Name_____ Date of interview_____

1. **General information**

Location of interview

County _____ Subcounty _____

Location _____ Ward_____

2. **Respondent and general household information**

2.1 Name of Respondent	
2.2 Respondent gender	Sex M=1 { } F=2 { }
2.3 Educational level	1=college/university 2=completed secondary 3=completed primary 4=Dropped from primary 5 =dropped from secondary 6 =in primary 7 =in secondary 8 =adult education

	9=Did not attend { }
2.4 Age (years)	
2.5 Marital status	1=married 2=separated 3=widowed 4=single 5=divorced 6=N/A { }
2.6 Main occupation	1=salaried employee 2=farmer 3=self-employment/business 4=casual laborer 5=student 6=housewife 7 =unemployed 8= other (specify) 9= N/A { }

2.7 What is the household's main source of income (Livelihood)?

1=Formal employment 2= farming 3= Casual labour 4= Fishing 5= business 6 any other (specify)_____

2.8 What is the average monthly income of the household? ……Ksh

2.8.1 How much is spent on food? ……Ksh

Guava production practices

3. Do you cultivate guavas in your farm?

1=Yes { } 2=No { }

3.1 If yes, what portion of land is allocated to guava farming

1. Marginal (<0.02ha)

2. Small (>0.02 to 0.99ha)
3. Medium(1-2.99ha)
4. Large (3ha and above)

4 How did you attain your guava plantation?

1. Plantation
2. Naturalization/wild

5. What varieties do you plant on your farm?

1. White fleshed
2. Pink/red fleshed
3. Other (specify)……

5. How many years have you cultivated guava trees/fruits?_____

7. What is the main purpose for producing guavas?

1-Sale

2-consumption

3-Medicinal purposes

Others (Specify)_____

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

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

_____

9. Do you sell guava fruits

1=Yes { } 2=No { }

9.1 If yes, to whom do you sell the guavas?

1. Directly to consumers
2. Retailers
3. Wholesalers
4. Exporters
5. Processors
6. Governmental corporation
7. Other (specify): .....

9.2 If yes, what is the estimated income (Ksh) from guava sales per season _____

10. What is the share of the income from guavas in your household income?

1. Up to 25 %
2. 26 – 50 %
3. 51 – 75 %
4. 76 – 100 %

11. Do you experience pest and diseases attack on the fruits ?

1=Yes { } 2=No { }

12. Do you use pesticides

1=Yes { } 2=No { }

12.1 If yes, which types are they?

1. Organic

2. Inorganic

3. Any other(specify)

13. How do you imagine the future of your guava farming in the next ten years?

1. You will quit guava farming
2. You will continue guava farming
3. You will allow a family member(s) to the manage guava farms
4. You will sell/rent guava farm for agricultural purpose
5. Other (please specify).....

Utilization of guava fruits

14. **Do you consume guavas?**

1=Yes { } 2=No { }

14.1 If yes, where do you source from?

1. Own farm
2. Vendors
3. Market/Supermarket
4. Any other(specify)……**…**

14.2 If yes, how do you consume guava fruits?

1. Fresh

2 In Processed forms

3. Others (*specify*)…….

14.3 If in processed forms please list the products

1. Juice
2. Nectar
3. Jams
4. Jellies
5. Blends
6. Others (Please specify)_____

15. Do you process guava fruits 1=Yes { } 2=No{ }

15.1 If no, why?_____

15.2 If yes, please list the products

1. Juice
2. Nectar
3. Jams
4. Jellies
5. Blends
6. Others (Please specify)_____

15.3 If yes, what do you do with the guava by products such as seeds?

1. used as animal feed
2. Processed into other products (please list them)_____
3. Disposed of
4. Any other (Please specify)_____

16. Are there guava products you would wish to access but are not available?

1=Yes { } 2=No { }

16.1 If yes what guava products are these?_____

17. When guavas are in season how often do you consume guavas per week?

1. Once a daily { } 2. Twice daily{ }

3. Once a week{ } 4. Twice a week

5. { } Other {specify }_____

17.1 Do they consume with peels or without? 1 with peels 2. Without peels

Any reason for answer above_____

17.2 What quantity do you consume at a go?_____kg

18. How has your guava/guava products consumption been in the previous three years?

1. Increasing
2. Decreasing
3. Variable

18.1 Please give reasons

_____

19. Are there any traditional guavas products you know of?

1=Yes { } 2=No { }

If yes, please lists them_____

Processing and preservation of guavas

20 Do you store guavas ? 1=Yes { } 2=No { }

20.1 How do you store guava fruits?

1. Crates

2. Carton/plastic packages

3. Modified packaging

4. Low temperature conditions

5. Any other

20.2 How long do they store before spoiling?_____ days

21. What processing techniques do you apply in the preservation of guavas?

1. Drying

2. Pulping

3. None

4. Any other, specify_____

22. Do you know of any traditional methods used to preserve guava fruits?

1=Yes { } 2=No { }

If yes, please list the product _____

23. Please rate the ease of access to guava fruit-based products in your area

1. Highly available
2. Moderate
3. Less available
4. Not available

24. Do you experience guava postharvest losses?

1=Yes { } 2=No { }

24.1 If yes, what kind of losses are they?

1. Mechanical injuries
2. Overripening and rotting
3.Guava shriveling
4. Microbial and fungal attack
5 Others (specify)_____.

24.2 If yes what are the causes?

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)_____.

24.3 If no, what food preservation techniques/methods do you use for surplus guava preservation?

1. Drying

2. Use of Preservatives

3. Use of modified storage

3. Other (specify)_____

Post-harvest handling of guavas

25. What determines guava fruits harvesting?

1. Change of fruit color

2. Fruit sizes

3. Full ripe level

5. Others (specify _____

26. Immediately after harvesting, where do you store your guavas?

1. Exposed to direct sunlight

2. Put under shades

27. Do you sort harvested guavas?

1=Yes { } 2=No { }

28. Do you wash harvested guavas?

1=Yes { } 2=No { }

28.1 If yes, is the water used treated and what chemicals are used

_____

29 How are guava fruit s transported from the farms?

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

30. How are harvested guava fruits packaged?

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

31. What causes guava fruit postharvest losses at retailing shops

1. Poor storage conditions
2. Mechanical damage (rough handling)
3. Poor quality produce (disease, pest, premature fruits)
4. Others,(specify)_____

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

1. Wet seasons _____
2. Dry seasons _____

33. What strategies do you put in place to extend 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)_____

34. Do you have controlled atmosphere storage (CAS) for your guavas

1=Yes { } 2=No { }

34.1 If yes, specify the conditions _____

35. What do you do with over ripened guava fruits?

1. Sold at lower costs
2. Given as animal feeds
3. Disposed of
4. Other (Specify)_____

Constrains in production and processing of guavas

36. What have been the significant challenges in guava production?

1. Lack of funds for supplies (e.g., seed, fertilizer)

2. Lack of adequate labor
3. Lack of technical support and extension services
4. Lack of garden tools, equipment
5. Lack of knowledge on guava farming
6. Theft of guava fruits
7. Pest and diseases
8. Lack of right varieties
9. Poor market returns from guavas
10. Others (specify)_____

37.What are the main challenges affecting the processing of guavas?

1. Lack of adequate knowledge on guava value addition
2. Lack of processing equipment
3. Lack of capital
4. Lack of skilled human resources
5. Others (specify)_____

38. Rate the marketing challenges for fresh and processed guava on a scale of 1-4

1=severe 2=moderate 3=low 4=Not a challenge

39. How is accessibility to the market a challenge for fresh and processed guava on a scale of 1-4?

1=severe 2=moderate 3=low 4=Not a challenge

40. According to you, what can be done to fully exploit the nutritional and economic potential of guavas ? _____

41.Any comments you would like to share

1._____

2._____

Thanks

Appendix 2: Key informant interview questionnaire

Name_____

Organization_____

Position_____

Introduction

This study is being conducted by **Gekonge Duke**, a Ph.D. student from the University of Nairobi, under the Fruits and Vegetables for all Seasons (FruVaSe) Project. This study focuses on establishing trends of utilization, processing, and preservation of guava fruits in this area. We request that you take part in this study and be free to share with us the information you have on the guava fruits value chain.

Questions

1. Before we start, please tell me your role as a stakeholder in the guava value chain in this area?
    a. For how long have you been in this role, and what is your opinion concerning your role? Rate your importance in the guava value chain.
    b. Have you ever sought to increase your involvement in the guava value chain? If yes, did you succeed, and what do you adduce for your success/failure?
    c. From now on, would you be willing to increase your involvement in this value chain?
2. Please tell us about the guava varieties that commonly grow in this area and whether there are any improved varieties

3. How is the marketability of guavas in the area and the surroundings? If the marketability is poor, why is this so?
    a. Which specific market areas do the people rely on to sell guavas in this area?
    b. Are there any differences in the pricing across seasons and the various markets? Please elaborate.
4. In terms of gender and age group, who are the most involved in the guava fruits value chain? Please state while substantiating the role of each.
5. Are there any other stakeholders in the guava value chain? What roles do they play?
6. With reasons, how would you rate the utilization of guava fruits in this area?
    a. Do you have any recommendations to any of these stakeholders that may help improve the utilization of guava fruits in the area?
7. Have you ever considered value addition for guavas in this area?
    a. What do you think hinders the guava value addition?
8. Are there any traditional value-addition practices of guava fruits in processing and preservation practiced in the area?
    a. Which specific areas are they done?
    b. What would you adduce to the successful practice of these techniques in this area? (If these practices ceased, why did people abandon them?)
9. Are there any women or farmer groups involved in the preservation and processing of guavas in this area?
    a. If no, any reason for this?
10. Are there any success stories of value addition for other crops that you would wish can be emulated for the value chain for guava fruit that you know of with specific examples?
11. What would you cite as the most significant impediment to the value-addition of guava fruits in the area?

12. What are the opportunities presented for value-addition for guavas in this area?
13. What are your future plans as a stakeholder in the guava value chain?
14. Do you have any other comments you that you would love to share with us that we have not discussed today?

Thank you for participating

Appendix 3: Focus group

Introduction

This study is conducted by Gekonge Duke, a Ph.D. student from the University of Nairobi, under the Fruits and Vegetables for all Seasons (FruVaSe) Project. The focus group discussion aims to determine the challenges and opportunities presented in the guava value-addition techniques. Feel free to participate in the group as utmost confidentiality was upheld. Remember all answers given during the discussion are respected, and all of us are free to contribute.

Please fill in the details of the participants below.

Name	Gender (M/F)	Age (yrs)	Marital status	Role in guava fruits value chain
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

1. What is your role in the value chain of guavas?
    a. Have you ever explored to increase your scope of operation in the guava value-chain? Please elaborate with examples.
    b. Who are the most outstanding participants in terms of gender and age in the value chain of guava? Please specify the roles played.
2. How do you relate the marketability of guavas in this area?
    a. If low, what would be the reasons?
3. Please tell me the value-addition practices such as preservation techniques and processing of guavas that you know of?
4. With reasons, how would you rate the attention guavas have received among policymakers?
    a. If poor, how can it be corrected?
5. Are there any farmer groups or community-based organizations focused on improving the production and value-addition of guavas? Please give specific examples.
    a. If yes, what are the successes and challenges the organization has faced?
    b. If No, why is this so?
6. What are your plans concerning guava production and processing?
    a. Any other comments that you may have?

THANK YOU FOR PARTICIPATING