UNIVERSITY OF NAIROBI

EFFECT OF SELECTED ENVIRONMENTAL PARAMETERS ON QUALITY OF *SYZYGIUM CUMINII* FRUITS IN KENYA

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has been properly acknowledged and referenced in accordance to the University of Nairobi's requirements.

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To my dear loving Mother; Reaver Shanyisa, who always supported me emotionally and financially with constant encouragement, may God continue to bless you mum.

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ABSTRACT

Syzygium cuminii tree species belongs to the Myrtaceae family. The problem of underutilization of indigenous and traditional food resources can be addressed by promoting the utilization of these fruits to strengthen the food availability and adequacy systems in Kenya. This research investigated the effect of selected environmental parameters namely; temperature, rainfall, sunshine, relative humidity and soil types on the quality of the *Syzygium* fruits. The parameters studied include fruit size, moisture content, color, pH, Total Soluble Solids, Titratable acidity, minerals, vitamin C, crude proteins, crude fat and fibre, carbohydrates and energy. Analysis was done using standard methodologies including use of an Inductively Coupled Plasma – Optical emission Spectrometer for elemental analysis and High Pressure Liquid Chromatography for the determination of Vitamin C that ranged between 76.55 ± 0.02 and 965.24 ± 0.21 mg/100 g. There was a significant difference at P = .05 in ash content with Kwale recording a mean value of 2.74± 0.01 *Vis avis* 1.61 ±0.02 percent from Bungoma. There was a positive correlation between TSS with fruit Maturity. Soil pH, Na, Mn, and Zn were significantly different between the two counties, $P = 0.05$. Soil porosity highly influenced soil pH, while particle density caused an increase in bulk density, which in turn increased fruit weight, fruit pH, and ash content. Five out of 12 models with $P = 0.05$ were used to predict the dependent variables; Model 3 can predict ascorbic acid with the highest accuracy at $R^2 = 0$ .93, 5, crude protein, $R^2 = 0.87$, 6, Zinc, $R^2 = 0.98$, 9, ascorbic acid, $R^2 =0.99$ and 12, Zinc, $R^2 = 0.99$. The quality of fruits was affected by the tree canopy orientation with fruits oriented towards the east developed higher TSS, Vitamin C content and intense color. Higher annual rainfall of 1700 mm in Bungoma compared to 1032 mm in Kwale resulted in low Total Soluble Solids of 14.27 ± 0.01 to 15.05 ± 0.18 and high Titratable acidity, 0.74 ± 0.01 – 0.78 ± 0.02 for over 51 percent of the fruits that were analyzed. Fruits obtained from Kwale at low altitude, 162 ± 7 m had better quality than those from Bungoma at higher altitude, 1612 ± 18 m. Although the brix content and pH of fresh fruit varied with the prepared juice, no significant difference relating to abiotic factors was observed. The results of this revealed that *Syzygium cuminii* fruit is rich in most of the dietary macro and micro elements such as Vitamin C, needed for health, and the fruits can be used for establishing small and medium enterprises. Hence, there should be increase in efforts to provide the much needed resource base for product development, value addition and development of organic fruit juices.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS AND SYMBOLS

ANALAR	Analytical Reagents
ASALs	Arid and Semi-Arid Lands
BD	Bulk density
Cd	Cadmium
CIFOR	Centre for International Forestry Research
Cr	Chromium
Cu	Copper
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GHGs	Green House Gases
HPLC	High Pressure Liquid Chromatography
ICP – OES	Inductively coupled Plasma – Optical Emission Spectrum
IPCC	Inter governmental Panel on Climate change
KEBS	Kenya Bureau of Standards
KEFRI	Kenya Forestry Research Institute
LOD	Limit of Detection
MC	Moisture content
Mg	Magnesium
Mn	Manganese
Na	Sodium
PD	Particle density
RH	Relative humidity
TA	Titratable acidity
Ti	Titanium
TSS	Total Soluble Solids
TVC	Total Viable Count
USFDA	United States Food and Administration

CHAPTER 1

INTRODUCTION

1.1 General Background

Environmental conditions influence the quality and quantity of food production thus severely compromising agricultural production and access to food in many African countries. This, apart from increasing malnutrition cases in the continent, has adversely affected the struggle against food insecurity (Reynolds *et al*., 2015). The primary objective of feeding the world each year has become more difficult as agriculture faces more challenges. Global food systems continue to be threatened by climate change, land degradation, and other stressors while the demand for food and other agricultural products is driven by population growth and changes in diet associated with rising incomes.

Arable farming that depends on rainfall is moderately suitable for intermediate altitudes and areas with average rainfall areas; however, there is a likelihood that crops may fail due to frequent droughts and rainfall that is not distributed evenly. Despite having a lot of land, farmers always grow crops that are unsuitable for either the rainfall regime or the soil type (Gachimbi *et al.*, 2005). There is, therefore, a need to introduce more sustainable adaptation strategies like those of indigenous fruit trees into the agricultural systems to maintain rural livelihoods, increase yields, and use natural resources efficiently (Bryan *et al.*, 2009).

Constituents of a healthy and well-balanced diet include fruits and vegetables, which provide several vital components to human populations. Phytochemicals and other bioactive components with potential anti-carcinogenic and cardiovascular risk reduction properties are constituted in fruits and vegetables that are endowed with vitamins A and C (Sun *et al.*, 2002). Fruits and vegetables add colour, texture, and diversity to food plants, in addition, they are good sources of minerals, water, and fibre (Slavin and Lloyd, 2012). Postharvest conditions influenced all these properties. Among these are humidity, temperature, and improper handling of the fruits that cause significant losses of health benefits (Nunes, 2008), resulting in low-quality fruit products such as juices, jams, and wine.

Gachimbi *et al.*, (2005) estimated that yields from rain-fed agriculture would reduce by up to 50% in 2020. Irrigated and rain-fed are the two agricultural production systems practiced in Kenya. The latter was entirely dependent on the bimodal rainfall, where crops are planted twice a year apart from areas with a higher altitude.

A tree is said to be indigenous if it is native to a specific country or region. Some of the well-known indigenous wild fruits found in Kenya include; *Adansonia digitata* (Baobab - Mbuyu), *Syzygium cordatum* (Mzambarau), *Tamarindus indica* (Mkwaju), and *Schlerocarrya birrea* (Amarula). Among the roles that Indigenous fruits play in the community and world in general include; nutrition, human health (Isabelle *et al.,* 2010), and food security.

Universal research focuses on food crops (Poole *et al.,* 2021) and recently vegetables and legumes (Ojiewo *et al.,* 2015), which have shown a reduction in the amounts harvested and their nutritional quality in response to the impact on the environment. However, not very much has been done on fruits, nuts, and seeds, and yet they contain nutrients needed for good health (Alae-Carew *et al.,* 2020).

In this study, a variation of selected environmental parameters for the quality of *Syzygium* fruits, which are found in Kenya, but are highly underutilized, was established; these were; temperature, rainfall, altitude, relative humidity, and % sunshine. Soil pH, porosity, bulk and particle density, elemental concentrations: Sodium (Na), magnesium (Mg), Titanium (Ti), Manganese (Mn), Copper (Cu), and Zinc (Zn) were also investigated in the soils from Bungoma and Kwale Counties, based their influence on fruit quality from literature. Quality of the fruits namely; Fruit size, moisture content, colour, pH, ash content, Total Soluble Solids, maturity index, Titratable acidity, Vitamin C content, proteins, carbohydrates, crude fibre, crude fat, energy and minerals (Na, Mg, Cr, Mn, Fe, Cu, Zn, and Cd) were also determined, and results shall be used to inform stakeholders on the potential of these fruits as an essential beverage during famines. This information will similarly be used to address the food security issues in the country, in cases where communities adopt the value addition of fruit into products like juices, jam, and wine for sale to generate income.

1.2 Statement of the Problem

Climate change has a great impact on the state of the environment, crop productivity, and the quality of the produce; hence, it directly or indirectly affects food security and sustainability. It affects ecosystem resources including water, forests, wetlands, crops as well as food quality, human and environmental health, coastal zones, industrial activities, and human growth and development factors. There is a likelihood that the impact of a changing environment can become worse if measures to control it are not implemented. In addition, the growing population and the large proportion of the rural population facing food insecurity mean that more people will fall back on forest resources for survival. Forest fruit products and rural poverty are strongly dependent on Non –timber (Sunderland *et al.,* 2004), which leads to deforestation and loss of both flora and fauna biodiversity.

1.3 Objectives

1.3.1 Overall Objective

To determine the effect of selected environmental parameters on the quality of *Syzygium* fruits in Bungoma and Kwale Counties, Kenya.

1.3.2 Specific Objectives

i. To determine the quality parameters; Moisture content, size, colour, pH, % ash, Total Soluble Solids, maturity index, Titratable acidity, Vitamin C content, Protein, carbohydrates, crude protein, crude fibre energy and elements (Na, Mg, Cr, Mn, Fe, Cu, Zn, and Cd) of *Syzygium* fruits in Bungoma and Kwale Counties.
ii. To determine the effect of soil physicochemical properties: Soil pH, Particle density, bulk density, porosity, and elements (Na, Mg, Ti, Cr, Mn, Cu, Zn, and Cd) on the quality of *Syzygium* fruits in Bungoma of and Kwale Counties.
iii. To assess the effect of environmental factors: altitude, temperature, rainfall, relative humidity, and sunlight on the quality of *Syzygium* fruits from Kwale and Bungoma Counties.
iv. To determine the nutritional content of *Syzygium* juice using fruits from Bungoma and Kwale Counties and correlate with abiotic factors.

1.4 Justification

Whereas data on the variation of environmental factors on fruits is not recorded, for crops it is available, there are no similar sets of data for indigenous fruits (Moretti *et al.*, 2010). Whereas the *Syzygium* species, in general, has been explored extensively such as the distribution of *Syzygium guineense* by Nakabonge *et al*., (2006), dye extraction from tree bark by Tadesse *et al.,* (2012) and Sibandze *et al.,* (2010). *Syzygium cuminii leaves* have also been studied by Chatuverdi *et al.,* (2012) and Sharafeldin and Rizvi (2015).

Syzygium cuminii fruit pulp is endowed with various minerals such as K, Na, P, Ca, Zn and Fe (Ahmed *et al.,* 2020). In addition, Mg, Mn, Cu, Pb, and Cr were reported by Ghosh *et al.,* (2017) in the edible portion of *Syzygium cuminii* fruits pulp from India. In addition, sulphur and chlorine were reported from *S .cuminii* fruit pulp by Ayyanar and Subash – Babu (2012).

Phytochemical studies on *Syzygium cuminii* seeds have also been studied by Murti *et al.*, (2012), who reported that seeds were rich in phytochemicals, justifying their traditional use for wound healing. Rahman *et al.,* (2013) reported that *Syzygium cuminii* seeds increase the ability to remember in aged rats. *Syzygium aromaticum* leaves were explored by Razafimamonjison *et al.,* (2014), reporting that essential oils of the leaves, buds, and stem from Madagascar, Zanzibar, and Indonesia samples. *S. jambos* leaves have been widely studied (Sharma *et al.*, 2013; Musabayane *et al.,* 2005; Mohanty and Cock, 2010), though no impact of the environment on fruits has been reported.

Fruit quality parameters such as colour (Barett *et al.,* 2010) and vitamins for other indigenous fruits like Baobab (Dehelean and Magdas, 2013) have been studied, but so far there is no documented work for similar parameters on *Syzygium* (Mzambarau – Kiswahili) from Kenya. Previous experiments have been done in a Controlled Atmosphere (CA) e.g. green houses (Hamini – Kadar et al., 2014), Classification of the soil type and how it affects fruit trees has not been recorded.

This research investigated the effect the environment has on the quality of indigenous fruits. Such information is desirable for product development and value addition of high-quality products, such as fruit juices, jam, and even wine, for the fruit industries, for they shall be informed to employ the best plan of action and logistics for sustainably acquiring value added products to take to the market. Data on how fruit quality changes over time is important. In this regard, packaging, storage materials, and even transportation systems are determined by the chemical characteristics and quality of the fruits. This study sought to provide data on the potential of locally produced fruit formulations as low-cost alternatives to supplement emergency feeding programs that will strengthen food security, reduce malnutrition and mitigate chronic diseases in Kenya.

Indigenous fruits have been reported to be highly nutritious (Stadlmayr *et al.,* 2013), and this is exemplified by the consumer preferences for wild foods in their diets and medicinal purposes (Bhatt *et al.,* 2017), hence values obtained will determine their quality, thus advice industrialists in the fruit products industries and help strengthen the food security in the country.

CHAPTER 2

LITERATURE REVIEW

2.1: Environmental Variation

The increase in food insecurity is a result of environmental variations caused by the drainage of soils and high population density, all when combined increased the susceptibility of communities to variation in environmental factors (Mwanga, 2015). According to Christensen, et al.. (2007) and Hulme *et al.,* (2001), model-based predictions of future man-made variation in the environment in Africa, suggests that an increase in temperature may be a common occurrence due to the variation in climate now as compared to many years ago. Monitoring data have indicated an increase of 0.05 ^{o}C every decade (Wang et al., 2022) with June–November seasons warming slightly more than the December–May season (Hulme *et al.*, 2001).

Nalianya *et al.*, 2020 reported the climate for the Bungoma study site (Figure 2.1) as having temperatures averaging about 20.3^{o}C and annual rainfall of 1102 mm The rains are realized most of the year-round hence making the short dry season have minimal impact. However, there is generally a reduction in rainfall and an increase in the temperature trends within the study sites with Mount Elgon having more rain due to altitude advantage (Nalianya *et al.*, 2020).

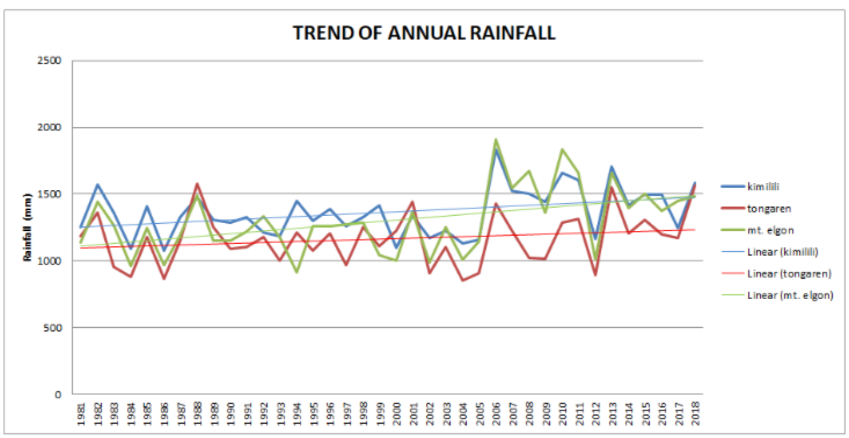


Figure 2.1: Trends in the Rain Pattern for Mt. Elgon, Tongareni, and Kimilili in Bungoma County, Kenya (1981-2018).**Source:** Nalianya *et al.*, 2020

Kwale County recorded mean rainfall amounts of 88 mm of rain, about five days of rains and a relative humidity of 77 % for 12 twelve years (Figure 2.2).

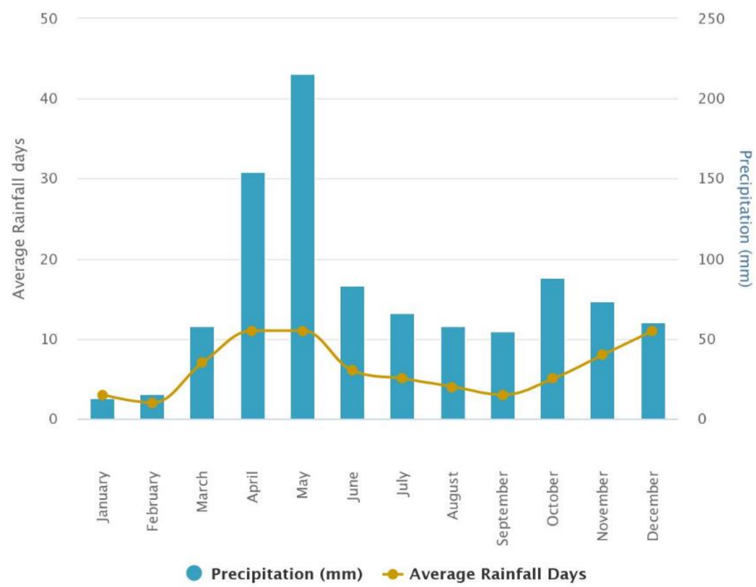


Figure 2. 2: Mean Monthly Rainfall for Kwale County 2010 – 2022

Source: Kenya Meteorological Department

Syzygium trees fruit twice a year in both Bungoma and Kwale, i.e. between March and July, which is also the period for long rains, and around November to February, which coincides partly with the short rains in the area. Flowers have are aromatic, tiny ranging between 0.5 cm in diameter. This fruiting period varies with climatic conditions.

In situations where the environment is not able to precipitate for a long time causing a lack of moisture, the loss of both plants and animals is said to be a drought (Ngaira, 2004). There has been an increase in the frequency of droughts in Kenya between 1980 and 2010 with the number of affected people sharply rising. Agriculture has been most hit hence the food insecurity in the ASALs (Huho, 2010).

2.2 Taxonomy of the Myrtacea Family

The Myrtaceae family consisting of cloves, guavas, and Eucalyptus average contains 5,500 species with four large genera. The fleshy *Myrcia s.l., Syzygium* and *Eugenia* are found in the Neo-tropical genera, and the capsular-fruited Australasian *Eucalyptus* in the fourth genera (Ladiges *et al.*, 2003). With Kew's Royal Botanic garden research interest focused primarily on the fleshy-fruited tribes of *Myrtaceae*, it has specifically *p*rioritized *Syzygieae* in Africa. Of both economic and ecological importance is *Myrtaceae* which is the eighth-largest family among flowering plants (Snow *et al.*, 2011).

2.2.1 *Syzygium cordatum*

The tree *is* medium-sized ranging between 5 and 6 m with the tallest ranging up to 20 m, the dwarf forms range between 30 and 45 m in height. When young, the trunks are banded, grey, and white and are quite smooth. The older trees have a dark brown bark or reddish that is normally thick, rough, and flakes off in corklike thick flakes. This is a riverine species that grows along fresh watercourses in lowlands ranging up to the high altitude forests. It is believed that its appearance indicates the presence of underground water and it is highly resistant to fire. The tree is an indicator that certain areas are suitable for sugarcane growing especially in Natal, South Africa. Surprisingly, it is not resistant to frost but too cold (Orwa *et al.,* 2009).

Figure 2. 3: *Syzygium cordatum* Fruits

Source: Random harvest plant, S.A

Syzygium cordatum (Tsisioma – Luhya) fruits are slightly acid and have many uses: eaten raw by humans, wild animals, and birds, or used to make an alcoholic drink. The ripe fruit makes a nice jelly, whereas the bark gives a blue dye that when dried, can be used to poison fish turning the water bluish for three days. As the wild animals eat the ripe fruit (Figure 2.3), they also browse the leaves. Flowers also give good quality honey.

2.2.1.1 *Syzygium cordatum* subspecies *Shimbaense* Verdc.

The *Syzygium shimbaense*, a sub-species of *Syzygium cordatum* is 7 m tall, medium in size with similar characteristics as *S. cordatum*. Rounded leaves range between 2.5, 10 cm long, and 1.5 to 4.6 cm wide. Fruits are narrow at both ends, slightly asymmetrically ellipsoid, 1.8 cm long, and one cm wide; fruiting pedicels are 7 mm long. *Syzygium shimbaense* is commonly found at the Giriama point, Shimba hills, Kwale, and Tanzania at an altitude of between 1 and 450 m (Verdcourt, 2001).

2.2.1.2 *Syzygium cordatum* Hochst. ex C. Krauss subsp. *cordatum*

This 20 m tall tree is small and sometimes medium or even a shrub. The leaves are cordate and amplexicaul at the base and this species is found from South Africa up to an altitude of 2,400 m up to Angola, Kenya, and the Democratic Republic (Van Wyk and Nigel, 2000). Both *Syzygium cordatum* and *Syzygium guineense* (Willd.) DC are connected by a range of intermediates and the two species hybridize with each other also the latter hybridize with *Syzygium gerardii* (Orwa *et al.*, 2009).

2.2.2 Syzygium guineense

This evergreen tree ranges from 15 to 30 m. The tree is medium-sized with grey or white young ones. With a length of five to about 18 cm and 1 to 8 cm width, the leaves have narrow ends. The branched flowers have a diameter of 3 cm whereas the fruits (Figure 2.4) are either oval or elliptical and appear in bunches of between 20 and 30. The fruits are green when raw and turn to dark purple when ripe (Nakabonge *et al.*, 2006).

Figure 2. 4: *Syzygium guineense*

Source: Tropical plants database

Syzygium guineense (Tsishitole – Kabras) is a riverine species found in rainforests that are both low and mountainous. They are also found in the "Miombo" woodlands, East Africa, Zimbabwe, Senegal, Botswana, South Africa, Somalia, Lesotho, Mozambique, Namibia, Swaziland, and Zambia. Found between sea level and an altitude of about 2,100 m above sea level with an average temperature of 10 to 30 ^{o}C, and mean annual rainfall of 1,000 to 2,300 mm. It prefers wet soil in areas where the water table is high (Balemie and Kebebew, 2006). Its wood is burned to produce smoke for seasoning milk containers.

2.2.3 Syzygium cuminii

Syzygium cuminii (L.) Skeels is a large evergreen tree ranging up to 30 m with leathery leaves that are about 6 to 12 cm long and oblong to elliptic in shape. The tree has scented flowers that are either green or white and are clustered in groups of between 10 and 40. The fruits (Figure 2. 5) are berries and oblong is shape with a dark purple colour (Figure 2.5). (Ayyanar and Subash – Babu, 2012). *Syzygium cuminii* is "Jamna" in - Luo.

Figure 2. 5: *Syzygium cuminii* Fruits

Photo taken by Rose Chiteva.

2.3 Environmental Impact

2.3.1 Temperature

Variation in the environment is associated with the elevation in temperature together with the effects of Green House Gases (GHGs) such as carbon dioxide, methane, ozone etc. Climate change is evident in Kenya since temperatures have gone up, and rainfalls can no longer be predicted since they have become irregular and more intense when they pour (Nzau, 2013). These changing climatic patterns have adverse effects on Kenya's socio-economic sectors such as agriculture.

Temperature affects the biochemical processes in the plant. Flowering and fruit maturity are sensitive to temperatures, between 25 and 29 ^{o}C, that causes a decrease in fruits per plant. There is higher transpiration of fruits at higher temperatures causing a reduction in weight (Lokesha *et al.,* 2019). Higher temperatures of over 35 ^{c}o. cause a delay in fruit coloration (Sato *et al.,* 2000).

2.3.2 Rainfall

The effect of rainfall may differ depending on rainfall characteristics (drop size, intensity, and duration) and the crop growth stage exposed to rain (Suleiman *et al.*, 2021). Water is important in transpiration since it regulates the stomata thus essential to photosynthesis.

2.3.3 Light intensity/Sunshine

Amount and intensity of light during the growth of a plant influence amount of ascorbic acid formed. This and the illumination of the fruits have been shown to increase the synthesis of ascorbic acid (Gruda, 2005). According to Watson *et al.,* (2002), glucose and sucrose are negatively affected when plants grow under shade whereas tomatoes and strawberries grown in a lot of sunlight obtain more sugar and dry matter (Caruso and Villari, 2004). The orientation of fruits on the tree affects the quality of fruits (Jifon and Syvertsen, 2001).

2.3.4 Pre-harvest Relative Humidity (RH)

Low RH of between 60 and 65 % has been reported to reduce evaporation and fruit quality. Higher values of 90 to 95 % at the ripening stage give the best fruit quality and humidity controls is the storage life of fruits and vegetables (Ahmed *et al.*, 2018). High RH has been reported to affect plant formation (Jeon *et al.,* 2006).

2.3.5 Altitude

Fruit weights and total soluble solids increased (Naryal *et al.*, 2020; Timilsina and Tripathi, 2019) with increasing altitude, however, ascorbic acid and titratable acidity decreased with increasing altitude (Rokaya *et al.,* 2016).

2.3.6 Soils

Soil structure is largely influenced by the environment and agriculture, it's important therefore to understand the structural state and size of the soil (Singh, 2009). The proportion of sand, silt, and clay (soil texture) on the other hand gives soil its physical and chemical properties, and soil components vary with the location (Muenchow *et al.*, 2013)**.** *Syzygium* species grow in a variety of soils, and higher yields have been reported in loamy soils that hold sufficient or only what the tree requires. The tree can grow in salty environments, marshy and highly eroded land with a pH of up to 10.5 (Singh, 2009).

2.3.6.1 Soil pH

This determines the availability of nutrients to plants. In acidic soils, some nutrients become "tied up" in the soil at certain pH levels (pH 4.5 – 6.0) causing a deficiency of Molybdenum, Calcium, and Magnesium and higher levels of manganese and aluminium. Soils at pH 7 to 8 are alkaline and lead to a lack of manganese, copper, boron, and zinc., however, this pH is preferred by melons (Tian *et al.*, 2023). Most plants are suited for neutral soils; whereas others like pears are suited for other pH levels, e.g. Blueberries and Cranberries prefer acidic soils (Ladiges *et al.*, 2003). Soil solutions are considered Strong acids if pH is less than 5, Moderately acidic between 5 and 6, Neutral from 6.5 to 7.5, and moderately alkaline between 7.5 and 8.5, and values above these are given by Strong alkaline solutions (Jensen, 2010).

2.3.6.2 Soil Particle Density

This is the average of both the organic and inorganic parts of the soil. The densities of the inorganic materials are between two and three while those of the organics are equal to or less than 1.5 g cm^{-3}. The density of the organic part of soil found on the surface is usually between 2.5 and 2.6 g cm^{-3}. Estimation of particle density is essential in the determination of air spaces between particles (Blake, 2008). This also provides information on the ability of the soil to release carbon during decomposition.

2.2.6.3 Soil Bulk Density

Soil bulk density indicates the health status of soil (Abbott and Manning, 2015). This soil property also affects the production level of organic matter and the quality of the environment (Kimble *et al.,* 2000). Since soil bulk density is active, it changes with influence by anthropogenic activities and long-term environmental changes (Norman et al., 2016; Flues *et al.,* 2004), damaging the flora and fauna. Soil bulk density is also used to quantify carbon in soils therefore used by governments in their record of greenhouse gas emissions, water stability, and storage of nutrients (Makovníková *et al.,* 2017).

2.3.6.4 Soil Porosity

This is the amount of space in soil and subsequently, water and air it can store and how fast they can move within the soil. This helps researchers to determine how the soil behaves, the possibility of floods, which living things the soil can support, the possibilities of a change in the soil, and how it is best suited for anthropogenic activities. Soil porosity is influenced by bulk density (Logsdon, 2012 ; Norman *et al.,*2016).

2.3.6.5 Soil Mineral Content

Soil minerals form the inorganic part of the soil which is about 45 % mineral content (Muchukuri *et al.,* 2004). Ti content in soils varies from 0.1 – 9 % originating from small pieces of a parent rock in form of sand (0.1 to 2 mm), silt (0.002 to 0.1 mm), and clay (less than 0.002 mm). Ti is used for plant growth and relates oppositely with Iron (Lyu *et al.,* 2017).

2.4 *Syzygium* Fruit Quality

Quality can be defined both from the product's and the consumer’s view. From the product’s outlook, quality products are natural and quantitative, whereas, from the consumers’ viewpoint, the properties are qualitative (Gruda, 2005). The physical (Weight, size, and moisture content) and chemical (pH, colour, Titratable acidity, Total Soluble solids, Vitamin C, Ash, and mineral content) properties of fruits indicate which can be used in product development and value addition. They are useful in brewery's juice and jam industries. Hence meeting the requirements for industrial use is important as processing curbs wastage when the fruit is in season and makes it possible for marketing in different product forms.

2.4.1 Size

Variation in size could be a result of genetic makeup (Ahmed *et al.*, 2018) and age (Arshad *et al.*, 2014; Hamadzrip, 2012). Insufficient light in the immediate surrounding area of the fruits reduces vitamin C content, size, Total soluble solids, acidity, and weight. Smaller fruits have less weight and have a short lifespan therefore having a reduced market value (Gruda, 2005).

2.4.2 pH

The presence of organic acids in fruits causes their pH to vary between 2.5 and 4.5 (Calvacanti *et al.*, 2006). This is mainly a result of citric, tartaric, and malic acids. Variation of the acid content depends on the fruit, in pear juice; the total acid content is 0.2 % whereas, in lime, it is 0.8 %. It is worth noting that; lower pH enhances microbiological and physicochemical stability (Gayon, *et al.*, 2006).

2.4.3 Colour

Natural pigments give fruits and vegetables their colour as they mature and ripen. The gel cap type of chlorophylls are green in colour, carotenoids depict yellow, red, and orange colours and anthocyanins are responsible for red and blue colours, flavonoids give yellow colour whereas betalains give red colour (Barett *et al.*, 2010). Colour is affected by fruit position (Arshad *et al.*, 2014). Fruit colour is the first attribute that influences a consumer’s preference followed by the firmness of the fruit and then the taste, all these are influenced by organic compounds such as vitamins (Callahan, 2003). Colour is one of the subjective maturity indexes used by producers based on their experience of visualizing how a fruit appears when mature (Reid, 2002; Watkins, 2003).

Sunlight is a radiation including visible, radio, gamma and x-rays in which both electrical and magnetic fields fluctuate concurrently between 380 – 740 nm, and the ability by human beings to perceive color-vision spectrum as shown in Figure 2.6

color	wavelength interval	frequency interval
red	~ 625-740 nm	~ 480-405 THz
orange	~ 590-625 nm	~ 510-480 THz
yellow	~ 565-590 nm	~ 530-510 THz
green	~ 500-565 nm	~ 600-530 THz
cyan	~ 485-500 nm	~ 620-600 THz
blue	~ 440-485 nm	~ 680-620 THz
violet	~ 380-440 nm	~ 790-680 THz

Figure 2. 6: Colour and Wavelengths

Source: http://en.wikipedia.org/wiki/Color

2.4.4 Total Soluble Solids (TSS)

The positive correlation between the fresh matter mass and sugar is one of the quality traits of fruits. Total soluble solids is therefore expressed as a percentage of the correlation. Specific gravity can be used to estimate maturity and time of harvest for some fruits. when it is greater than one, the TSS content is high and therefore the fruits are mature, the reverse is true (Narayana *et al.*, 1999).Bix content measures how much solid is dissolved in a liquid through specific gravity. As fruits mature, the surface, chemical composition, and flavour change (Chahidi *et al.*, 2008). This is due to variations in the ratio of TSS and organic acids that indicates the level of fruit maturity.

2.4.5 Titratable Acid (TA)

TA is used to determine the maturity of fruits and how sour citrus fruits taste. The ability of the fruit to be well stored and the eventual taste is determined by its maturity. The most predominant acids to be titrated include malic, citric, and tartaric acids. Governments have put in place quality standards based on TA or the ratio of Brix content to TA for the consumer's protection. Immature fruits exhibit a low sugar-to-acid ratio whereas mature ones give a high sugar-to-acid ratio.

2.4.6 Vitamin C

Light influences plant growth and in this case vitamin C formation in fruits (Isabelle *et al.,* 2010), thus causing an increase in its content (Okiei *et al.*, 2009).

Post-harvest quality varies according to locality. Low temperatures suppress antioxidant capacity of vitamin C in plants. In most living things and foods like fresh vegetables and citrus fruits, a water-soluble vitamin called vitamin C (Ascorbic acid) is common. This acid is involved in wound healing, biosynthesis of collagen, absorption of Iron, antioxidant (Okiei *et al.*, 2009) that fights radical-induced diseases, activation of the immune response, and the formation of bones (Pisoschi *et al.*, 2009).

2.4.7 Ash Content

Dry ashing is done at a temperature of between 500 and 600 ^{o}C in a muffle furnace removing organics, water, and any volatile compounds. This leaves oxides that are then analysed for minerals.

Ash content is the total amount of minerals in the fruits and is determined for the;

(i) Food labelling*:* Amounts and nature of minerals present in food should be displayed on the label
(ii) Quality. This depends on the nutrition of the food, flavour, and ability to withstand degradation
(iii) Antimicrobial properties: The presence of minerals may inhibit some microbes
(iv) Diet: There are essential (Ca, Mg, etc.) and toxic (Pb Hg) minerals
(v) Formulation:_ The physical and chemical nature of food is influenced by the mineral composition (Gwarzo and Solanki, 2015).

2.4.8 Mineral Content

Type of fruit, minerals in the soil, composition of water, conditions of the weather, environmental pollution from industries and automobiles (Tufuor *et al.,* 2011), (Bragança *et al.,* 2012) and (USFDA, 2013 Agricultural practices e.g. types and amounts of fertilizers influence the levels of trace metals in juices (Nour *et al.,* 2011).

2.4.9 Crude Protein (CP)

Proteins constitute the structure of many foods including fruits. They contain over twenty amino acids, and energy and have a variety of uses among them; the formation of gels, thickeners, etc. CP is approximated by the multiplication of all the Nitrogen obtained in the analysis by the Kjeldahl method with a factor of 6.25, with an assumption that all the nitrogen originated from protein (Levey *et al.,* 2000).

2.4.10 Carbohydrates

Indigenous wild fruits have been reported to have similar or higher carbohydrate content than domesticated known fruits e.g. mangoes, pomegranate, guava, apples, oranges, and pears (17.00, 17.10, 14.30, 13.81, 11.54, 10.65 % respectively) (Mahapatra *et al.,* 2012).

2.4.11 Crude Fat

Fat is a constituent of most foods and has two times the energy that is provided by either carbohydrates or proteins. Fat also gives food a sense of taste and delays the stomach from discharging waste. The required daily intake of fat is between 15 and 25g per day. Lack of fats in the human body causes loss of weight (Gopalan *et al.,* 2004).

2.4.12 Crude Fiber (CF)

This is mainly roughage found in the cell walls of fruits and remains as a filtrate after analysis. An insoluble carbohydrate also does not dissolve in the reaction of chemicals. The estimation of CF indicates the freshness of the food. CF helps the passage of food through the gut and maintains the health of the gastrointestinal tract, regulating body weight (Guo *et al.,* 2019; Howarth *et al.*, 2001). However, it binds trace elements when in excess causing a lack of elements such as Zn and Fe.

2.4.13 Energy Content

The existing methodologies for the determination of energy values rely on the bomb calorimeter. This is a measure of energy from burning a sample giving a value that is corrected for food samples. Caloric value is the quantity of heat dissipated is when a unit weight is burnt. . High heating value is obtained, and subsequently, a lower value can be obtained from calculation assuming that what remains after combustion is vapour. This is shown in equation 1.

$$\textit{Lower calorific value x d} = \textit{Higher calorific value x d} - 2\ 4.42\ \textit{x Hydrogen}\ \%\ \textit{of}\ \text{the d}\textit{ry sample}\ldots(2.1)$$

2.5 *Syzygium* Fruit Juice

Fresh fruit juices are nutritious and rich in minerals and vitamins (Chanson-Rolle et *al.*, 2016). They also contain plant chemicals that prevent the formation of cancerous cells. (Franke *et al.,* 2010). Juices are water-based products obtained from fruits (Fraternale *et al.,* 2011). Currently, there is an increase in demand for fresh fruit juices (Abedelmaksoud *et al.,* 2022) which are prepared by expressing the juice physically from the fruit either using blenders or otherwise. Since most fruits are acidic, flavouring is done e.g. by sugar to make it acceptable/palatable to the consumers. (Bagde and Tumane, 2011). Ripe *Syzygium* fruits are edible and can be processed to juice, jam, jelly, sauces, and wine. The unripe ones are used in making vinegar, which causes increased urine output among other uses. The juice can be stored at ambient temperature for about 5 days and at 4 ^{o}C for 20 days (Singh, 2009).

2.6 Analytical Instrumentation

2.6.1 High-Performance Liquid Chromatography (HPLC)

Chromatography has the same basic principle of separating samples into basic constituents due to differences in relative affinities of various molecules in the mobile and stationary phases. Depending on the spatial arrangements of atoms and their bonds, the molecules of substance slows down when going through the stationary phase. The precise forces between the molecules determine the elution time causing separation and being detected by UV detector, which distinguishes samples passing through.

Normal Phase HPLC shall be used. Here the analytes are separated based on polarity. The Normal Phase HPLC uses polar silica, as a stationary phase and non–polar mobile phases e.g. chloride, chloroform, and hexane. Using the Reverse Phase HPLC**:** The hydrophobic or non – polar column forms the stationary phase while polar liquids e.g. water and methanol mixtures or acetonitrile form the mobile phase.

High Pressure Liquid Chromatography based at the Kenya Forestry Research Institute (KEFRI), using a Shimadzu LC20A system with an SPD 20A Ultra violet detector set at 254 nm was used to determine vitamin C in the Syzygium fruits. Analysis used Reverse Phase HPLC, whose column was a shim pack VP – ODS (150 mm x 4.6 mm, with an internal diameter of 5µm and a column oven CTO 20A. With 70% acetonitrile as the mobile phase

2.6.2 Inductively Coupled Plasma – Optical Emission Spectrum (ICP – OES)

This is a spectrometric method where there is an excitation of atoms when impacted by energy from the plasma membrane and subsequent release of emitted rays on returning to lower energy levels. The wavelength of the rays is then recorded. The position of the light rays and their intensity determines the element analysed. Argon is used first to ionize and plasma is produced at a temperature of 10,000 ^{o}C, which then causes an emission of a sample. Samples are introduced in atomized solution form through the middle of the torch.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Areas

Soils and fruits were obtained from two counties chosen to represent contrasting environmental conditions in Kenya. Kwale is at a lower altitude with both high humidity and temperatures, whereas Bungoma is the reverse. These environmental parameters together with others have been reported to bring about a variation in the quality of fruits (Jaakola and Hohtola, 2010; Sridevi and Giridhar, 2013).

Syzygium fruit trees were sampled from eight out of the 12 sub-counties in Bungoma County. These are; Cheptais, Webuye east (Mihuu, Maraka, Nabuyole), Kimilili – Tongaren (Kimilili township, Ndalu, Binyenya), Bungoma north (Naitiri/kabuyefwe), Tongaren (Ndalu), Kopsiro (Korn'gotuny), Sirisia (Malakisi) and Webuye west (Mahanga, Lugulu, Milo).

The mapped soil is from Bungoma county includes: Acrisols which are highly acidic, Arenosols that are not well developed, and dominated by sand, cambisols mainly found in the forests with a high Iron content, ferralsols and gleysols are low in minerals and are dominated by clay, luvisols that are highly leached and nitosols developed from old rocks and very fertile (Ralph *et al.,* 2005).

Figure 3.1 shows sampling sites in Bungoma County that is, located on the southern slopes of Mt. Elgon and bordering Uganda from the North West. The county covers an area of 3,032 km^2 and is located at latitude 00 45' 00" N and longitude 34 35' 00" E (Ralph *et al.,* 2005). The altitude is 1385 to 1441m above sea level. Temperature ranges from 15 to 20 ^oC reaching a maximum of 22 ^oC to 30 ^oC (Nalianya *et al.,* 2020) and the 2 rainfall seasons range between 1200 and 1800 mm annually.

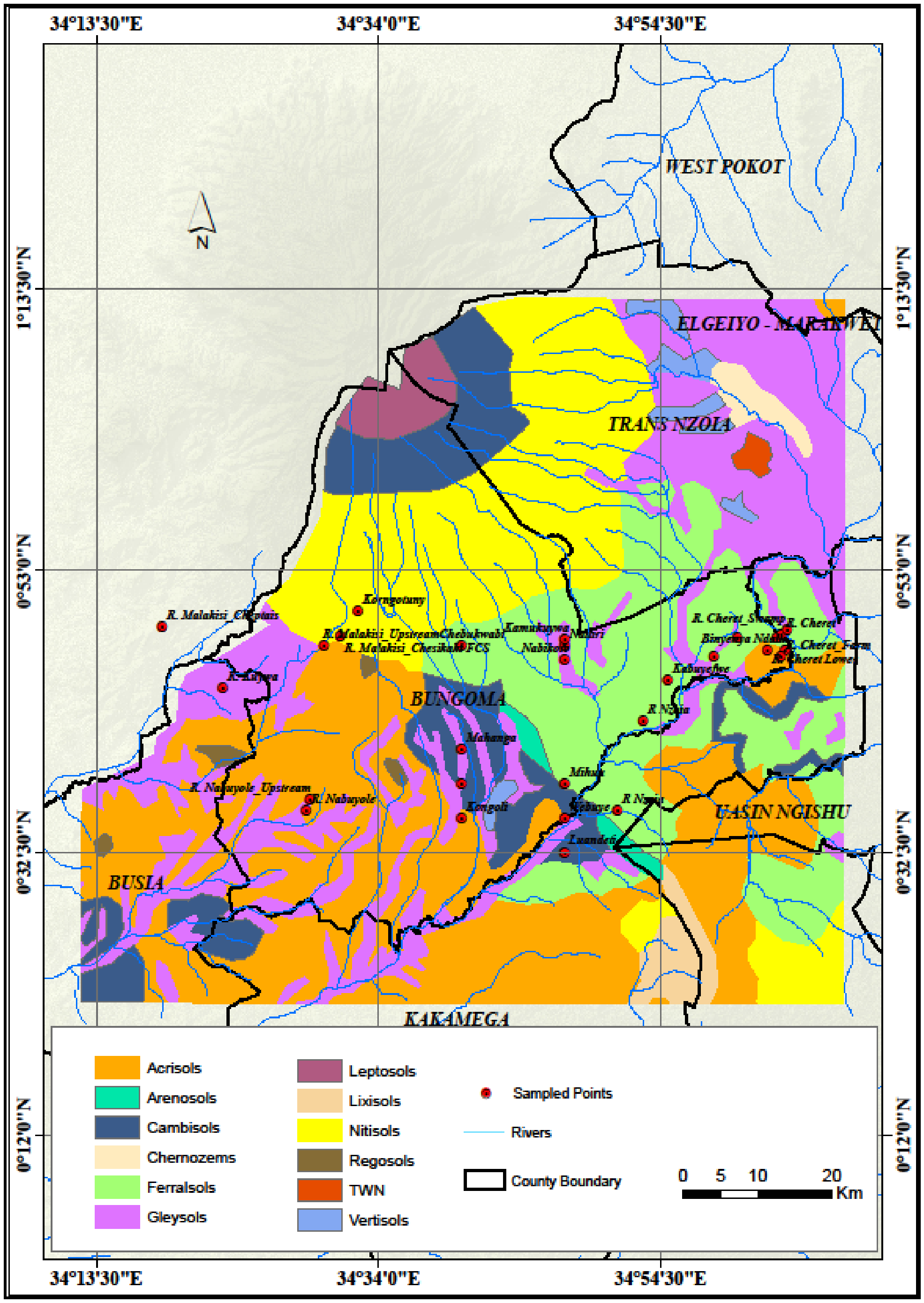


Figure 3. 1: Bungoma County Soil and Fruits Sampling Points

Source: Rose Chiteva

The other study site is Kwale County (Figure 3.2) which is located on the Kenyan south coast, at latitudes 4° 10′ 0″ S and longitudes 39° 27′ 0″ E and altitude of between 382 and 408 m above sea level.

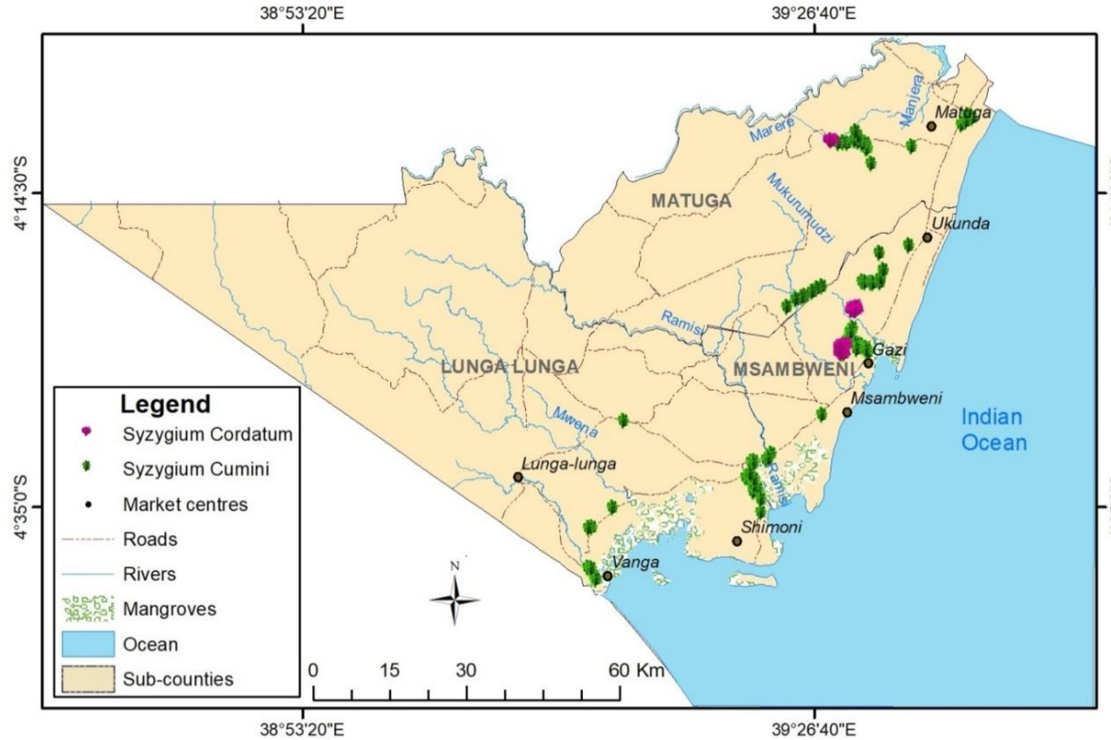


Figure 3. 2: Kwale County Soil and Fruit Sampling Points

Source: Rose Chiteva.

Tanzania is found on its SW and the county has a monsoon climate with January to April being hot and dry and the coolest season being June to August. Long rains are experienced from April to June while short rains come from October to December. In some years, off-season rainfalls do occur especially in January during the El Nino years and in July when the East African low-level jet is active. The total annual rainfall ranges from 400 to 1680 mm. Samples were collected from all four sub-counties in Kwale County: Matuga (Waa, Denyenye, Kombani, Vuga, Mwaluvanga, Vinuni, Vumoni, Mtsangatamu, Golini, Ngombeni), Msambweni (Ramisi, Nikaphu, Wasaa, Vivini, Kikoneni), Kinango (Kilibasi, Vigurungani, Marere) and Lunga (Mwarutswa, Kivuleni, Mkambini).

3.2 Study Design

This study was undertaken during the *Syzygium cuminii* fruiting period: March to May in Kwale and June to August in Bungoma.

3.3 Sampling Techniques

Multistage sampling was used by applying different techniques at different stages; Purposeful sampling was used to select the two counties from literature (Palinkas et al., 2015; Ames et al., 2019) and due to their difference in climatic conditions. The same technique was used to select eight out of the 12 sub-counties from Bungoma and all the four sub-counties of Kwale due to the availability of *S. cuminii* fruit trees. A snowball sampling technique where fruit trees were sampled followed this based on reference by current subjects who recruit future ones. 40 trees per county were marked using Global Positioning System (GPS) for future reference and identification. Information on the availability of these fruits in the two counties was obtained from the literature (Orwa et al., 2009). Stratified/cluster sampling was used to divide the tree canopy into three parts; Eastward. Middle and westward. Purposeful sampling was employed to pick ripe, dark purple (mature) fruits. Finally, systematic random sampling was used to pick the first ripe fruit from the East, skip two and pick the next totalling 10 fruits per strata. This was done for the middle and westward.

3.4 Fruit Sample Collection

The collected fruits were carefully packed in ice cooler boxes that were immediately transferred to the Kenya Forestry Research Institute (KEFRI) laboratory for analysis. Ice was re-filled frequently until arrival at the laboratories. This was to avoid the deterioration of the fruits since they are highly perishable.

3.5 *Syzygium* Fruit Sample Preparation

The ripe fruits were cleaned with water and seeds separated from the pulp. The fresh samples were then used for analysis except for moisture content where the samples were oven-dried.

3.5.1 Ready-to-Drink *Syzygium* Fruit Juice preparation

The ingredients included 50 % fruit pulp, 40 % boiled and cooled water, 10 % sugar, and 0.2 % gum Arabic. Frozen fruits were first thawed to room temperature (25 ^{o}C) before weighing. They were then washed and de-pulped separating the seed from the edible portion. The pulp was blended to ensure maximum juice extraction, mixed with sugar, and pasteurized at 80 ^{o}C for 30 min to destroy microorganisms and inactivate spoilage enzymes. Thus making the juice was made purely organic using gum Arabic was added as a natural preservative the juice was then stored in sterilized bottles.

3.5.2 Quality Determination of *Syzygium* Fruit Juice

Prepared Syzygium fruit juices (Figure 3.3) were taken to the Kenya Bureau of Standards for verification. The following parameters were determined and compared with the KEBS standard for fruit juices and nectars. pH, TSS, Acidity, Ethyl alcohol, Microbial load (Total viable count (TVC), *Escherichia coli*, Yeast, and moulds).

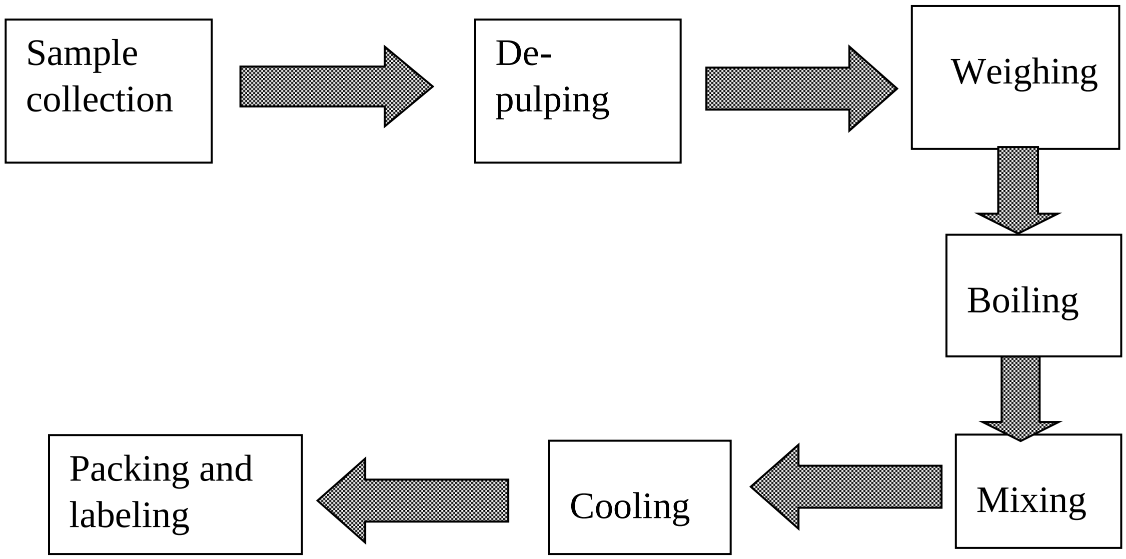


Figure 3. 3: Flow Diagram on the Processing of *Syzygium cuminii* Fruit Juice

3.6 Instrumentation

Laqua pH/ion meter, F-72, DS 411 drying oven, Gallenkamp size 2 muffle furnace, Shimadzu AUX 220 weighing balance, Shimadzu LC20A High-Pressure Liquid Chromatography (HPLC) system equipped with an SPD 20A Ultra Violet detector at 254 nm), Agilent 5110 Inductively Coupled Plasma – Optical Emission Spectrometer (ICP – OES), Digital refractometer model ATAGO PR – 101α, Konica Minolta, CR 410 colorimeter, digital veneer calliper, , YOSHIDA 1013J Bomb, KOKISAN Table top centrifuge H – 3 6 α, Garmin Montana Global positioning system (GPS).

3.7 Quality Properties

Fruit quality parameters include; size (Length, breadth, and weight), skin colour, pH, Titratable acidity, Total Soluble solids (TSS), Vitamin C, ash content, crude fat, crude fibre, crude protein, energy content and mineral content (sodium (Na), magnesium (mg), manganese (Mn), iron (Fe), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu).

3.7.1 Size of Fruits and Moisture Content

Fruits were categorized as large, medium, and small. Whole fruit size (length and width) was determined using digital veneer callipers, whereas weight was determined by Shimadzu AUX 220 model electronic balance to the nearest 2 decimal places, Moisture content was determined by drying fruit samples in an oven as described by Shahnawaz & Sheikh, (2011).

3.7.2 Skin Colour

Fruit skin colour was measured using a colorimeter after calibration against a white background. Skin colour measurement was taken in triplicates along the equatorial axis of each fruit. The colorimeter was standardized during each sample measurement. Three readings of each colour index in the Hunter scale (L^*, a^*, and b^*) were taken according to the method by Al-Said *et al*., (2009).

Where L^* = dark to bright scale, ^+a = red and ^-a = green, ^+b = yellow and ^-b = blue

$$Hue\ angle\ H^o = tan^{-1} b^*/a^* \quad \ldots\ldots\ldots \quad (3.1)$$

Where H^o = difference of determining colour about the grey of the same lightness

$$\%\ Total\ Acidity\ (TA) = M_2 x\ V_{2\,x} E^1\ x\ d.f\ x\ 100/V_s \ldots\ldots\ldots \quad (3.3)$$

$$Intensity\ of\ colour\ C^* = \left(a^{*2} + b^{*2}\right)^{1/2} \ldots\ldots\ldots \quad (3.2)$$

calculated according to Pathare *et al.*, (2013).

3.7.3 pH Measurement

The pH meter was calibrated by dipping it in the buffer at pH 4.0 and pH 7.0. The electrodes were then dipped in the fruit juices for each sample at a time for about 20 to 30 seconds and pH was recorded at room temperature. These readings were taken in triplicates and an average giving a pH value for the sample, following the method by Nirmala and Subba (2011).

3.7.4 Tritable Acidity

10 g of the edible part of the fruit was mixed with 200 ml of de-ionized water and boiled for one hour. On cooling, the mixture was filtered, transferred to a 250 ml volumetric flask, and made up to the mark.

The fruit juice was titrated with NaOH (0.1M) and 1% phenolphthalein indicator then calculated according to Bhattarai and Gautam (2006)

$$\%\ Total\ Acidity\ (TA) = M_2 x\ V_{2\,x} E^1\ x\ d.f\ x\ 100/V_s \ldots\ldots\ldots \quad (3.3)$$

Where; M_2= Molarity of the base, V2= volume of NaOH, E_1= milli-equivalent weight of tartaric acid (0.075), V_s = volume of Syzygium juice, d. f. = dilution factor.

3.7.5 Total Soluble Solids (TSS)

To ensure that the digital refractometer (model ATAGO PR – 101α) is clean and dry, a drop of homogenous fruit pulp was put on its prism and the equipment started. % sugar (^{0}Brix) was determined at 25 ^{0}C (AOAC, 2000b).

3.7.6 Vitamin C (Ascorbic acid)

To avoid oxidation of ascorbic acid to de-hydro ascorbic acid, fruits were immediately thawed after picking. 30 g of the fruit pulp was weighed and mixed with 80 ml of 3 % meta-phosphoric acid for about one minute. The extract was filtered through filter paper and washed by using vacuum pump filtration. The filtrate was quantitatively transferred to a 100 ml volumetric flask and topped up using 3 % metaphosphoric acid according to the method described by Najwa and Azrina, (2017).

Three portions of 30 µl were each put in 1.5 ml vials. The same amount of 5mM tris [2 - carboxyethyl] phosphine Hydrochloride in water was reacted with each aliquot for 20 minutes in darkness. The samples were then centrifuged at 16,000 rpm at four ^{o} C for 5 minutes using KOKUSAN table top centrifuge H – 36 α.

High Pressure Liquid Chromatography based at the Kenya Forestry Research Institute (KEFRI), With 70 % acetonitrile as the mobile phase, the flow rate was set at 1.5 ml/min with a retention time of 3 minutes and a delay of 5 minutes between injections to allow elution of the uric acid peak.

3.7.7 Ash Content

The ash content was determined on a dry weight basis from a 5 g fruit sample placed in a muffle furnace at 550 ^{o}C for 3 hours and then cooled in a desiccator according to method 942-05 (AOAC, 2000a).

3.7.8 Crude Fat

A Soxhlet apparatus was used to determine crude fat. 3 g of fresh fruit pulp was weighed into a clean thimble and the weight of both was noted. The top of the sample was covered using cotton wool and the thimble placed in a soxhlet flask, which was placed in a heating mantle and connected to a reflux condenser. 0.15 L of petroleum ether was added to the thimble and extraction was undertaken for 16 hours at a temperature of between 60 – 80 ^{o}C, which is the boiling range for petroleum ether. The sample was then placed in an oven at 100 ^{o}C, dried for one hour, cooled, and weighed. Determination was done in triplicates and the average was used to calculate crude fat content using Equation 3.4.

$$Crude\ fat\ (\%) = \text{Final weight of thimble and residue} - Weight\ of\ empty\ thimble / Weight\ \text{of fresh fruit pulp}\ x\ 100 \ldots\ldots\ldots\ldots (3.4)$$

Crude fat was extracted following the (AOAC, 2006a) procedure, method number 920-39.

3.7.9 Crude Fibers

The crude fibre was determined according to method No. 978-10 (AOAC, 2005) procedures. 2 g extract from crude fat was placed in a round-bottomed flask and 0.2 L hot 0.1M H_2SO_4 was added.

This unit was attached to a reflux condenser for 40 minutes, extract and filtered using filter paper, washed with hot water, and tested for acidity until litmus paper does not turn pink. The washed extract was mixed with 0.2 L hot 0.3M sodium hydroxide and refluxed for 40 minutes, filtered using filter paper, washed with distilled water, and finally with 20 ml ethanol. The sample was then placed in an oven at 105 ^oC until a constant weight was obtained. The resulting sample was ashed in a muffle furnace at 470 ^{o}C for three hours. The loss in weight was recorded as the amount of crude fibre in the fruits following the procedure (Ranganna, 2001).

3.7.10 Crude Protein (CP)

The crude protein of the *Syzygium* fruits was quantified using the Kjeldahl method (AOAC, 2006b) where fruits were digested by a concentrated sulphuric acid mixture of potassium sulphate, Iron sulphate, and copper sulphate in the ratio of 10: 1: 2. The mixture was diluted to 250 ml. This was reacted with 40% sodium hydroxide and the liberated ammonia was collected in 4 % Boric acid using methyl red indicator. $(NH_4)BO_3$. CP was calculated by multiplying the obtained N with a factor of 6.25.

3.7.11 Energy Content

One gram of fruit sample was wrapped in an ash-less paper, fastened with a wire, placed in a stainless steel sample holder, which also contained a platinum wire dipping in the sample, and held together by two electrodes. Excess oxygen was pumped into the vessel containing the cap to a pressure of 25 atmospheres. The tightly closed container was immersed in an insulated water bath fitted with a stirrer and thermometer noting the initial temperature of the water. Incineration was done by completing the circuit allowing electricity to go through the platinum wire thus combusting the sample. Stirring of the water was continued and the final temperature after combustion was noted. This procedure using a Bomb calorimeter at the Kenya Forestry Research Institute (KEFRI) followed what was described by Núñez-Regueira *et al.,* (2001).

Calculation of energy content/calorific value of *Syzygium cuminii* fruits was done as shown in Equation 3.5.

Let X (g) = weight of fruit sample

M (g) = weight of water in the calorimeter

ω (g) = Water equivalent

T_1 and T_2 (^{O}C) = Initial and final water temperatures in the calorimeter respectively

L (Cal/g) = High calorific value of fruits

Heat dissipated on combustion of fruits = XL

Absorbed heat during the combustion process = (M + **ω) (**$T_2 - T_1$)

Since the heat dissipated by the fruits is equal to what is absorbed by the water, equation 3.5 shows the combination.

$$XL = (M + \omega)\,(T_2 - T_1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.5)$$

$$\textit{High Calorific Value, } L\ \left(Cal/g\right) = (M + \omega)\,(T_2 - T_1)/X \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.6)$$

HCV is corrected due to errors introduced by fused wire that burns increasing heat (CF), and cooling time for the water (CT), the cotton thread used in fire is made of cellulose whose CV is 4140 Cal/g (CV). Due to high temperatures and pressure during the ignition, Nitrogen, and Sulphur present in the fruits react forming sulphuric and nitric acids, (CA).

Benzoic acid = 6335 Cal/g

The corrected equation is shown in Equation 3.7.

$$L\ (Cal/g) = (M + \omega)(T_2 - T_1 + CT) - (CF - CV - CA)/X\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.7)$$

The Carbohydrates in the fruits was obtained by subtracting the Proteins, ash, crude fat, and fibre and recorded as a percentage (Serrem *et al.*, 2011).

3.7.12 Mineral Content

Fruit samples were prepared by first de-pulping and juicing using a blender. Analysis was done for heavy metals namely; Cadmium, Manganese, Chromium, Zinc, and Copper. Other minerals are; Sodium, Iron, and Magnesium. 0.8 ml of Syzygium fruit juice was mixed with an equal amount of nitric acid (ANALAR) in separate vials and the mixture was allowed to pre-react for 30 minutes in a fume chamber. 0.6 ml 30 % H_20_2 was then added and samples were placed in closed Teflon receptacles for digestion using a microwave for 35 minutes at a temperature of 180 ^oC and maintained at the same temperature for 20 minutes. Samples were cooled and further diluted tenfold. 1 ml of each sample was spiked by an internal standard to give 0.5 mg/l yttrium, and 1 ml of yttrium was then diluted to 10 ml by 0.075 % nitric acid. Blank samples were made using nitric acid to 500 µl and diluted as in the multi-elemental standards. Analysis was done using an Agilent 5110 Inductively Coupled Plasma – Optical Emission Spectrometer (ICP – OES), at the Kenya Bureau of Standards (KEBS), as described by Karahan *et al.*, (2020).

3.8 Climate Data for Bungoma and Kwale Counties

Four climate variables (temperature, rainfall, relative humidity, and % sunshine) were documented by the Food and Agriculture Organization of the United Nations AQUASTAT Climate information tool was used in this study.

3.8.1 Soil Analysis

3.8.1.1 Soil Sampling

The soil samples from Kwale and Bungoma were obtained randomly around 40 identified Syzygium trees per county, using a soil auger. Zero – 20 cm depth of soil was obtained in a vertical direction. Removing roots, leaves, and stones from each sample. Triplicate soil samples of 200 g from each sample plot were dug and put on aluminium foil mixed to form a composite sample from which 500 g was taken to the Kenya Forestry Research Institute (KEFRI) laboratory for analysis.

3.8.1.2 Soil Sample Preparation

The samples were air-dried and sieved using a 2 mm sieve. Triplicates 5 g samples from each sample plot were placed in crucibles and oven dried at 105 ^{o}C for 3 hours, allowing them to cool before final weighing.

3.8.1.3 Determination of Soil pH

20 g of soil was mixed with 40 ml of de ionized water by stirring in a beaker and left to stand for 20 minutes. The pH of the soil was determined following the procedure by Sahlemedhin and Taye (2000).

3.8.1.4 Determination of Soil Porosity

100 ml of water was poured into a cup and a line was drawn. The water was dumped out. The cup was first filled with soil samples up to the meniscus. Using a graduated cylinder, slowly and carefully pour water into the cup until the water reaches the top of your sample. The volume of water remaining in the graduated cylinder was recorded. The remaining volume was subtracted from the total volume; this is the amount of water added to the sample (pore space). Porosity was determined following the method by Carter and Gregorich (2007).

$$Porosity\ (\%\ pore\ space) = P.s\ /\ V_t x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots..(3.8)$$

Where, p.s is pore space and V_t is the total volume

3.8.1.5 Determination of Bulk and Particle Density

Bulk density (D_b) was determined using the core method; a cylindrical core sampler. A smooth ‘‘undisturbed’’ vertical or horizontal surface at the sampling depth was prepared and a core sampler was used to extract soil without rocking the container (Walter *et al.*, 2016). The soil was dried at 105 $^{\circ}$C for 3 hours and weighed. Bulk density was calculated as shown in Equation 3.9

$$D_b = M_s / V_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Where *b* is the bulk density in mg/m^{3,} M_s is the oven-dried mass and V_s is the volume of the dried soil in m^3 according to the method by Han (2016).

Particle density is calculated using Equation 3.10

$$Particle\ density = Bulk\ density\ x\ 100/1 - Porosity \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.10)$$

3.8.1.6 Digestion and Mineral Characterization of Soil

5110 Inductively Coupled Plasma – Optical Emission Spectrometer (ICP – OES) whose instrument conditions are shown in Table 3.1 as used for analysis. Deionized water was prepared using a pure water treatment system and digestion was done in a closed vessel microwave digester (Mars 6, CEM, US). The rotor was 40 positions and the heating apparatus (BHW-09C, Shanghai Botong Chemical Technology Co. LTD, China) was used to remove the remaining acid.

Table 3. 1: Instrument Operating Conditions

Parameter	Setting
Read time (s)	20
Replicates	3
Sample uptake delay (s)	1
Stabilization time (s)	20
Pump speed (rpm)	12
Rinse time (s)	1*
Fast pump (80 rpm)	No
Background correction	Off-peak
RF power (kW)	1.5
Nebulizer flow (L/min)	0.70
Plasma gas flow rate (L/min)	12.0
Aux flow (L/min)	1.0
Viewing height (mm)	15.0
Gas	Argon

***Samples were auto - diluted**

Standard Preparation

A multi-elemental stock solution was used to prepare standards, which were then diluted by the Aqua regia mixture made of HNO_3 and HCl in the ratio 2:1. The stock solution was auto- diluted to 50, 20, 10, 5, 2, and 1, and an internal standard, yttrium added to the aqua regia automatically.
Standards were prepared based on the expected concentration of analytes; Cu and Zn (0 to 1.5), Mn (0 – 10), Ti (0 – 15), Fe, Na and Mg (0 – 300) mg/L

Interference was corrected using the Fast Automated Curve-fitting Technique (FACT) which concurrently corrects interferences of spectral correction of composite soils (U.S. EPA, 2007).

Soil Digestion

0.20 g soil samples were weighed to the nearest 0.001 and put in Teflon vessels. 9.0 ± 01 ml $HN0_3$ and 3.0 ± 0.01ml HCl (Aqua regia) were added and digested using the microwave program shown in Table 3.2. This process ensures the stabilization of some elements like Fe and aluminium and a breakdown of complex medium thus increasing precision.

Table 3. 2: Microwave Digestion Program

Step	Temp (^{o} C)	Pressure limit (bar)	Ramp time (min)	Hold time (min)	Power limit (%)
1	150	35	5	5	80
2	195	35	2	20	100
3	50	35	1	15	0

After cooling to room temperature, the digestion solution in the Teflon vessel was evaporated to about 1 ml in a heating apparatus at 195 °C. 100 ml solutions were made from the stock and de-ionized water. Blanks were made of all reagents except the soil sample.

3.9. Statistical Analysis

A multivariate model that uses multiple regression analysis was used with the general Equation 3.11 showing that dependent variables are influenced by several factors

$$Y = f\left(X_1,\ X2 \ldots X_j\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.11)$$

Where Y is the dependent variables

X = the independent variables

The multi-linear regression function was estimated using obtained data represented by Equation 3.12;

$$y = \mathrm{B}_0 + \mathrm{B}_1 x_1 + B_2 x_2 + \mathrm{B}_3 x_3 + \mathrm{B}_n x_n + SE \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12)$$

Where;

y = dependent variable/predicted variable being predicted from the many independent variables/predictor variables

β_0 = y-intercept where the regression line/model crosses the Y axis

n = linear slope for variable

x_n = n representing independent variable

β_n = coefficients of the independent variables

SE = Standard/regression error of the model

Testing the regression function was done by calculating the coefficient of determination R^2 (Equation 3.13) and F – statistic.

F – Statistic was obtained using Analysis of Variance (ANOVA). This is a calculation of the regression ratio to the residuals.

$$F^2 = R^2 / 1 - R^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

This was obtained from the explained variance and the entire variance indicating how well the regression line fits with the measured data.

The model was tested to ensure that there was no heteroscedacity, i.e. residuals have the same variance, auto-corrected, and do not have multi-collinearity (independent variables appearing as linear functions of another independent variable). The latter can be tested using;

$$\textit{Tolerance value } T_j = 1 - R^2{}_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

$$\textit{Variance inflation factor } VIF_j = 1/1 - R^2{}_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1: Physicochemical Composition of *Syzygium cuminii* fruits from Bungoma and Kwale Counties.

Appendix 1 and 2 shows quality parameters (Physical and chemical) composition of *Syzygium cuminii* fruits from Bungoma and Kwale Counties. The physicochemical analysis of *Syzygium cuminii* fruits was done on a dry weight basis as moisture affects the amounts of the constituents (Ali *et al.*, 2011).

4.1.1 Fruit Size

The average length and breadth for *Syzygium* fruits in this study from Bungoma county were; 25.13 ± 1.84 and 15.53 ± 0.95 mm. The heaviest fruits were found oriented toward the eastern side of the tree canopy; these were samples 6, 8, and 21 with weights of 5.95, 5.91, and 5.61g respectively. They were followed by those in the middle part of the tree canopy; samples 37 and 39 weighed 5.42 and 5.38 g respectively. The East and middle part of a tree canopy receive radiation more hours of the day compared to the westward side, thus enabling the fruits to manufacture and store more matter. It is for the same reason that the same middle fruit samples are longer (29.18±0.75 mm) and broader (17.65±0.95 mm) than the rest.

Fruits from Kwale County weighed between 2.83± 1.11 and 8.07±1.72 g with only 38 % of the sampled fruits weighing above the average of 4.64±0.69 g. There were very significant differences in the fruit lengths that ranged from 19.44±1.24 to 33.5±0.01mm. There was also a significant difference in the breadth of the various fruit samples with 12.17±0.16 mm recorded as the lowest and 21.02±0.03 mm as the highest. Consumers' choice of large fruit creates a big variability in price between larger and smaller fruit sizes (Shahnawaz *et al.,* 2014). The separate fruits are based on known standards of quality without destroying chemical analysis (Arshad *et al.*, 2014). The consumers that know the significance of the properties, select and separate the products into categories.

In comparison to the literature, weights of 8.99±1.189 g in Syzygium. *Jambolanum* from Brazil by Sabino *et al.,* (2018), length of 19 to 39 mm in *Syzygium cuminii* from India by Gajera *et al.,* (2018), and mean breadth of 10.38 ±0.94 mm in *Syzygium cuminii* from Sri Lanka by Prasajith *et al.,* (2019) were documented. A study carried out by Stiletto and Trestini (2021) found that consumers associated size with the maturity and quality of the fruits. The size of the fruit has been used to influence price variability (Boca, 2021).

4.1.2 pH and Titratable Acidity of Fruits

pH values of between 3.41 and 3.73 were obtained from Bungoma fruit samples in this study. . Improved and indigenous Jamun fruits from Pakistan recorded pH values of 3.87±0.01 and 3.77±0.01 respectively as reported by Shahnawaz and Sheikh (2011). pH is used to measure the ability of microbes to thrive in certain foodstuffs whereas titratable acidity determines how the flavour of foods is affected by the dominant organic acids which dissociate partially affecting food properties (Tyl and Sadler, 2017). This study reported 1.09 as the highest titratable acidity and 0.51 as the lowest value. Higher titratable acidity values of 1.26 ± 0.03 and 1.58 ± 0.02 were reported by Shahnawaz and Sheikh (2011) for improved and indigenous *Syzygium* fruits respectively.

Fruits from Kwale gave an average fruit juice pH of 3.16 ± 0.01 and indication of the acidic nature of the fruits. *Syzygium cuminii* fruits from Pakistan recorded similar results of; 3.10±.01 reported by Sartaj et al., (2013) in apricots from Pakistan. Similarly, 3.77 ad 3.87±0.0 was reported by Akhila and Umadevi (2018; Ghosh et al., 2017) in *Syzigium cuminii* fruits from India. Titratable acidity varied from 0.58 to 1.06 %. 1.26 % and 5.66 ± 0.04 % were reported by Akhila and Umadevi (2018; Sartaj *et al.,* 2015) in *S. cuminii* fruits from India and Pakistan respectively. A ratio of TSS with %TA indicates the maturity of fruits. The higher the ratio the more mature and vice versa (Tharanathan *et al.,* 2006). When fruits ripen, acids reduce due to degradation, sugars increase, and the ratio between the two increases. However, when fruits are over-ripe, this causes a lack of flavour due to loss of starch and sugar.

4.1.3 Moisture Content

Moisture content (Appendix 1) for the fruits from Bungoma County was between 82.02±0.28 and 88.88±0.09 % with 81% as the lowest value. The average percentage moisture content in fruits from Kwale was 85.36 ± 0.35, with no significant difference in the means at p = 0.05. This was comparable to 86.26 ± 1.45% by Sartaj *et al.,* (2015) and 16.34 ± 0.49 by Raza *et al.,* (2015) in *S. cuminii* fruits. The higher the Moisture content, the more perishable a fruit and the shorter the shelf life (Han *et al.,* 2020). Lower values of; 32±0.203, 80.14±0.087, and 79.21 ±2.21 were reported by Shahnawaz and Sheikh, (2011; Abeytilakarathna *et al.,* 2013) for improved and indigenous Jamun respectively.

4.1.4 Colour

Fruits with red-coloured tips had high Total Soluble Solids (TSS) and green ones had low TSS in fruits from Bungoma county. According to Abeytilakarathna *et al.,* (2013), red-coloured fruits have a balanced acid content and sugars and normally have good flavour and quality. Change in colour from green to red tips is a sign of maturity

(Vianna-Silva *et al.,* 2008; Agoreyo, 2010). Colour is considered to be one of the important external factors in determining fruit quality, as the appearance of the fruit greatly influences consumers (Tehrani *et al.*, 2011).

Kwale fruit samples showed colour L* (Lightness) mean values range from 24.86 to 42.74, a* from 36.94 green colors to 99.79 red colors, and average values for b were between 0 (yellow) to -43.63 (blue). Data analysis showed very little significant difference for the means of the three variables L*, a*, and b* due to the large errors emanating from the estimation of three readings taken from different parts of the fruits, however, fruits with high L values also showed low colour intensity.

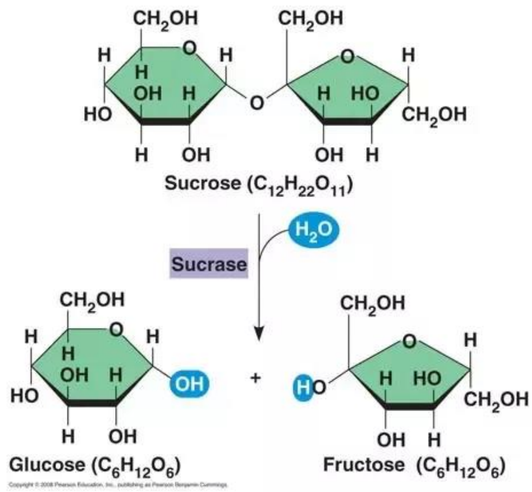
There was no significant difference in colour between the sites at $P = 0.05$. However, over 50 % of the analysed fruits were dark purple towards red (a*) an indication that they were all mature. However, Kwale fruits had a higher colour intensity (87.4 ± 0.02) and low mean L value (32.84 ± 0.09), i.e. low colour intensity, thus the fruits were dark purple and more mature than those picked from Bungoma 82.22 ±0.01 and 33.63 ± 0.01 respectively. Hu *et al.,* (2010) reported a positive correlation between L*, a*, and chlorophyll.

4.1.5 Ash Content

The ash content of fruits from Bungoma County ranged between 0.19 and 2.74 % dry weight. This agrees with 1.03 ±0.08 % reported by Ghosh *et al.*, (2017) in the *Syzygium cuminii* fruits from India. 1.22 ± 0.01 to 3.58 ± 0.01% was reported from Kwale County in this study. Ash content is the inorganic part of the fruits, which comprise the mineral elements. The appreciable levels show *Syzygium* fruit as a potential food supplement for humans and animals.

4.1.6 Total Soluble Solids (TSS)

An average of 12.85 ^{o}bit TSS content was obtained in this study, compared to 13.60, and 9.11±0.45 reported by Agrawal *et al.,* (2017 and Sartaj *et al.,* (2013) respectively. In this study, both TSS and acidity from the two counties were very close. The acidity of fruits decreases while the TSS increases as the fruits mature and start reducing in overripe fruits. The increase in TSS is a result of sucrose changing to invert sugars as shown in the Equation 4.1



…………………………. (4.1)

Syzigium cuminii genotypes with high TSS gave lower acidity values. Higher values of 13.75±0.501 and 15.82±0.50 ^{o} Brix were reported by Shahnawaz & Sheikh, (2011) for improved and indigenous varieties of the fruits respectively. 7.7 ^{o}Brix content was found to be the highest in red strawberries and a lower 5.3 ^{o}Brix in half-colored (Abeytilakarathna *et al.*, 2013). The sugar content of fruits from Kwale County was between 11.2 and 23.43 ^{o}Brix. and 15 ^{o}Brix was reported by Akhila and Umadevi (2018; Benherlal and Arumughan 2007) in *Syzygium cuminii* fruits from India. The high sugar content is an indication that fruits are a good source of energy essential in human diets.

According to (Guedes *et al.*, 2013), TSS, acidity, and L* value correlate positively with Mg. In this study, the highest TSS value of 20.9 was recorded from sample 6, which also had the highest Mg value of 1641.4 mg/kg from Bungoma fruits. The sample with the highest Mg value of 846.26mg/kg from Kwale also recorded the highest L* value of 42.39 and TSS of 22.43, however, the same samples had the lowest % TA in both counties.

Figure 4.1 summarises the analysis of physicochemical properties from the two counties;

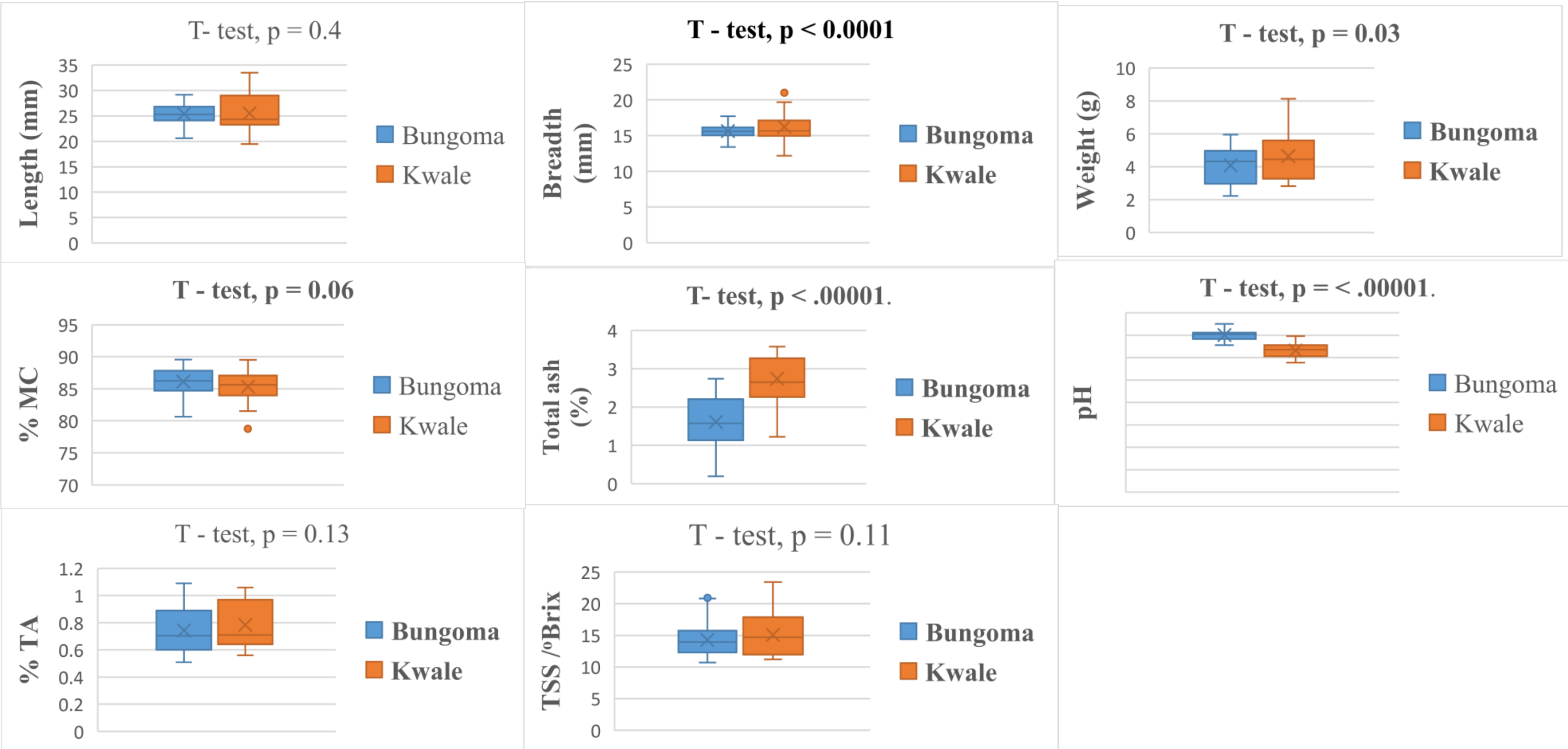


Figure 4.1: Box plots for the Physicho chemical Parameters of *S. cumini* Fruits

4.2 Nutritional Composition of *Syzygium cuminii* Fruits from Bungoma and Kwale Counties.

Appendix 3 and 4 shows the nutritional composition of the fruits from Bungoma and Kwale Counties;

4.2.1 Carbohydrates

The average carbohydrate content in the *Syzygium cuminii* fruits from Bungoma county was 19.46 ± 4.56 g/100g. Mapunda and Mligo (2019) reported 16.33 ± 0.35 mg/100g from *Syzygium guineense* in the Miombo woodlands in Tanzania. Ghosh *et al.,* (2017) reported higher values of 97.59 ± 0.09 % in *Syzygium cuminii* fruits from India. Appendix 5 shows the nutritional composition of fruits from Kwale County. This study reported average values of 20.1 ± 1.82 mg/100 g carbohydrates in the fruits from Kwale County. Kshirsagar et al., (2019) reported 31.62 mg/100 g in *S. cuminii* fruits from India, and 16.33 ± 0.35 mg/100 g from *S. guineense* were documented by Mapunda and Mligo (2019) in pomegranate from South Africa. These fruits can provide more energy than cultivated fruits; apples, avocados, guava, mangoes, oranges, and pineapples (12, 5.9, 15.7, 15, 10.6, 12), (Sánchez-Moreno *et al.*, 2006). The carbohydrate content is equivalent to that of bananas. Carbohydrate content in the fruits was linked to an increase in Total Soluble Solids. 13.5mg/100 g was reported by Ying *et al.*, (2019) who noted that middle *Syzygium samaragense* fruits from south China, have less Carbohydrates due to shading.

4.2.2 Crude proteins (CP)

This study reported a low mean value of 1.38 ± 0.12 mg/100g from Bungoma fruit samples, and 0.41 – 3.34 mg/100 g in the fruits from Kwale County. This compared well with 1.97±0.59 % in *S. cuminii* fruits and seeds from Pakistan (Raza *et al.*, 2015). Muthai *et al.*, (2017) reported 2.20 ± 0.22 mg/100 g of CP from Kenyan baobab. 76.2 ± 1.0 mg/100 g of crude proteins were recorded by Osman (2004) in Baobab from Saudi Arabia and 0.65±0.03 mg/100 reported by Ghosh e*t al.*, (2017) in *Syzygium cuminii* from India. Gajera *et al.*, (2018) reported 0.13 to 0.70 % protein content in *Syzygium cuminii* fruits from India, noting the similarity between protein content and fruit size. The recommended Daily intake for proteins on average is 0.8g/kg body weight (Campbell *et al.*, 2001).

USDA, (2004) documented 0.3, 1.5, 1.2, 1.1, 0.6, 0.1, 1.0, 1.2 mg/100 g from cultivated fruits; apples, avocados, bananas, guava, mango, melon, orange, pineapples respectively. Kshirsagar et al. (2019) on the other hand reported a protein content value of 3.84 mg/100g in *Syzygium cuminii* fruit seeds from India.

4.2.3 Crude Fiber

Crude fibre content from Bungoma fruits was 0.96 ± 007 mg/kg and 0.99 ± 0.09 mg/100g documented from the Kwale fruits. Kshirsagar *et al.*, (2019; Ghosh *et al.*, 2017) reported values of 7.01 and 0.53±0.06 mg/kg in *S. cuminii* fruits from India respectively. 8.83 ± 2.56 mg/kg was reported by Muthai *et al.*, (2017) from baobab fruit pulp in Kenya and 31.34 ± 0.53 was reported for *S. guineense* fruits from South Africa by Mapunda and Mligo (2019). There was a strong relationship between the size of fruits and crude fiber. Gajera *et al.,* (2018) reported 1.3 to 1.93 % in *Syzygium cuminii* fruits from India, sighting that smaller fruits had higher crude fiber.

4.2.4 Crude Fat

A mean value of 0.46 ± 0.14 mg/kg was reported in this study from Bungoma samples and 0.49 ± 0.24 mg/kg from Kwale samples. These values increased with an increase in energy, whose averages were 332.1 ± 0.0 and 334.24 ± 3.67 Kcal/mol respectively. *Syzygium cuminii* in this study reported more energy than apples, mangoes, plums, oranges, and pears (USDA, 2004). 0.18±0.02 mg/kg was reported by Ghosh *et al.,* (2017) in Syzygium *cuminii* fruits from India. Other *Syzygium* varieties like *Syzygium caryophyllatum* and *Syzygium zeylanicum* from India recorded 0.95 ± 0.020 and 2.89 ± 0.024 respectively (Shilpa *et al.*, 2015). The lower fat values indicate that *Syzygium cuminii* fruits are poor energy sources.

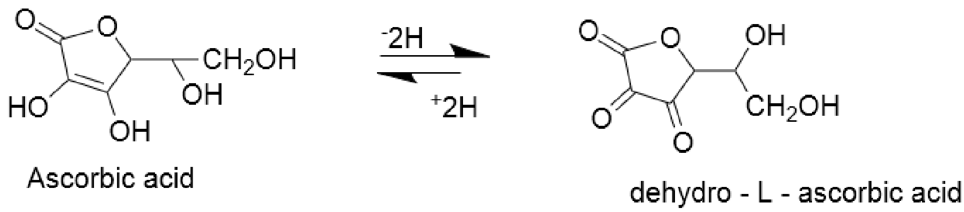
4.2.5 Vitamin C

Very high values of between 7.99 and 802.09 mg of vitamin C for every 100g fruit sample were reported from Bungoma fruits in this study, an indication that the fruits have high antioxidant potential. Agrawal *et al.,* (2017; Sartaj *et al.,* 2013; Ayyanar and Subash–Babu 2012), reported vitamin C content of 30.7, and 57 to 180 mg/kg in *Syzygium cuminii* fruits from India, and yzygium*yzygium cuminii* from India respectively. Gajera *et al.*, (2018) reported that TSS increases with fruit size in *Syzygium cuminii* fruits from India.

0.49 g/100 g was reported from the Kwale samples in this study, a value that is higher than what is documented for most exotic fruits except raspberries (0.6 mg/100 g). Kshirsagar *et al.*, (2019) reported 1.02 mg/100 g in *Syzygium cuminii* fruit seeds from India. Very high values of Vitamin C were reported in this study, between 76.24 and 965.24 mg/100 g. This is more than four times higher than the documented rich source of raspberry and guava (200 and 183.5 mg/100 g), (USDA, 2004). A very low value of 0.21 mg/100 g was reported by Kshirsagar *et al.*, (2019) from *Syzygium cuminii* fruits from India.

246.81±0.1 and 353.61±1.22 mg/100 g were obtained from Bungoma and Kwale fruit samples. This corresponds to acidity levels of 0.74±0.01 and 0.78±0.02 as low acidity means low vitamin

C content. Akhila and Umadevi (2018) reported values of 19.4 mg/100g in *Syzygium cuminii* from India and 30.46±2.18 by Sartaj *et al.,* (2015) in *Syzygium cuminii* from Pakistan. The high discrepancies are a result of the labile nature of Vitamin C that changes as seen in the Equation 4.2.



(4.2)

4.2.6 Energy Content

This study reported a mean energy value of 332.1± 0.0 Kcal/mol in fruits from Bungoma, which was higher than what was reported for other wild fruits in Ethiopia namely; *Balanites aegeyptica, Cordia africana, and Ziziphus spania-chrsti* (266.52 ±4.93, 277.97 ± 10.88 and 325.16 ± 5.21 Kcal/100 g). 384.02 ± 0.15 and 355.67 ± 0.53 Kcal/100 g for Syzygium *caryophyllatum* and *Syzygium zeylanicum* were documented by Shilpa e*t al.,* (2015). Average energy values of 334.24 ± 3.67 Kcal/mol were reported from Bungoma fruits in this study. Previous studies documented 327, 307, and 275 Kcal/mol from *Adansonia digitata* by Abdel-Rahm *et al.,* (2011) in fruits and vegetables from Sudan, *Balanites aegyptiaca* by Parkouda *et al.,* (2007) in fruits from Burkina Faso, and *Tamarindus indica* by Soloviev *et al.,* (2004) respectively.

Mineral composition of *Syzygium cuminii* fruits from Bungoma and Kwale Counties are shown in appendices 4 and 5. There was a significant difference in the minerals between the two counties.

4.2.7 Sodium (Na)

This study reported a range of 28.73 to 222.49 mg/kg Na in fruits from Bungoma, lower than 262 mg/kg reported by Jaiswal *et al.,* (2005) in *Syzygium cuminii* fruits from India. Ghosh *et al.,* (2017) reported 117.3±1.7 mg/kg, which is within the reported range in this study. According to Lugwisha *et al.,* (2016), Recommended Dietary Allowance (RDA) for Na is 500 mg/day. Na content in the fruits from Kwale County varied widely among the samples; 10.47 to 146.8 mg/kg. Over 75 % of the analyzed fruits had less than 20 mg/kg. These were very low values compared to 321.0± 0.5 mg/100 g reported by Bhat *et al.,* (2010) in nutraceuticals from Malaysia. Variations in the Na content of fruits may be caused by the type of soil or environmental conditions (Ahmed *et al.,* 2020). Na levels reduce during fruit maturity (Appiah *et al.,* 2011). This study showed that sample 6 with the lowest Na value of 28.73mg/kg recorded the highest maturity index of 40.98.

4.2.7 Magnesium (Mg)

The magnesium content from Bungoma fruits in this study was 175.76 to 1641.4 mg/kg. 10.05±2.00 and 350 mg/kg of the edible portion was reported by Sartaj *et al.,* (2013; Jaiswal *et al.,* 2005; Ayyanar and Subash – Babu 2012) in apricots from Pakistan and *S. cuminii* fruits from India. RDA for Mg is 2000 mg/day. The positive correlation of 0.84 between the Mg and L values of colour is because the former is used in chlorophyll formation (Guedes *et al.,* 2013). Mg content was between 155.92 and 1641.4 mg/kg in fruits from Kwale. 627.2±1 mg/kg reported by Bhat *et al.,* (2010) in nutraceuticals from Malaysia, was within the range of this study.

At pH 4.5 to 6, Mg tends to be tied up in the soil hence the lower values compare to 779.12 ± 7.45 reported by Seraglio *et al.,* (2018) in Myrtaceae fruits from Brazil. Reported values are higher than those reported by Nisha and Radhamany (2020) for four pineapple varieties from Kerala, India which ranged between 586 to 813.3 mg/kg and 159.5mg/kg reported for blackberry cultivars from Brazil by Guedes *et al.,* (2013). Mg levels increase with an increase in maturity (Appiah *et al.,* 2011). 1641.4 mg/kg of Mg was reported in this study as the highest by sample 6 with the highest maturity index of 40.98.

4.2.8 Manganese (Mn)

10.05 to 179.15mg/kg of Mn in the fruits was reported in fruits from Bungoma. This is higher than 2±0.07 mg/kg documented by Ghosh *et al.,* (2017) in *Syzygium cuminii* from India and; 13.3 mg/kg by Shahnawaz *et al.,* (2014) in *Syzygium cuminii* fruits from Pakistan. Manganese deficiency leads to a decrease in colour (Papadakis *et al.,* 2005). 7.29 to 76.19 mg/kg were recorded as the Mn content for the fruits from Kwale County, whereas 9.6± 0.1 mg/kg was reported by Bhat *et al.,* (2010) in nutraceuticals from Malaysia. Presence of high Mn content in fruits may also be a result of agricultural practices (Pohl, 2007).

4.2.9 Iron (Fe)

A range of 8.62 to 151.81mg/kg of Fe was reported from Bungoma fruits, whereas 12 to 16.2 mg/kg was reported by Ayyanar and Subash – Babu (2012) and in *Syzygium cuminii* from India. was reported from Indian fruits by Jaiswal *et al.,* (2005). There was a positive correlation of 0.86 between Fe and TSS, Titratable acidity. Enzymes with a Fe component activate carbohydrates. Low Fe values of 5.19 to 196.87 mg/kg were reported from Kwale County samples with one sample giving an outlier of 1053.33mg/kg. The outlier is probably a result of fertilizers and pesticides (Pohl, 2007). 685 ± 1.6 mg/kg was reported by Bhat *et al.,* (2010) in nutraceuticals from Malaysia. Fe forms part of the haemoglobin and myoglobin (Hemalatha *et al.,* 2007). RDI for Fe is 15 mg (Millikan, 2012), hence only 5 % of the analysed fruit samples did not meet this requirement.

4.2.10 Copper (Cu)

4.41 to 33. 4 mg/kg of Cu was reported in this study in the fruits from Bungoma, 2.3 and 18 ± 4.1 mg/kg reported by Ghosh *et al.,* (2017) from *Syzygium cuminii* and India respectively. Low Cu values of 0.7 – 3.2 and 2.3 mg/kg were reported by Jaiswal *et al.*, 2005) in *Syzygium cuminii* from North Bangladesh,. Cu correlates with TSS since, during respiration, organic acids are in some way made from Cu thus determining the flavour of fruits (Guedes *et al*., 2013). Cu values ranged between 2.49 and 26.18 mg/kg in the fruits from Kwale, comparable to 11.3± 1.0 mg/kg reported by Bhat *et al.,* (2010) in nutraceuticals from Malaysia. The higher value may have resulted from fertilizers and pesticides (Pohl, 2007) since most Syzygium trees either grow on the farm or river banks.

4.2.11 Zinc (Zn)

0.38 – 18.85 mg/kg of Zn was reported in the fruits from Bungoma in this study, whereas 2.8±0.3; 21.1 mg/kg were reported in Bangladesh and Pakistan by Jaiswal *et al.,* (2005; Sartaj *et al.,* 2013) respectively from *Syzygium Cuminii* fruits. Zn correlated negatively with pH and TSS this is because Zn aids in the degrading of sugars. A low value of 0.11 to a high of 13.2 mg/kg of Zn was reported in fruits from Kwale in this study in line with 4.3±.0.2 reported by Bhat *et al.,* (2010). This trace element is useful for the immunity of the human body. The great variability in Zn is an s a result of genetic variation of the *Syzigium* fruits (Tryphone *et al.* 2010). The highest Zn content in fruits from Bungoma was obtained from the same fruits that had the highest pH (3.75), consequently, in Kwale; 13.2 mg/kg of Zn was obtained in the same fruits that had the highest pH of 3.47. In general, there was a significant difference in Na, Mg, Mn, Cu, and Zn between the two counties at $p < 0.05$. Fruit samples with the highest Mn, Cu, Fe, Zn, and L* values also had high TSS and acidity. Bungoma fruit sample 6 recorded the highest Mn, Cu, and L* values as 179.15; 33.34, 151.81, 18.85 mg/kg, and 33.14. The same relationship was seen between the same parameters in Kwale county fruit samples.

4.2.12 Potassium (K)

This study in fruits from Kwale shows that *Syzygium cuminii* is an excellent source of K (1362.14 ± 25.86 mg/100g). Bungoma samples had 1340.1 ± 58.94, this was 8 times higher than 172.4±17.23 mg/100 g reported by Ghosh *et al.,* (2017) in Syzygium *cuminii* fruits from India, and 1240 ± 30 mg/100g reported by Osman (2004) in baobab fruits from Saudi Arabia. K is an electrolyte that helps body fluids to function properly. 9.91± 0.39 mg/100 g of Ca was reported from this study, whereas 295 ± 1 mg was documented by Osman (2004) for baobab from Saudi Arabia. This value is higher than what was reported by USDA (2004) for apples and bananas (6 & 5 mg/100g respectively). Andrés-Bello *et al.,* (2013) reported that weight and TSS in fruits increased with an increase in K. A balance between K and organic acids is determined by tissue pH since the element exists together with the acids.

4.2.13 Calcium (Ca)

This study reported a Calcium content of 15.51 ± 4.31 mg/100g from the Bungoma and 9.91 ± 0.39 mg/100g from Kwale fruits. Calcium is mainly associated with pectic acids *(Al – Kindy et al.*, 2001), 44.42 ± 0.39 mg/100 g in *Syzygium guineense* was reported by Mapunda and Mligo (2019) in edible indigenous fruits from Tanzania, 8.3 – 15 mg/100 g was reported by Ayyanar and Subash – Babu (2012) in *Syzygium cuminii* from India.

4.2.14 Phosphorus

22.29-± 1.02 mg/100 g phosphorus was reported in fruits from Kwale and 21.22 ± 1.08 mg/100g in fruits from Bungoma. This value is higher than what is documented by Sánchez-Moreno et al., (2006) for cultivated fruits; Apples, oranges, and pawpaw sans pineapples (11,14,5,8 mg/100g). 112.01 ± 5.52 mg/100 g was reported in *Syzygium guineense* from South Africa by Mapunda, and Mligo (2019) and RDA for adults over nineteen years is 700 mg (Sánchez-Moreno *et al.*, 2006).

4.2.15 Chromium and Cadmium

The Inductively Coupled Optical Emission Spectrometer did not detect these metals, since they were below detectable limit of the equipment. The lowest detectable limit for the ICP OES is in parts per billion. Table 4.1 gives a summary of the quality parameters of *Syzygium cuminii* from the two counties

Table 4. 1: Summarised Physicochemical and Nutritional content of *Syzygium cuminii* Fruits from Bungoma and Kwale Counties

	County			**ρ -value**	**Significance ($\rho < .05$)**
Parameter	**Bungoma**	**Kwale**	**T value**		
Fruit weight (g)	4.09 ± 0.8	4.56 ± 0.69	-1.61	.05	*
Fruit length (mm)	23.38 ± 6.5	25.52 ± 1.27	-0.22	.41	Ns
Fruit breadth (mm)	15.62 ± 1.04	16.24 ± 0.67	-1.70	.04	*
Colour					
L*	33.63 ± 0.01	32.84 ±0.09	0.90	.18	ns
a*	78.88 ± 0.04	79.43 ±0.06	-0.16	.44	ns
b*	-31.51 ± 0.37	-30.9 ±1.44	-0.19	.42	ns
C*	82.22 ± 0.01	87.4 ±0.02	-0.67	.25	ns

Moisture content (%)	86.12 ± 1.78	85.36 ± 0.35	1.52	.06	n’s
Ash content (%)	1.61 ± 0.02	2.74 ± 0.01	-7.47	< 0.0001	*
pH at 25 ºC	3.5 ± 0.0	3.16 ± 0.01	11.27	< 0.0001	*
TSS (ºBrix at 25 ºC)	14.27 ± 0.1	15.05 ± 0.18	-1.07	.14	n.s
Titratable acidity (%)	0.74 ± 0.01	0.78 ±0 .02	-1.14	.13	n.s
Vitamin C (mg/100g)	246.81 ± 0.1	353.61 ± 1.22	-1.57	-.06	n.s
Crude fat (mg/100g)	0.46 ± 0.14	0.49 ± 0.24	- 0.54	.29	n.s
Crude fiber (mg/100g)	0.96 ± 007	0.99 ± 0.09	- 0.19	.43	n.s
CHO (mg/100g)	19.46 ± 4.56	20.1 ± 1.82	- 0.47	.32	n.s
Energy (Kcal/mol)	332.1 ± 0.0	334.24 ± 3.67	- 0.24	.40	n.s
Protein (mg/100g)	1.38 ± 0.12	1.53 ± 0.14	-0.94	.17	n.s
Na (mg/kg)	112.56 ± 0.07	348.63 ± 0.05	7.76	<0.0001	*
Mg (mg/kg)	574.08 ± 0.14	393.13 ± 0.19	2.71	0.004	*
Mn (mg/kg)	55.57 ± 0.13	19.27 ± 0.17	5.29	<0.0001	*
Fe (mg/kg)	58.58 ± 0.06	26.33 ± 1.1	- 0.76	0.22	n.s
Cu (mg/kg)	17.72 ± 0.08	7.76 ± 0.03	7.05	<0.0001	*
Zn (mg/kg)	6.95 ± 0.28	4.3 ± 0.37	2.79	0.003	*
Ca (mg/kg)	15.51 ± 4.31	9.91 ± 0.39	-0.39	0.35	n.s
K (mg/kg)	1340.1 ± 58.94	1362.14 ± 25.86	-0.44	0.33	n.s

P (mg/kg)	21.22 ± 1.08	22.29 ± 1.02	-0.51	0.30	n.s

N = 40, results expressed as mean ± Standard error

n.s = no significant difference at $p < 0.05$, * = significant difference

L* = 0: (black), L* = 100 (colorless): a* > 0 (red), a*< 0 (green): b* > 0 (yellow), b* < 0 (blue), C* = Intensity.

4.3 Physico Chemical Properties of Soils from Bungoma and Kwale Counties.

Properties of soils from the two counties are shown in Appendices 7 and 8

4.3.1. Soil pH

Soil pH from Bungoma ranged between 4.53 and 6.87 (moderately acidic to near neutral) according to soil grading by Kanyanjua *et al.,* (2002). As pH increased towards neutral, concentrations of trace metals reduced; Mn (190.77 to 10.06), Cu (1.88 to 0), and Zn from 20.7 to 1.08 mg/kg. Confirmed that when soil pH increases with depth, this is an indication that either bases that can be exchanged have moved downwards or upwards, this causes fewer hydrogen ions to be liberated because of the reduced carbon downwards along the soil profile.
The average pH of soil samples at a depth of zero - 20 cm from Kwale, was 5.26 ± 0.01. This is an indication that Syzygium fruits thrive well in moderately acidic to neutral according to soil grading Kanyanjua *et al.,* (2002). The most favourable pH for plants is between 6 and 6.8, Cd however is more soluble in acidic solutions (Liu *et al.*, 2021).

4.3.2 Porosity

50 – 77 % porosity was reported from the soils from Bungoma, this is the ratio of empty spaces and the total volume of material, and they are used in the exchange of air and water with the environment. Porosity varies from one soil to another giving soil with varied carbon content, consistency, and makeup (Matko, 2003). Anthropogenic activities affect porosity (Gysi *et al.*, 2000; Cameira *et al.,* 2003; Osunbitan et al., 2005). Activities that affect soil makeup, increase soil porosity (Shaver *et al.,* 2003). The particle density of the soils from Kwale ranged between 2.26 and 2.69 g/cm^3. Variation may be a result of which part of the slope sampling was done or the type of minerals present in the soil (Ball *et al.*, 2000).

The average porosity in soils from Kwale was 60 %. Soil porosity includes its texture/matrix and structure and influences soil moisture (Kebeney *et al.,* 2015). Increased porosity is an indication of more sand and carbon content and less loam and clay. Lower porosity is an indication of more clay in the soil sample (Barbera *et al.,* 2013). The average soil particle density was 2.72 ± 0.07 g/cm^3. A common range is between 2.55 and 2.7g cm^3 (Blake, 2008).

4.3.3 Bulk Density

This study reported bulk density of between 0.53 and 1.06 g/cm^3 in soils from Bungoma. Karuma *et al.*, (2014 and Muya *et al.*, (2011) reported 1.27 g/cm^3 and 1.05 to 1.10 g/cm^3 respectively in soils from Kenya. Bulk density is reported by Muya *et al.*, (2011) to increase with depth. According to Hazelton and Murphy, (2007), a bulk density that is less than 1 is very low; 1 to 1.3 is considered low, from 1.3 to 1.6 g/cm^3 is reasonable; 1.6 to 1.9 is high and bulk density of values higher than 1.9 g/cm^3 is rated very high. Therefore, this study reported soils that have very low bulk densities.

The average bulk density of soils from Kwale was 1.24 g/cm^3, whereas the standard range is between 1.1 and 1.5 g/cm3 in soil obtained from the surface and these values increase with depth and in sandy soils. The values tend to be lower in soils with high carbon content (Bolinder *et al.*, 2010; Cardoso *et al.,* 2013; Kimble *et al.,* 2001), In soils from Northern Sweden, and Brazil respectively. Bulk density affects many aspects of the soil among them an environmental quality that affects aeration (Kimble *et al.,* 2000).

4.3.4 Sodium

Sodium content in the Bungoma soil samples ranged between 0.01 and 54.2 mg/kg. Maingi *et al.*, (2020) reported 8.61 ± 0.51 mg/kg of Sodium in the soil from Molo Kenya, even though it is not necessary for plants; it is utilized in trace amounts for the formation of chlorophyll. Na content was 0.09 to 15.4 mg/kg., and Flues *et al.*, (2004) reported 0.25 – 0.41mg/kg from soil collected at a depth of 0 – 20 cm on the highways in Brazil. Soils with a lot of sodium (Sodic) cause an increase in soil pH and affect the soil structure. Na content from Kwale samples was 0.09 to 15.4 mg/kg., and Flues *et al.,* (2004) reported 0.25 – 0.41mg/kg from soil collected at a depth of 0 – 20 cm on the highways in Brazil. Soils with a lot of sodium (Sodic) cause an increase in soil pH and affect the soil structure.

4.3.5 Magnesium

Soil Mg values in the Bungoma samples ranged between 10.5 to 578 mg/kg with one sample appearing as an outlier with a value of 1075 mg/kg. This soil may have been developed from a magnesium parent rock (Maingi *et al.,* 2020). Soil magnesium affects fruit size, hence from this study; the lowest Mg level (10.5 mg/kg) corresponds to the smallest fruit (2.22 g) according to Zhang *et al.,* (2020). Magnesium is a constituent atom in chlorophyll thus useful in photosynthesis (Hermans *et al.,* 2010). Mg content in Kwale samples ranged from 2.02 to 301.68 mg/kg. 124.8 mg. kg was reported by Khadka *et al.*, (2017) from the same depth in Japan. Soil magnesium decreases with an increase in soil pH (Liu *et al.,* 2021).

4.3.6 Manganese (Mn)

The Mn content in the soils from Bungoma and Kwale varied from 10.06 to 190.77 and 1.57 to 93.82 mg/kg respectively. Maingi *et al.,* (2020; Khadka *et al.*, 2017, and Wang *et al.*, 2003) reported Mn content of 15.26 ± 1.12 2.14 mg/kg in soils from Kenya, Japan and China respectively. Mn facilitates the production of enzymes needed in the growing of plants and forming of chlorophyll. Manganese content in soil decreases with an increase in soil pH (Ali et al., 2011), in this study, the latter decreased from 7.65 to 3.8 mg/kg.

4.3.7 Copper (Cu)

This study reported Cu content between 0 and 1.88 mg/kg, while Maingi *et al.*, (2020; and Wang *et al.*,2003) reported average values of 0.59 ± 0.12 and 1.20 mg/kg in soils from Kenya and China respectively. Cu is distributed according to climate and geographical factors. Human activity may also increase Cu content in the soil (Ballabio *et al.,* 2018). Very low values of 0 to 2.78 mg/kg Cu were obtained in soils from Kwale, 0.42 and 15.1±6.6 mg/kg were reported by Khadka *et al.*, (2017; and Flues *et al.,* 2004) for the same depth of 0 – 20 cm in Japan and Brazil respectively. The machine detection level for Cu is 0.02 µg/L.

4.3.8 Zinc (Zn)

Soil Zn content of 1.08 to 20.7 mg/kg was obtained from Bungoma soils, Wang et al., (2003) and Maingi *et al.,* (2020) reported 1.6 and 12.96 ± 2.04 mg/Kg from soils in China and Kenya respectively. High levels of Zn may result from increased carbon content. The element is useful in plant development and the lack of it causes the inability to withstand stress (Kawachi *et al.*, 2009; Lee *et al.,* 2010). 0 to 5.78 mg/kg Zn content was reported from Kwale soils. 0.5 and 22.4±4.3 was reported by Khadka *et al.,* (2017; and Flues et al. 2004) respectively. The Inductively Coupled Plasma membrane Optical Emission Spectrometer (ICP – OES) detection level for Zn is 0.01 µg/L

4.3.9 Titanium (Ti)

Titanium values in soils from Bungoma County, ranged between 0.05 to 92.85mg/kg whereas reported worldwide values range between 0.02 to 2.4 % (Kabata-Pendias and Mukherjee, 2007). These high values could be attributed to foliar sprays, and weathering of rocks (Wojcik and Wojcik, 2001)., According to Lyu *et al.,* (2017), Fe and Ti have synergistic and antagonistic relationships, and the presence of Ti in the soil also causes an elevation of vitamin C and total sugar in the fruits (Kleiber & Markiewicz, 2013). 0 to 369.23 mg/kg Ti was reported in soils from Kwale. Ti is a common element in the soil and ranges up to 2% in volcanic soils in form of silicates ($TiSi0_4$) and $Ti0_2$. High Ti levels provoke a counteraction of its lethal levels, especially in plant roots (Wojcik & Wojcik, 2001). Hruby *et al.,* (2002) reported that Ti is responsible for the increase in the formation of chloroplasts, and certain roles related to the nucleus and nucleoli.

Table 4.2 shows correlation analysis of the soil properties.

Table 4. 2: Analysis of the Properties of Soils from Bungoma and Kwale Counties

Properties	**County**		**R - Score**	**P - value**
	Bungoma	**Kwale**		
Altitude (m)	1612	162	-0.17	.28
PH	5.66 ± 0.02	5.27 ± 0.01	0.48	.001
Porosity (%)	61.5 ± 2	60.08 ± 1	-0.19	.24
Bulk density (g/cm^3)	0.78 ± 0.0	1.17 ± 0.13	-0.23	.16
Particle density (g/cm^3)	2.47 ±0.06	2.73 ± 0.05	0.04	.8
Na (mg/kg)	10.83±0.13	4.16 ±0.15	0.46	.01
Mg (mg/kg)	144.05±0.41	68.98±0.17	0.25	.12
Mn (mg/kg)	88.03±0.27	32.81±0.21	-0.48	.01
Cu (mg/kg)	0.92±0.15	0.6±0.1	0.01	.96
Zn (mg/kg)	8.27±0.12	1.43±0.09	0.43	< .01
Ti (mg/kg)	12.44±0.13	57.53±0.2	0.05	.76

Soil pH (Table 4.2) and Na, Mn and Zn were significantly different (P = .05) between the two counties.

4.4 Effect of Soil Physicochemical Properties of on Quality of Fruits from Bungoma and Kwale Counties.

Soil pH, Na, Mn, and Zn were significantly different between the two counties a correlation matrix of the different fruit and soil parameters is shown in Figure 4.3. There was a strong positive correlation between Na with Zn (0.91) and Mn (0.85). Mg was positively correlated with pH (0.79) and Ti (0.94). Mn highly influenced soil porosity (0.96) and Zn (0.95), whereas soil porosity was highly influenced by Zn (0.93).

From this study, soil porosity highly influenced the soil pH (0.79). Fruit weight highly influenced the percentage ash content (0.96 and 0.96) respectively. pH correlated positively with percentage ash (0.94). Fruit maturity was highly influenced by protein and carbohydrate content (0.97: 0.98). Carbohydrates had a very strong correlation with protein (0.99). There was a weak positive correlation between TSS: TA (fruit maturity) and soil Mg (0.14). This was also reported by Shiri *et al.,* (2016) who stated that the TSS of kiwi fruits correlated with both magnesium and manganese in the soil, and Liu et al., (2021) reported that Zinc and copper were the main factors that contributed to the Total soluble solids in pepper.

Figure 4.2 compares soil with quality parameters within the two counties in a correlation matrix

	Na	Mg	Mn	Cu	Zn	Ti	Soil pH	Bulk density	Particle density	Soil porosity	Fruit weight(g)	Breadth	pH	% Ash	TSS:TA	CHO	Protein
Ti	1.00																
Mg	-0.43	1.00															
Mn	**0.85**	-0.58	1.00														
Cu	0.10	-0.32	0.36	1.00													
Zn	**0.91**	-0.55	**0.95**	0.27	1.00												
Ti	-0.40	**0.94**	-0.56	-0.34	-0.53	1.00											
Soil pH	0.72	-0.56	0.81	0.30	0.79	-0.53	1.00										
Bulk density	-0.82	0.78	-0.92	-0.35	-0.90	0.77	-0.78	1.00									
Particle density	-0.68	0.71	-0.79	-0.21	-0.71	0.72	-0.67	**0.85**	1.00								
Soil porosity	0.86	-0.69	**0.96**	0.34	**0.93**	-0.67	**0.79**	-0.97	-0.86	1.00							
Fruit weight(g)	-0.72	0.68	-0.85	-0.26	-0.76	0.67	-0.67	**0.87**	**0.80**	-0.88	1.00						
Breadth	0.22	0.33	0.11	-0.10	0.16	0.34	0.07	0.06	0.14	0.02	0.04	1.00					
pH	-0.74	**0.79**	-0.82	-0.21	-0.78	0.78	-0.69	**0.90**	**0.81**	-0.88	**0.96**	0.09	1.00				
% Ash	-0.72	0.67	-0.77	-0.11	-0.72	0.68	-0.65	**0.84**	**0.79**	-0.84	**0.94**	0.09	**0.94**	1.00			
TSS:TA	-0.29	0.14	-0.30	-0.44	-0.33	0.10	-0.41	0.27	0.05	-0.24	0.18	-0.34	0.18	0.14	1.00		
CHO	-0.28	0.10	-0.29	-0.42	-0.31	0.05	-0.43	0.24	0.03	-0.22	0.14	-0.29	0.14	0.11	**0.98**	1.00	
Protein	-0.30	0.11	-0.29	-0.46	-0.31	0.07	-0.39	0.25	0.06	-0.23	0.14	-0.25	0.14	0.11	**0.97**	**0.99**	1.00

Figure 4. 1: Correlation Matrix for the Physicochemical and Nutritional Content of *Syzygium cuminii* fruits with Soil Parameters.

Bulk density corresponded to high ash content, fruit pH, and fruit weight , this is in agreement with Aruani *et al*. (2011) who reported that soil features positively or negatively influenced fruit appearances in Argentina. Particle density on the other hand positively correlated with Ash content, fruit pH, and fruit weight (0.79: 0.81:0.8). Fruit weight highly contributed to ash content (0.99).

The mean bulk density (BD) for soils from Bungoma and Kwale counties was 0.78±0.01 and 1.17±0.01respectively. BD affects Vitamin C content and TSS as shown in sample 6 with the highest BD of 1.06 g/cm^3 corresponding to the highest TSS value of 20.9 and 2.69 particle density in Bungoma. Sample 15 from Kwale recorded the highest BD of 1.58g/cm^3 which corresponded to a high TSS value of 22.43. Liu *et al.,* (2021) related soil bulk density to the quality of tomato fruits in China.

There was a negative correlation between soil Mn and fruit pH in the Bungoma sample 6 that recorded the lowest Mn content of 10.06 ±0.02 mg/kg corresponding to the highest fruit pH of 3.75. This is also seen in colour (L*, a*, b*). This was the general trend between the counties. As the fruit matures, manganese is released during chlorophyll degradation increasing anthocyanin (responsible for the fruit's purple colour). This is supported by Guedes *et al.*, (2013) in the report on blackberries from Brazil.

The highest soil pH of 6.87 in sample 31 corresponded to the lowest Fe content of 8.62 mg/kg in fruits from Bungoma, and pH 7.73 yielded a Fe content of 8.1 mg/kg in sample 33 from Kwale County. This is because, at higher pH, Fe is readily oxidized to insoluble ferric oxides, at lower soil pH; the oxide is made available to the plants (Morrissey and Guerinot, 2009). The Ferrasol type of soils that are rich in Fe found where the fruits were sampled also contributes this.

Low Zn in soil causes high Fe content in fruits. This is shown in sample 6 from Bungoma, 1.08 and 151.81mg/kg respectively. Similarly, 0.11mg/kg of Zn in soils from Kwale, sample 14 caused a high Fe uptake of 196.87 mg/kg. This was also observed in the samples that had Zn contents below detectable levels. Soil composition determines mineral composition in fruits (Nour *et al.*, 2011).High Iron content may cause leaf chlorosis or yellowing and very little root growth (Rout and Sahoo, 2015)

4.5 Effect of Environmental Factors on the Quality of *Syzygium cuminii* Fruits from Kwale and Bungoma Counties.

Mean temperatures, rainfall, relative humidity, and percentage sunshine for Bungoma and Kwale Counties were obtained from the FAO AQUASTAT tool as shown in Figures 4.3 and 4.4.

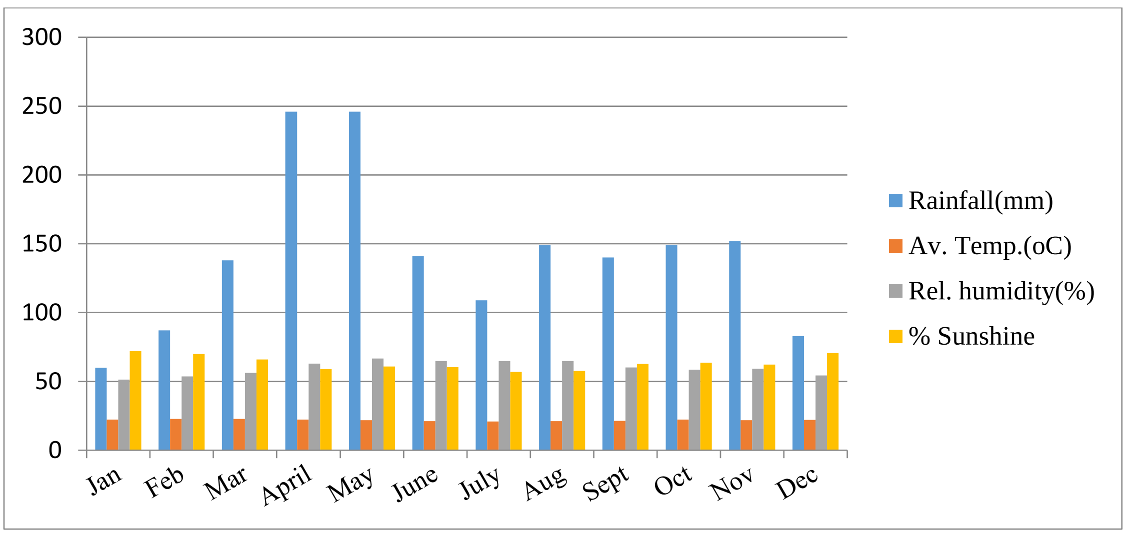


Figure 4. 2: Environmental Parameters for Bungoma County (2018 – 2021)

Source: (FAO 2021).

Average temperature, humidity and percentage sunshine for Bungoma County within the study period were 21.89 ^{o}C, 59.82 and 63.47 % respectively. The temperatures have increased and the humidity has reduced compared to the values recorded by Merkel for the period between 1992 and 2012; an indication of Climate change (IPCC, 2021). Average annual rainfall during the study period was 1700 mm; this was within the range of 400 – 1800mm per annum given by Ralph *et al*. (2005) in Kenya.

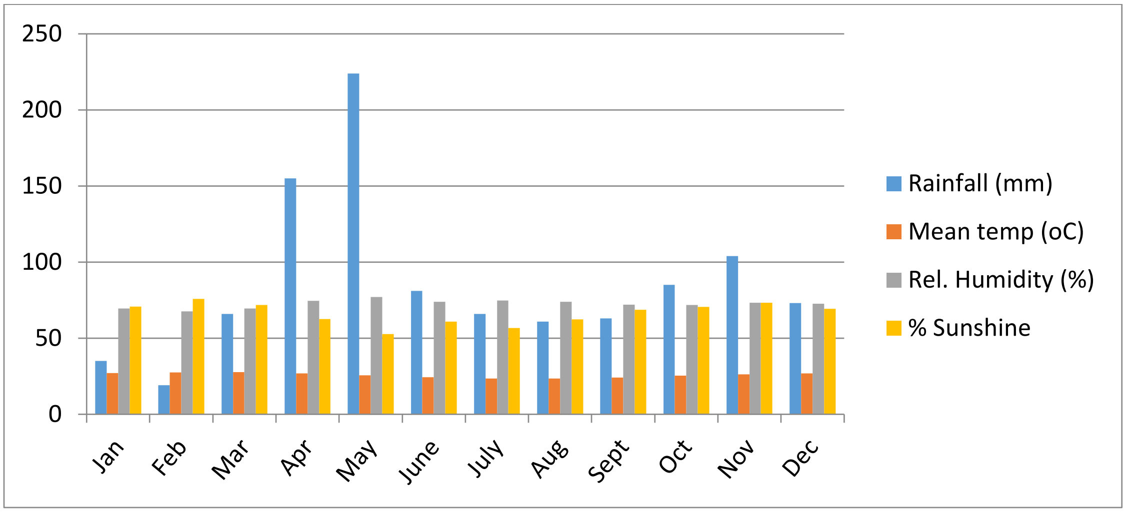


Figure 4. 3: Environmental parameters Kwale County, 2018 – 2021.

Source: **(**FAO, 2021**)**

4.5.1 Rainfall

The average total annual rainfall for the period of study was 1032 mm; this was within the reported range of 400 to 1680mm in the Kwale County Integrated Development plan 2018 – 2022. Recorded average temperatures were 25.72 ^{o} C much higher than 23.5 ^{o} C reported between 2009 and 2018 by FAO (2021). Relative humidity was 72.57 % lower than 74.2 % and radiation/sunshine was 66.29 % *Vis avis* 67.4 % for the period reported in the same study. Rainfall causes fruits to take up more water thus causing variations in fruit quality. There was low TSS and high acidity during the months with high rainfall, with over 51 % of the analysed fruits from Bungoma registering below the average Total Soluble solids of 14.27 and 15.05 reported from Kwale fruits

4.5.2 Sunshine, Temperature, and Canopy Position

The same samples from both counties had higher L* (lightness) values for their fruit skin colour according to orientation. The same was noted for a* values, all in the eastward orientation which had a* values over 90. This means the fruits were wholly red towards purple colour a sign of maturity. Fruit samples with colour intensity C* over 90 oriented from the eastward side in both counties.

High temperature has been reported to affect the accumulation of minerals with exposure to sunlight causing an increase in calcium, magnesium and potassium (100 %, 51 %, and 60 % increase in potassium content). This was also related to the movement of water (Mditshwa *et al.*, 2013; Moretti *et al.*, 2010)

Ali *et al.,* (2011; Siriwoharn et *al.,* 2004) reported that the tastes of fruits are affected by variations in % sunshine and temperatures. According to Arshad *et al.,* (2014), fruits picked from the middle/inside of the tree canopy experience less sunshine and lower temperatures, this, in turn, affects the TSS, Vitamin C, and colour (Arshad *et al.,* 2014). Fouche´ *et al.,* (2010) in their study on apples noted that fruits in the inner, middle, and outer parts of the canopy received; 2, 10, and 54 % sunshine respectively. The outer fruits were also exposed to a temperature of 5 ^{o}C more than the rest of the fruits.

4.3.3 Relative Humidity

Low relative humidity of 59.82 % in the Bungoma fruits contributed to increased water loss and consequently contributed to low fruit quality as reported by Ahmad *et al.,* (2006), in bananas from Pakistan. Kwale recorded higher humidity of 72.57 % translating to higher fruit quality.

4.5.4 Altitude

Syzygium cuminii fruits were collected between 1275 to 1788 m above sea level in Bungoma. TSS varied from 11.1 to 20.9, while in Kwale, high TSS values of 13.85 – 22.43 were reported from higher altitudes of over 400 m above sea level. Fruits obtained from low altitudes had better quality than those from higher altitudes (Timilsina and Tripathi, 2019). Higher altitudes and variations in temperatures affect fruit color (Guedes *et al.,* 2013). Low percentage TA values of between 0.51 – 0.55 were reported with increasing altitudes of 1587 to 1729 m above sea level.

4.6 Multilinear Regression Modelling of *Syzygium cuminii* Fruit Quality with Selected Environmental Parameters

Predicted variables include; were Fruit breadth, Fruit Weight, Ascorbic acid level, Crude fibre content, Protein content and Zinc content. Predictor variables/environmental variables showing high inter correlations were excluded from the analysis to avoid overfitting the models developed (Table 4.4).

Analysis of the data resulted in the development of 12 models (MD1 to MD12). Data from Bungoma was used to develop six models (MD1-MD6), while the other six models (MD7-MD12) were built from the Kwale data (Appendix 2). There were two models for each predicted variable each developed from data from either study area.

Table 4. 3: Modelling of *Syzygium cuminii* Fruit Quality with Selected Environmental Parameters

	Predicted Variables/Dependent variables											
	Bungoma						**Kwale**					
Predictor variables/ independent variable	Fruit breadth (**MD1**)	Fruit weight (**MD2)**	Ascorbic Acid (**MD3**)	Crude Fibre (**MD4**)	Protein (**MD5**)	Zinc (**MD6**)	Fruit breadth (**MD7**)	Fruit weight (**MD8**)	Ascorbic Acid (**MD9**)	Crude Fibre (**MD10**)	Protein (**MD11**)	Zinc (**MD12**)
Intercept	19.2753	-39.18	-0.0012	1.3781	1.0345	161.949	98.1674	117.795	4696.136	2.135139	-11.665	1.51076
PH	-3.2977	-20.55	200.30	-0.315	-0.106	3.6757	-5.9903	-1.7201	-80.4275	1.238526	-3.7909	-0.3068
Sodium	-0.1163	0.4199	-9.676	0.0117	-0.097	-0.0678	-	-	-	-	-	-
Magnesium	-0.0072	-0.019	0.0718	-	0.0005	0.0071	0.1802	0.2441	6.2496	0.016342	-0.0506	-
Zinc	-3.9985	-4.527	73.370	-0.513	-0.074	-2.3414	-10.456	-14.694	-466.536	0.56959	-2.0029	0.42603
Titanium	-0.0756	-0.029	6.4770	-	-	-0.0301	-0.2877	-0.1757	-3.8712	0.01448	0.05877	0.01595
Copper	17.583	30.838	-	1.342	-	-	101.20	74.362	2674.52	-6.06024	-.95733	1.95487
Manganese	-	-	-	-	-	-	1.4451	0.4246	39.4124	-0.15295	-.28416	0.11316
Relative humidity	0.1167	0.8157	8.5270	-	-	-0.9672	-0.8543	-1.0803	-55.0479	-0.06563	0.4893	-.02009
Sunshine	-0.0579	-0.050	0.5618	0.0081	0.0041	-0.3548	0.3394	-0.1002	5.0374	-.03899	0.04816	0.01789
Altitude	1.2420	5.773	-	-	0.0820	-3.9525	-3.8592	-2.4441	-80.5594	0.21453	0.32893	- 0.09049
Rainfall	-0.0242	-0.063	-0.5500	-.0005	-.0006	0.0409	0.0810	0.0583	-2.1007	-0.00339	- 0.01545	0.00300
F- value	0.101	7.828	18.820	3.426	11.00	64.5	7.667	3.446	777.6	4.218	1.977	137.1
P – value	0.9896	0.2718	**0.0173**	0.0989	**0.0176**	**0.0154**	0.2745	0.3981	**0.0279**	0.3632	0.5067	**0.0073**
Adjusted R^2	-4.471	0.8613	**0.9283**	0.5696	**0.8664**	**0.9811**	0.8584	0.6898	**0.9986**	0.7452	0.4705	**0.9911**

From the analysis models: MD3, MD5, MD6, MD9 and MD12 whose p values are < .05 are reliable models, which can be used to predict the dependent variables. By substituting, the estimates of coefficients and y- intercept (Iman et al., 2011) of the five models, the equations can be expressed as follows;

MD3

***Ascorbic Acid** = -0.0012 + 200.30 (pH) - 9.676 (Na) +0.0718(Mg) + 73.37 (Zn) + 6.477 (Ti) + 8.527 (Relative Humidity) + 0.5618 (Sunshine) -0.55 (Rainfall).*

F value=18.82, p value=0.0173, Adjusted R^2=0.9283

For one unit change in Ascorbic acid level, there is 200.30 change in PH level, -9.676 change in Na level, 0.0718 change in Mg level, 73.37 change in Zn level, 6.477 change in Ti level, 8.527 change in relative humidity, 0.5618 change in sunshine and -0.55 in rainfall.

Independent variables with negative coefficients (negative regression) means that they are inversely related to the dependent variable, such that as their values increases, the dependent variable value decreases. Conversely Independent variables with positive coefficients (positive regression) means that they are directly related to the dependent variable implying that when their values of such independent variable increases, the value of the dependent variable also increases.

In this study, fruits oriented towards the East were exposed to sunshine for longer periods, and higher temperatures during the fruiting season and hence developed higher TSS, Vitamin C content, and intense color. These are samples 6 (20.9), 8(20.8), 21(19.8), and 28(17.6) all from Bungoma County. Samples 15(22.43) were sampled from the westward side, 28 (20.12), and 34 (19.6) both from the Eastward orientation had the highest TSS in the Kwale fruits. Vitamin C content also varied in fruit samples from Kwale; Middle e.g. samples 5 and 36 (255.16; 226.69 mg/100 respectively), Westward; 14, 15 (902.21 and 965.24 mg/100 g respectively) and eastward e.g. 3 & 22 (940.42 and 895.61 mg/100 g respectively). Bungoma fruits; Samples 6, 8, and 21 from eastwards contained 759.47, 802.09, and 760.82 mg/100g of vitamin C, Westward e.g. samples 15 and 28(529.94 and 759.42 mg/100g), Middle; 5 and 18(76.36 and 76.64 mg/100g) respectively. This was also reported by Dey *et al.,* (2016) on Pumelo fruits in India.

Lee and Kader (2000; Dumas *et al.,* 2003) also noted that low % sunshine caused fruits to have low levels of Vitamin C in; horticultural crops from the U.S. and tomatoes from Spain respectively.

MD5

Protein*=1.0345 - 0.106 (pH) - 0.097 (Na) + 0.0005 (Mg) -0.074 (Zn) + 0.0041 (Sunshine) + 0.0820 (Average Temperature) - 0.0006 (Rainfall)*

F value=11, p value=0.0176, Adjusted R^2=0.8664

There was positive regression between protein and; Mg, sunshine and average temperature. Hindrance in the formation of proteins in fruits is as a result of deficient chlorophyll or Magnesium in the leaves (Bo and Ying, 2018). High levels of sun rays caused a decrease in malate and aspartate type of proteins in grapes from Israel (Reshef *et al.,* 2017). Rainfall causes a decrease in protein content in fruits (Hribar and Vidrih, 2015).

MD6

Zinc*=161.949 + 3.6757 (PH) - 0.0678 (Na) + 0.0071(Mg) - 2.3414 (Zn) - 0.0301(Ti)- 0.9672 (Relative humidity) - 0.3548 (Sunshine) - 3.9525 (Average Temperature) + 0.0409 (Rainfall)*

F value=64.5, p value=0.0154, Adjusted R^2=0.9811

There was positive regression between Zinc and pH, Mg and rainfall. This agrees with the report by Velmurugan and Swarnam (2017) on the positive relationship between pH of soils and zinc in rice from India. There is a weak correlation between soil pH and zinc in fruits (Niwayama & Higuchi, 2019).

MD9

Ascorbic acid *= 4696.136 - 80.427 (pH) + 6.249 (Mg) - 466.53 (Zn)-3.871(Ti) +2674.52 (Cu) + 39.41(Mn) - 55.047 (Relative humidity) - 5.037 (Sunshine) - 80.55 (Average Temperature) + 2.10 (Rainfall)*

F value=777.6, p value=0.0279, Adjusted R^2=0.9986

There was positive regression between Ascorbic acid and Mg, Cu, Mn and rainfall in the fruits from Kwale. Copper also has a major effect on thickening the cell wall and improving skin strength, maintaining the integrity of the fruit. There is positive correlation between ascorbic acid with copper and Zinc (Abdel-Rahm *et al.*, 2011).

MD12

***Zinc** =1.510 - 0.306 (PH) + 0.426 (Zn) + 0.0159 (Ti) + 1.1955 (Cu) + 0.0113 (Mn) - 0.020 (Relative humidity) + 0.0178 (Sunshine) -0.090 (Average temperature) + 0.003 (Rainfall)*

F value=137.1, p value=0.0073, Adjusted R^2=0.9911

There was positive correlation between Zinc in the fruits from Kwale with Zinc in the soils, Ti, Cu, Mn, sunshine and rainfall as reported by Iwane and Bessho (2006) in apple fruits from Japan.

4.7 Quality of *Syzygium* juice using Fruits from Bungoma and Kwale Counties and Correlation with Abiotic Factors.

4.7.1 Quality of *Syzygium cuminii* Juice

The quality of Syzygium cuminii juice was determined against the Kenya Bureau of Standards guidelines (Table 4.5), these were; ethyl alcohol, acid insoluble ash, pH, these were Total Plate Count, Escherichia coli, yeasts, and mold, all these then correlated with temperature, rainfall, humidity, and % sunlight.

Table 4. 4: Quality Characteristics of *S. cuminii* Fruit Juice from Bungoma and Kwale Counties

Sample no.	Characteristics				Microbial load		
	Ethyl alcohol 0.5% v/v	Acid insoluble ash, in HCl mg/kg	TSS (ºBrix)	pH	Total viable count (cfu/g)	*Escherichia coli*, (cfu/g)	Yeasts and Moulds (cfu/g)
Bungoma							
1(13)			20.80	4.19			
2(14)	Nil	Not detected	20.95	4.35			
3(23)			21.00	4.20			Not detected
4(27)			20.55	3.42		Not detected	
5(32)			20.70	3.36			
6(38)			20.85	4.24	> 300		
Kwale							
1(5)			21.49	4.22			
2(13)			21.36	4.16			
3(14)	Nil	Not detected	21.51	4.29			Not detected
4(22)			21.63	4.35			
5(26)			21.22	4.0			
6(31)			21.68	3.99		Not detected	
Requirement	3 maximum	2 maximum	10 minimum	4.5 maximum	1,000,000 maximum	Shall be absent	Shall be absent
Method of test	KS ISO 2448:1998	KS ISO 763:2003	KS ISO 2172:1983	KS ISO 1842:1991	KS ISO 4833-2:2013	KS ISO 7251:2005	KS ISO 21527-2:2008

4.7.1.1 Ethyl Alcohol and Acid-insoluble Ash

Syzygium fruit juices analysed did not contain ethyl alcohol or acid-insoluble ash since they were freshly prepared. Acid insoluble ash is an inorganic matter containing minerals in a food sample which when determined indicates the safety of the food. Ethyl alcohol forms during fermentation and excess may inhibit juice degradation but also affect the taste

4.7.1.2 Total Soluble Solids (ºBrix)

The Brix content of juice was higher than that of the juice due to the addition of sugar during juice preparation, e.g. Brix content of 11.83 ±0.15; 12.27 ±0.06 was recorded from samples 23 and 27 from Bungoma. The same trend was noted for Kwale fruits fruit juice. 20.55 – 21.00 ^{o}Brix reported for *Syzygium cuminii* fruit juice from Bangladesh by Shakil *et al.,* (2021).

The increase in the Brix content of *Syzygium* fruits is probably due to the conversion of starch to glucose, sucrose, and fructose (Bashir and Abu-Bakr, 2003; Omid *et al.,* 2011), a process that also leads to the increase in pectin thus causing softening of fruits will increase, leading to fruit softening (Mansour and Jila, 2010).

4.7.1.3 pH

The Average pH of the fruit juice from Bungoma and Kwale fruits were 3.96 and 4.17 respectively compared to the narrow range of 4.3 – 4.9; 3.36 – 4.35 reported by Tehrani *et al.,* (2011; Ahmed *et al.,* 2020) in *Syzygium aqueum* from Malaysia and *Syzygium cuminii* fruits from Bangladesh respectively. In other studies, a pH of 3 was reported in Sanguinello orange juices by Kelebek *et al.,* (2008), 4.2 to 4.4 in stored peaches by Zhang ,(2008), 3.0 to 3.5 in citrus fruits by Chahidi *et al.,* (2008) and 4.0 in tomatoes Bhattarai & Gautam, (2006). Low pH of fruit juice (below 2.6) inhibits the growth of microorganisms (Lorenzo *et al.,* 2018; Núñez-Regueira *et al.,* 2001), however, during the processing, the nutritional composition changes e.g. denaturing vitamin C thus reducing the quality of the juice (Landon, 2007). The pH also increased for the fruit juices from both counties due to the production process.

4.7.1.4 Vitamin C

All samples recorded reduced Vitamin C content due to pasteurization. According to Devi (2015), foods loose about 50 % of the Vitamin C in cooking. Bofars, (2022) noted that citrus fruits such as lemon, reticulate and paradise showed reduced vitamin C content on heating these varying according to temperature, method used to apply heat and the environmental conditions. Vitamin C content of pineapples reduced from 1.50 ± 0.06 to 1.33 ± 0.03 mg/ml, and water melon from 1.16 ± 0.03 to 1.06 ± 0.07 mg/ml on heating (Kaleem et al., (2016).

4.7.1.5 Total Viable Count, *E.coli,* Yeasts and Moulds

Levels were within allowed limits. Contamination is normally introduced through the fruits, during juice preparation in an unhygienic environment (Oliveira *et al.,* 2006; Hariyadi, 2013). From a study by Jimma *et al.,* (2022), both *Escherichia coli* and *Salmonella typhi* were absent in the three commercial juices that were analysed. Contrary results were reported for homemade juices that recorded over 88% for the *Escherichia coli* and 40 % for the *Salmonella typhi*

4.7.1.6 Heavy metals

Chromium and cadmium were below detectable levels for the inductively coupled Plasma Optical Emission Spectrometer (ICP – OES). The equipment lowest detection level was parts per billion (ppb).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

There was no significant difference in fruit length, moisture content, TSS, and TA between the two counties, however, Ash content varied significantly with Kwale recording a mean value of 2.74± 0.01 *Vis a vis* 1.61 ±0.02 percentage from Bungoma. Mg correlated positively with TSS, Maturity, L* value for fruit skin colour, and negatively with TA, whereas Mn, Cu, Fe, Zn, and L* values correlated positively with TSS and TA. Zn correlated positively with pH, and vitamin C negatively with TA. This study reported higher Fe values from the Bungoma fruit sample than *Syzygium Cuminii* fruits from India and Pakistan. Heavy metals like Cr, Cd were not detected by the ICP OES, Their Limit of detection (LOD for Cr = 0.01mg/L) , this shows how safe the *Syzygium* fruits are for human consumption, however, their levels need to be regularly monitored as this would be an indication of a polluted environment.

Soils from Bungoma and Kwale counties were moderately acidic with all analysed characteristics within common ranges. Soil Mg affected fruit pH and size positively. Soil pH positively correlated with soil Mn and soil Na, whereas the latter negatively correlated with fruit pH and colour indices (L*, a* b*). High soil pH caused low Fe content in *Syzygium. cuminii* fruits and the high Fe content was conversely caused by low soil Zn. Soil porosity correlated positively with % TA and negatively with TSS. Bulk density on the other hand correlated positively with TSS and particle density. The presence of elevated levels of Ti in the soils can be attributed to foliar sprays on farms.

Fruits oriented towards the East were exposed to sunshine for longer periods, and higher temperatures during the fruiting season and hence developed higher TSS, Vitamin C content, and intense colour. The same samples from both counties had higher L* (lightness) values for their fruit skin colour according to orientation. The same was noted for a* values, most of the fruits were red towards purple colour a sign of maturity. Total rainfall from Bungoma over the study period was 1700mm compared to 1032mm from Kwale, as a result, over 51% of fruits analysed from this county had low TSS and high % TA. Fruits obtained from low altitudes (Kwale) had better quality than those from a higher altitude (Bungoma). Ascorbic acid, proteins and Zinc from both sites, were found to be reliable models which can be used to predict the dependent variables.

Syzygium fruit juices analysed did not contain ethyl alcohol, a sign of freshness, acid-insoluble ash, or microbes since they were freshly prepared. There was a significant variation in TSS and pH of fresh fruit with prepared juice, but no significant difference relating to abiotic factors since the juice is adjusted to meet KEBS verification standards and thus met KEBS requirements for a ready-to-drink fruit juice.

5.2 RECOMMENDATIONS

From this study, it is recommended that; *Syzygium* fruit tree age/fruiting period, and genetic make- up be determined since it influences its yield and other physical characteristics leading to a variation in its natural system. Tannins too should be determined to quantify the compounds causing the astringent taste. To avoid toxicity, *Syzygium* trees should be planted in a clean environment as the roots translocate toxic minerals to the fruits**.** It is also recommended that *Syzygium* fruits should be harvested before they over mature, they have a longer shelf life though their nutritional content is lower. Conversely, the reverse is true; therefore, a balance needs to be sought between the two quality parameters. In building resilience against the impacts of environmental variability, there is a need to establish and implement appropriate mitigation, adaptation measures, and coping strategies.

REFERENCES

Abbott, L., & Manning, D. (2015). Soil Health and Related Ecosystem Services in Organic Agriculture. *Sustainable Agriculture Research*, *4*(3), Article 3. https://doi.org/10.5539/sar.v4n3p116

Abdel-Rahm N.A-G, Mohammed MA-R, & Mohammed M.M. (2011). *Development of new convenient recipes from local Sudanese fruits and vegetables. 10*, 95–199.

Abedelmaksoud, T. G., Mohsen, S. M., Duedahl-Olesen, L., Altemimi, A. B., Elnikeety, M. M., Cacciola, F., & Feyissa, A. H. (2022). Positive Influences of Ohmicsonication on Phytochemical Profile and Storage Stability of Not-from-Concentrate Mango Juice. *Molecules*, *27*(6), Article 6. https://doi.org/10.3390/molecules27061986

Abeytilakarathna. P. D., Fonseka, R. M., Eswara, J. P., & Wijethunga, K. G. N. A. B. (2013). *Relationship between Total Soluble Solid content and red, green and blue colour intensity of strawberry (Fragaria x ananassa Duch.) Fruits*. *8*(2).

Agoreyo, B. O. (2010). *Acid phosphatase and alkaline phosphatase activities in ripening fruit of Musa Paradisiaca L*. *3*, 66-69.

Agrawal, V., Rangare, N. R., & Nair, R. (2017). *Variability studies in different accessions of Jamun (Syzygium cumini skeels) from Madhya Pradesh. 5*(3), 07-11.

Ahmad, S., Chatha, Z. A., Nasir, M. A., Aziz, A., & Mohson, M. (2006). *Effect of Relative Humidity on the Ripening Behaviour and Quality of Ethylene Treated Banana Fruit*. *2*(1), 5.

Ahmed, S., Ahmed, K. S., Hossain, M.S., Azam, M. S., Rahman, M., & Hoque, M. (2020). *Proximate composition and antioxidant activity of Syzygium cumini fruit grown at different regions in Bangladesh*. *4*, 1693–1699.

Ahmed, S., Shanks, C. B., Smith, T., & Shanks, J. (2018). Fruit and vegetable desirability is lower in more rural built food environments of Montana, USA using the Produce Desirability (ProDes) Tool. *Food Security*, *10*(1), 169–182.

Akhila, H., & Umadevi, S. H. (2018). *Physico-Chemical Properties of Jamun (Syzygium cumini L.) Fruits and It's Processed Products. 6*(6), 1317–1325.

Al – Kindy, S. M. Z., Abdulnour, A. O., & Al-Rasbi, M. M. (2001). Determination of sugar and mineral contents in some Omani fruits. *Science and Technology*, *6*, 39–44.

Alae-Carew, C., Nicoleau, S., Bird, F.A., Hawkins, P., Tuomisto, H. L., Haines, A., Dangour, A. D., & Scheelbeek, P. F. D. (2020). *The impact of environmental changes on the yield and nutritional quality of fruits, nuts and seeds: A systematic review*. *15*, 023002.

Ali A, Mahmud TMM, Sijam K, & Siddiqui Y. (2011). *Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (Carica papaya L.) fruit during cold storage.* 620–626.

Al-Said. F.A., Opara, L.U., & Al-Yahyai, R.A. (2009). *Physico-chemical and textural quality attributes of pomegranate cultivars (Punica granatum L.) grown in Sultanate of Oman. 90*, 129–143.

Ames, H., Glenton, C., & Lewin, S. (2019). *Purposive sampling in a qualitative evidence synthesis: A worked example from a synthesis on parental perceptions of vaccination communication*. *19*(26). https://doi.org/10.1186/s12874-019-0665-4

Andrés-Bello, A., Barreto-Palacios, V., Garcıa-Segovia, P., Mir-Bel, J., & Martı´nez-Monzo, J. (2013). *Effect of pH on Color and Texture of Food Products. 5*, 158–170.

AOAC. (2005). OAC Official Method 978.10 , Crude fibre. In *Official Methods of Analysis of AOAC INTERNATIONAL* (18th ed.). AOAC.

AOAC. (2006a). *Official methods of analysis, 920-39, crude fat*. AOAC.

AOAC. (2006b). *Official Methods of Analysis,984-13, crude protein*. AOAC.

Appiah F, Kumah P., & Idun I. (2011). Effect of ripening stage on composition, sensory qualities and Acceptability of Keitt mango (Mangifera indica l.) chips. *African Journal of Food, Agriculture, Nutrition and Development*, *11*(5), 5096–5109.

Arshad, M., Shahnawaz1, M., Shahkeela, S., Hussain, M., Ahmad, M., & Sher Khan, S. (2014). *Significance of physical properties of apple fruit influenced by preharvest orchard management factors. 4*(5).

Aruani, M., Barnes, N., Striebeck, G., Osre, B., & Machuca, Y. (2011). Physical and physico-chemical properties of saline soils and effects on yield and quality of ‘Williams’ pear in the upper Rio Negro valley, Argentina. *Acta Horticulturae*, *909*, 303–308. https://doi.org/10.17660/ActaHortic.2011.909.33

Ayyanar, M., & Subash – Babu, P. (2012). *Syzigium cumini (L.) Skeels: A review of its phytochemical constituents and traditional uses. 2*(3), 240–246.

Bagde, P. & Tumane, T. M. (2011). Neha I Studies on microbial flora of fruit juices and cold drinks. *Asiatic Journal of Biotechnology Resources*, *2*.

Balemie, K., & Kebebew, F. (2006). *Ethno botanical study of wild edible plants in Derashe and Kuch districts, South Ethiopia. 2*(1), 53.

Ball, B.C., Campbell, D.J., & Hunter, E.A.,. (2000). *Soil compactibility in relation to physical and organic properties at 156 sites in UK. 57*, 83–91.

Ballabio, C., Panagos, P., Lugato, E., Huang, J.-H., Orgiazzi, A., Jones, A., & Montanarella, L. (2018). *Copper distribution in European topsoils: An assessment based on LUCAS soil survey*. *636*, 282-298. https://doi.org/doi:10.1016/j.scitotenv.2018.04.268

Barbera, A. C., Maucieri, C., Cavallaro, V., Ioppolo, A., & Spagna, G. (2013). Effects of spreading olive mill wastewater on soil properties and crops, a review. *Agricultural Water Management*, *119*, 43–53. https://doi.org/10.1016/j.agwat.2012.12.009

Barett, D. M., Beauliu, J. C., & Shewfelt, R. (2010). *Color, Flavor, texture and nutritional quality of fresh—Cut fruits and vegetables: Desirable levels, instrumental and sensory measurement, and the effects of processing*. *50*(5), 369-389.

Bashir, H. A., Abu-Bakr , A., & Abu-Goukh. (2003). Compositional changes during guava fruit ripening. *Food Chemistry*, *80*, 557–563. https://doi.org/10.1016/S0308-8146(02)00345-X

Benherlal P.S, & Arumughan C. (2007). *Chemical composition andin vitro antioxidant studies on Syzygium cumini fruit. 87*, 2560-2569.

Bhat, R., Kiran, K., Arun, A.B., & Karun, A. A. (2010). *Determination of Mineral Composition and Heavy Metal Content of Some Nutraceutically Valued Plant Products. 3*, 181–187.

Bhatt, I.D., Rawat, S., Badhani, A., & R.S. Rawal. (2017). Nutraceutical potential of selected wild edible fruits of the Indian Himalayan region. *Food Chem.*, *215*, 84–91. https://doi.org/10.1016/j.foodchem.2016.07.143.

Bhattarai, D. R., & Gautam, D. M. (2006). *Effect of harvesting method and Calcium on harvest Physiology of tomato*. *7*, 37-41.

Blake, G. R. (2008). Particle density. In W. Chesworth (Ed.), *Encyclopedia of Soil Science* (pp. 504–505). Springer. https://doi.org/10.1007/978-1-4020-3995-9_406

Boca, G.D. (2021). Factors Influencing Consumer Behavior in Sustainable Fruit and Vegetable Consumption in Maramures County, Romania. *Sustainability*, 13: 1812. https://doi.org/10.3390/su13041812.

Bofars, M. S. (2022). Effect of Heated Temperature Environment on Vitamin C in Four fruit Citrus Juice. *South Asian Research Journal of Nursing and Healthcare*, 4(6): 79-83.

Bo Y. & Ying H. (2018). 2nd International Symposium on Resource Exploration and Environmental Science. *IOP Conference Series: Earth and Environmental Science*, *170*, 011001. https://doi.org/10.1088/1755-1315/170/1/011001

Bolinder, M., Kätterer, T., Andrén, O., Ericson, L., Parent, L., & Kirchmann, H. (2010). Long-term soil organic carbon and nitrogen dynamics in forage-based crop rotations in Northern Sweden (63–64°N). *Agriculture, Ecosystems & Environment*, *138*, 335–342. https://doi.org/10.1016/j.agee.2010.06.009

Bragança, V.L.C., Melnikov, P., & Zanoni, L.Z. (2012). *Trace elements in fruit juices. 146*, 256–261.

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). *Adaptation to Climate Change in Ethiopia and South Africa: Options and constraints. 12*(4), 413–426.

Callahan, A.M. (2003). *Breeding for fruit quality*. *622*, 295–302.

Calvacanti, A., Oliveira, K.F., Paiva, P.G., Dias, M., Costa, S., & Vieira, F.F. (2006). *Determination of total soluble solids content (Brix) and pH in milk drinks and industrialized fruit juices. 6*(1), 57–64.

Cameira, M.R., Fernando, R.M., & Pereira, L.S. (2003). *Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal. 70*, 131–140.

Campbell W.W, Trappe T.A, Wolfe R.R, & Evans W.J. (2001). *The recommended dietary allowance for protein may not be adequate for older people to maintain skeletal muscle. 56*, M373-M380.

Cardoso, E. J. B. N., Vasconcellos, R. L. F., Bini, D., Miyauchi, M. Y. H., Santos, C. A. dos, Alves, P. R. L., Paula, A. M. de, Nakatani, A. S., Pereira, J. de M., & Nogueira, M. A. (2013). Soil health: Looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? *Scientia Agricola*, *70*(4), 274–289.

Carter, M. R., & Gregorich, E. G. (Eds.). (2007). Soil Density and Porosity. In *Soil Sampling and Methods of Analysis* (2nd ed.). CRC Press.

Caruso, G., & Villari, A.,. (2004). *Quality characteristics of "Fragaria vesca L. " fruits influenced by NFT solution EC and shading. 648*, 161–174.

Chahidi, B., El-Otmani, M., Luro, F., Srairi, I., & Tijane, M. (2008). *Changes of fruit quality traits in 7 clementine selections during maturation*. *7*, 2565–2577.

Chanson-Rolle, A., Braesco, V., Chupin, J., & Bouillot, L. (2016). Nutritional Composition of Orange Juice: A Comparative Study between French Commercial and Home-Made Juices. *Food and Nutrition Sciences*, *7*(4), Article 4. https://doi.org/10.4236/fns.2016.74027

Chatuverdi, R. K., Prasad, S., Obaidullah, S. M., & Pandev, V.,. (2012). *Effect of dust load on the leaf attributes of the tree species growing along the roadside. 185*(1), 383–391.

Christensen, J.H., Hewitson, B., Busuioc, A., Kolli, R. K., T., K., W., Laprise, R., Magana Rueda, V., Mearns, L., Menéndez, C. G., Räisänen, J., & Sarr, A. (2007). Regional Climate projections. In *Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., ... & Whetton, P. (2007). Regional climate projections. Chapter 11.* (p. 94). Cambridge University Press, Cambridge.

Cock, I., & Cheesman, M. (2018). Plants of the genus *Syzygium* (Myrtaceae): A review on ethnobotany, medicinal properties and phytochemistry. In Bioactive Compounds of Medicinal Plants: Properties and Potential for Human Health (pp. 35–84).

Dehelean, A., & Magdas, D. A. (2013). *Analysis of mineral and heavy metal content of some commercial fruit juices by ICP – MS. 2013*, 6. https://doi.org/215423

Devi, R. (2015). *Food Processing and Impact on Nutrition*. *2*(4A), 304–311.

Dey, K., Ghosh, A., KOLEY, P., & DAS, B. (2016). INFLUENCE OF THE TREE CANOPY POSITIONS AND DIRECTIONS ON FRUIT MORPHOLOGICAL HARACTERS AND BIO-CHEMICAL COMPOSITION OF PUMMELO (CITRUS GRANDIS OSBECK.). *The Ecoscan*, *IX*(Special issue).

Dumas, Y., Dadomo, M., Di Lucca, G., & Grolier, P. (2003). *Effects ofenvironmental factors and agricultural techniques on antioxidant content of tomatoes. 83*, 369–382. https://doi.org/10.1002/jsfa.1370

FAO. (2021). *Indigenous foods can alleviate nutrition crisis in Southern Africa*. Food and Agriculture Organization of the United Nations. http://www.fao.org/africa/news/detail-news/en/c/1202340/

Flues, M., Sato, I. M., Cotrim, M. B., Salvador, V. L., Ranzani, A. C., Vallilo, M. I., & Oliveira, E. (2004). Soil characterization in a subtropical forest crossed by highways (Cantareira State Park, SP, Brazil). *Journal of the Brazilian Chemical Society*, *15*(4), 496–503. https://doi.org/10.1590/S0103-50532004000400009

Fouche´, J. R., Roberts, S. C., Midgley, S.J.E., & Steyn,W. J. (2010). *Peel Color and Blemishes in 'Granny Smith' Apples in Relation to Canopy Light Environment*. *45*(6), 899–905.

Franke, R., Gruska, A., Bossa, C., & Benigni, R. (2010). QSARs of aromatic amines: Identification of potent carcinogens. *Mutation Research*, *691*, 27–40. https://doi.org/10.1016/j.mrfmmm.2010.06.009

Fraternale, D., Ricci, D., Flamini, G., & Giomaro, G. (2011). Volatiles Profile of Red Apple from Marche Region (Italy). *Records of Natural Produsts*, 6.

Gachimbi, L. N, Kulen, van H., Thuranira, E. G., Karuku, A. M., Jager, de A., Nguluu, S., Ikombo, B. M., Kinama, J. M., Itabari, J. K., & Nandw, S. M. (2005). Nutrient balances at farm level in Machakos, Kenya. Using a participatory nutrient monitoring (NUTMON) approach. *Land Use Policy*, *22*, 13–22.

Gajera H.P., Gevariya SN.., Patel S.V., & Golakiya B.A. (2018). Nutritional profile and molecular fingerprints of indigenous black jamun (Syzygium cumini L.) landraces. *Journal of Food Science and Technology*, *55*(2). https://doi.org/10.1007/s13197-017-2984-y

Gayon, P. R., Glories, Y., Maujean, A., & Dubourdien, D. (2006). “Organic acids in wine. In: Handbook of enology. In *The chemistry of wine stabilization and Treatments* (2nd ed., Vol. 2, pp. 9–10). John Wiley and Sons,.

Ghosh, P., Pradhan, R. C., Mishra, S., Patel, A. S., & Kar, A. (2017). *Physicochemical and Nutritional Characterization of Jamun (Syzygium Cuminii)*. *5*(1), 23–25.

Gichau, A. W., Okoth, J. K., & Makokha, A. (2020). Moisture sorption isotherm and shelf life prediction of complementary food based on amaranth-sorghum grains. *Journal of Food Science and Technology*, *57*(3), 962–970. https://doi.org/10.1007/s13197-019-04129-2

Gopalan, C., Ramashastri, B. V., Balasubramanian, S. C., Rao, N. B. S., Deosthale, Y. G., & Pant, K. C.,. (2004). Nutritive Value of Indian Foods. *National Institute of Nutrition, ICMR Hyderabad.*

Gruda, N. (2005). *Impact of Environmentl factors on product quality of Greenhouse vegetables for fresh consumption. 24*, 227–247.

Guedes, M. N. S., Abreu, de A., C. M. P., Maro, C., L. A., Rafael, P., de Abreu, J. R., & de Oliveira, J. O. (2013). Chemical characterization and mineral levels in the fruits of blackberry cultivars grown in a tropical climate at an elevation. *Acta Scientiarum. Agronomy*, *35*(2), 191–196. https://doi.org/10.4025/actasciagron.v35i2.16630

Guo, K., Guo, Z., Guo, Y., & Qiao, G. (2019). *Fruit performance of kiwifruit in the loess area of Northwest China* [Preprint]. Physiology. https://doi.org/10.1101/633206

Gwarzo, U. S., & Solanki, H. (2015). Quantification of ash and selected primary metabolites from non-edible parts of several fruits. *International Journal of Pharmacy and Pharmaceutical Sciences*, *7*, 288–290.

Gysi, M., Klubertanz, G., & Vulliet, L. (2000). Compaction of an Eutric Cambisol under heavy wheel traffic in Switzerland—Field data and modelling. *Soil and Tillage Research*, *56*(3–4), 117–129. https://doi.org/10.1016/S0167-1987(00)00132-X

Hamadzrip, E. T., Theron, K.I, Muller, M., & Steyn, W. J.,. (2012). *The effect of canopy position on the fruit quality and consumer preferece of apples*. Stellenbosch.

Hamini – Kadar, N., Boutoutaou, R., Kihal M., & Henni, J. E. (2014). Antifungal activity of clove (*Syzigium aromaticum*) essential oil against phyto-pathogenic fungi of tomato (Solanum lycopersicum L.) in Algeria. *Journal of Experimental Biology and Agricultural Sciences*, *2*, 50.

Han, L., Wang, C., Yu, T., Gu, X., & Liu, Q. (2020). High-Precision Soil Moisture Mapping Based on Multi-Model Coupling and Background Knowledge, Over Vegetated Areas Using Chinese GF-3 and GF-1 Satellite Data. *Remote Sensing*, *12*(13), 2123. https://doi.org/10.3390/rs12132123.

Hariyadi, R.D. (2013). *Microbiological Quality and Safety of Fruit Juices. 1*, 54–57.

Hazelton, P., & Murphy, B. (2007). *Interpreting soil test results: What do all the numbers mean?* CSIRO Publ.

Hemalatha, S., Platel, K., & Srinivasan, K. (2007). Influence of heat processing on the bioaccessibility of zinc and iron from cereals and pulses consumed in India. *Journal of Trace Elements in Medicine and Biology: Organ of the Society for Minerals and Trace Elements (GMS)*, *21*(1), 1–7. https://doi.org/10.1016/j.jtemb.2006.10.002

Hermans, C., Vuylsteke, M., Coppens, F., Cristescu, S. M., Harren, F. J. M., Inzé, D., & Verbruggen, N. (2010). Systems analysis of the responses to long-term magnesium deficiency and restoration in Arabidopsis thaliana. *New Phytologist*, *187*(1), 132–144.

Howarth, N. C., Saltzman, E., & Roberts, S. B. (2001). Dietary fiber and weight regulation. *Nutrition Reviews*, *59*(5), 129–139. https://doi.org/10.1111/j.1753-4887.2001.tb07001.x

Hribar, J., & Vidrih, R. (2015). Impacts of climate change on fruit physiology and quality. *Proceedings . 50th Croatian and 10th International Symposium on Agriculture .*, 42–45.

Hruby, M., Cigler, P., & Kuzel. S. (2002). *Contribution to understanding the mechanism of titanium action in plant. 25*, 577–598.

Hu, H., Liu, H., Zhang, H., Zhu, J., Yao, X., Zhang, X., & Zheng, K. (2010). Assessment of Chlorophyll Content Based on Image Color Analysis, Comparison with SPAD-502. 2010. *2nd International Conference on Information Engineering and Computer Science, 1-3.*, 1–3.

Huho, J. M., Ngaira, J. K. W., & Ogindo, H. O. (2010). *Drought severity and their effects on rural livelihoods in Laikipia district, Kenya. 3*(3), 035–043.

Hulme, M., Doherty, R. M., Ngara, T., New, M. G., & Lister, D. (2001). *African climate change: 1900 – 2100. 17*(2), 145–168.

Imán, C.S., Bravo, Z.L., Sotero, S.V., & Oliva C.C. (2011). *Contenido de vitamina C en frutos de camu-camu. Myrciaria dubia (H.B.K) Mc Vaugh, en cuatro estados de maduración, procedentes de la Colección de Germoplasma del INIA Loreto, Perú. Scientia*. *2*(2011), 123–130.

IPCC. (2021). *The sixth assesment report The Physical Science basis*.

Isabelle, M., Lee, B. L., Lim, M. T., Koh, W. P., Huang, D., & Ong, C. N. (2010). *Antioxidant activity and profies of common fruits in Singapore. 9*, 77–84.

Iwane, A., & Bessho, H. (2006). Effects of Sunlight on the Mineral Content of Apple Fruit (Factors Affecting the Variation of Mineral Components of Apples: Part VI). *Journal of The Japanese Society for Food Science and Technology-Nippon Shokuhin Kagaku Kogaku Kaishi - J JPN SOC FOOD SCI TECHNOL*, *53*, 151–157. https://doi.org/10.3136/nskkk.53.151

Jaakola, L., & Hohtola, A. (2010). *Effect of latitude on flavonoid biosynthesis in plants. 33*, 1239–1247.

Jaiswal, S.G., Pate, M., & Naik, S. N. (2005). *Physicochemical properties of Syzigium cuminii (L.) Skeels jam and comparative antioxidants with other fruit jams. 6*(1), 9–15.

Jensen, T. L.,. (2010). Soil pH and the Availability of Plant Nutrients. *" IPNI Plant Nutrition TODAY*, *2*. www.ipni.net/pnt

Jeon, M.W., Ali, M.B., Hahn, E.J, & Paek, K.Y. (2006). *Photosynthetic pigments, morphology and leaf gas exchange during ex vitro acclimatization of micropropagated CAM Doritaenopsis plantlets under relative humidity and air temperature. 55*, 183–194.

Jifon, J. L., & Syvertsen, J. P. (2001). *Effects of moderate shade on citrus leaf gas exchange, fruit yield, and quality. Proceedings of the annual meeting of the Florida State Horticultural Society, 114: 177-181.*

Kabata-Pendias, A., & Mukherjee, A.B.,. (2007). *Trace Elements from Soil t human* (2007th ed., p. 550). Springer- Verlag.

Kaleem, A., Nazir, H., & Pervaiz, S. (2016). Investigation of the effect of temperatute on vitamin C in fresh and packed fruit juices. *FUUAST Journal of Biology*, 6(1), 117-120

Kanyanjua, S.M., Ireri, L., Wambua, S., & Nandwa, S.M. (2002). *Acidic soils in Kenya: Constraints and remedial options*. *11*.

Karahan, F., Ozyigit, I. I., Saracoglu, I. A., Yalcin, I. E., Ozyigit, A. H., & Ilcim, A. (2020). *Heavy Metal Levels and Mineral Nutrient Status in Different Parts of Various Medicinal Plants Collected from Eastern Mediterranean Region of Turkey*. *197*, 316–329. https://doi.org/10.1007/s12011-019-01974-2

Karuma, A., Mtakwa, P., Amuri, N., Gachene, C. K., & Gicheru, P. (2014). Tillage Effects on Selected Soil Physical Properties in a Maize-Bean Intercropping System in Mwala District, Kenya. *International Scholarly Research Notices*, *2014*, 497205–497205. PubMed. https://doi.org/10.1155/2014/497205

Kawachi, M., Kobae, Y., Mori, H., Tomioka, R., Lee, Y., & Maeshima, M. (2009). *A mutant strain arabidopsis thaliana that lacks vacuolar membrane zinc transporter MTP1 revealed the latent tolerance to excessive zinc,*. *50*(6), 1156–1170. https://doi.org/10.1093/pcp/pcp067

Kebeney, S., Msanya, B., Ng'etich, W., Semoka, J., & Serrem, C. (2015). Pedological Characterization of Some Typical Soils of Busia County, Western Kenya: Soil Morphology, Physico-chemical Properties, Classification and Fertility Trends. *International Journal of Plant & Soil Science*, *4*, 29–44. https://doi.org/10.9734/IJPSS/2015/11880

Kelebek, H., Canbas, A., & Selli, S. (2008). Determination of phenolic composition and antioxidant capacity of blood orange juice obtained from cvs. Moro and Sanguinello (Citrus sinensis (L) Osbeck) grown in Turkey. *Food Chemistry*, *107*, 1710–1716. https://doi.org/10.1016/j.foodchem.2007.10.004

Khadka, D. B. ., Shirai, Y., Yanagida, M., Ryan, J. W., & Miyano, K. (2017). Exploring the effects of interfacial carrier transport layers on device performance and optoelectronic properties of planar perovskite solar cells. *Journal of Materials Chemistry C*, *5*(34), 8819–8827. https://doi.org/10.1039/C7TC02822A

Kimble, J.M., Follett, R.F., & Stewart, B. A. (2000). Importance of Soil Bulk Density and Methods of Its Measurement. In *Assessment-methods-soil-carbon* (1st ed., p. 14). CRC press. https://www.taylorfrancis.com/books/mono/10.1201/9781482278644

Kimble, J.M., Lal, R., & Follett.R. F. (2001). Methods for assessing soil C pools. In R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (ed.). In *Assessment methods for soil carbon.* Lewis Publishers.

Kleiber, T., & Markiewicz, B. (2013). Application of 'Tytanit' in greenhouse tomato growing. *Undefined*, *2*, 117–126.

Kshirsagar, R.B., Desai, G.B., Sawate, A.R., & Deshmukh, N.M. (2019). Physico-chemical and nutritional properties of jamun (Syzygium cumini) seed. *Journal of Pharmacognosy and Phytochemistry*, *8*(2), 211–213.

Ladiges, P. Y., Frank Udovic, F., & Nelson, G. (2003). *Australian biogeographical connections and the phylogeny of large genera in the plant family Myrtceae. 30*(7), 989–998.

Landon, S. (2007). *Fruit juice nutrition and health. 59*, 533–538.

Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, *20*(3), 207–220. https://doi.org/10.1016/S0925-5214(00)00133-2

Lee, S., Kim, S.A, Lee, J., Guerinot, M.L, & An ,G. (2010). *Zinc deficiency-inducible OsZIP8 encodes a plasma membrane-localized zinc transporter in rice. 6*, 551–558.

Levey, D. J., Bissell, H. A., & O'Keefe, S. F. (2000). Conversion of Nitrogen to Protein and Amino Acids in Wild Fruits. *Journal of Chemical Ecology*, *26*(7), 1749–1763. https://doi.org/10.1023/A:1005503316406

Liu, Z., Huang, Y., Tan, F., Chen, W., & Ou, L. (2021). Effects of Soil Type on Trace Element Absorption and Fruit Quality of Pepper. *Frontiers in Plant Science*, *0*. https://doi.org/10.3389/fpls.2021.698796

Logsdon, S. (2012). Temporal Variability of Bulk Density and Soil Water at Selected Field Sites. *Soil Science*, *177*, 327–331. https://doi.org/10.1097/SS.0b013e31824d8db1

Lokesha, A. N., Shivashankara, K. S., Laxman, R. H., Geetha, G. A., & Shankar, A. G. (2019). Effect of High Temperature on Fruit Quality Parameters of Contrasting Tomato Genotypes. *International Journal of Current Microbiology and Applied Sciences*, *8*(03), 1019–1029. https://doi.org/10.20546/ijcmas.2019.803.124

Lorenzo, J. M., Munekata, P. E., Dominguez, R., Pateiro, M., Saraiva, J. A., & Franco, D. (2018). *Main Groups of Microorganisms of Relevance for Food Safety and Stability: General Aspects and Overall Description*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7150063/

Lugwisha, E.H., Fabian, C., & Othman, O.C. (2016). Postharvest Changes in Physicochemical Properties and Levels of Some Inorganic Elements in Sugar Apple (Annona squamosal L.) Fruits of Coast Region, Tanzania. *Journal of Food and Nutrition Sciences*, *4*(3), 41–48. http://dx.doi.org/10.11648/j.jfns.20160403.11

Lyu, S., Wei, X., Chen, J., Wang, C., Wang, X., & Pan, D. (2017). Titanium as a Beneficial Element for Crop Production. *Frontiers in Plant Science*, *8*, 597. https://doi.org/10.3389/fpls.2017.00597

Mahapatra, A., Mishra, S., Basak, U., & Panda, P. (2012). Nutrient Analysis of Some Selected Wild Edible Fruits of Deciduous Forests of India; an Explorative Study towards Non Conventional Bio-Nutrition. *Advance Journal of Food Science and Technology*, *4*, 15–21.

Maingi, F. M., Mbuvi, H. M., & Adamu A. (2020). *Physical-Chemical Characterization of Soils in Selected Potato Growing Areas of Molo, Nakuru County Kenya*. *7*(4).

Makovníková, J., Širáň, M., Houšková, B., Pálka, B., & Jones, A. (2017). Comparison of different models for predicting soil bulk density. Case study – Slovakian agricultural soils. *International Agrophysics*, *31*(4), 491–498. https://doi.org/10.1515/intag-2016-0079

Mansour, A. M & Jila RK. (2010). The comparison of carbohydrate and mineral changes in three cultivars of kiwifruit of Northern Iran during fruit development. *Australian Journal of Crop Science*, *4*.

Mapunda, E.P., & Mligo, C. (2019). *Nutritional content and antioxidant properties of edible indigenous wild fruits from miombo woodlands in Tanzania*. *13*(2), 849–860.

Matko, V. (2003). *Porosity Determination by Using Stochastics Method*. *44*, 155–162.

Mditshwa, A., Fawole,O. A., Al-Said, F., Al-Yahyai , R., & Opara, U. L. (2013). Phytochemical content, antioxidant capacity and physicochemical properties of pomegranate grown in different microclimates in South Africa. *South African*

Journal of Plant and Soil, *30*(2), 81–90. https://doi.org/10.1080/02571862.2013.802033

Millikan, M.B. (2012). *Nutritional Metals in Foods by AAS.Atomic Absorption Spectroscopy, Dr. Muhammad Akhyar Farrukh (Ed.),*. http://www.intechopen.com/books/atomic-absorption-spectroscopy/nutritional-metals-in-foods-by-aas

Mohanty, S., & Cock, I, E. (2010). *Bioactivity of Syzigium jambos methanolic extracts: Antibacterial activity and toxicity. 2*, 4–9.

Moretti, C. L., Mattos, L. M., Calbo, A. A., & Sargent, S. A. (2010). *Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: 43*, 1824–1832.

Morrissey, J., & Guerinot, M. L. (2009). Iron uptake and transport in plants: The good, the bad, and the ionome. *Chemical Reviews*, *109*(10), 4553–4567. https://doi.org/10.1021/cr900112r

Muchukuri, K., Kungu, N., Ayaga, G.O., & Gachini, G.N. (2004). *raining Notes for KARI Laboratory Staff on Soil and Plant Analysis Course Held at NARL-Kabete. Pp 62-74, 82-88.*

Muenchow, J., Hauenstein, S., Bräuning, A., Bäumler, R., Rodríguez, E. F., & von Wehrden, H. (2013). Soil texture and altitude, respectively, largely determine the floristic gradient of the most diverse fog oasis in the Peruvian desert. *Journal of Tropical Ecology*, *29*(5), 427–438. https://doi.org/10.1017/S0266467413000436

Murti, K., Paliwal, D., Madan, S., Kundu, R., & Kaushik, M. (2012). Exploration of preliminary phytochemical studies of seed of Syzigium cumini. *American Journal of Pharmacology and Toxicology*, *7*(1), 12–14.

Musabayane, C. T., Mahlalela, N., Shode, F. O., & Ojewole, J. A. (2005). *Effects of Syzigium cordatum (Hochst.) [Myrtaceae] leaf extract on plasma glucose and hepatic glycogen in streptozotocin – induced diabetic rats. 97*(3), 485–490.

Muthai, K. U., Karori, M. S., Muchugi, A., Indieka, A. S., Dembele, C., Mng'omba, S., & Jamnadass, R. (2017). Nutritional variation in baobab (Adansonia digitata L.) fruit pulp and seeds based on Africa geographical regions. *Food Science & Nutrition*, *5*(6), 1116–1129. https://doi.org/10.1002/fsn3.502

Muya, E. M., Obanyi, S., Ngutu, M., Sijali, I. V., Okoti, M., Maingi, P. M., & Bulle, H. (2011). *The physical and chemical characteristics of soils of Northern Kenya Aridlands: Opportunity for sustainable agricultural production*. *21*, 1–8.

Mwanga, D,. (2015). *Effects of climate change and global warming in Kenya. Climate change, IPCC, Kenya.* UNEP. Environment.www.mtaaniinsight.wordpress.com.

Najwa, F. R., & Azrina, A. (2017). *Comparison of Vitamin C content in fruits by titration and High Performance Liquid Chromatography (HPLC) methods*. *24*(2), 726–733.

Nakabonge, G., Roux, J., Gryzenhout, M., & Wingfield, M. J. (2006). *Distribution of chrysoporthe canker pathogens on Eucalyptus and Syzigium spp. In eastern and southern Africa. 90*(6), 734–740.

Nalianya, G. W., Wakhungu, J. W., & Nyandiko, N. O. (2020). *Trends and Patterns of Climate Change and Variability Experienced in Bungoma County, Kenya*. http://ir-library.mmust.ac.ke:8080/xmlui/handle/123456789/1843

Narayana, C.K, Pal, R.K.;, & Roy, S.K. (1999). Specific gravity and its influence on maturity of mango cv. Baneshan. *Journal of Applied Horticulture Lucknow*, *1*(1), 41–43.

Naryal,A., Bhardwaj, A. K., Kant, A., & Chaurasia, O. P.,. (2020). *Effect of Altitude on the Phenology and Fruit Quality Attributes of Apricot (Prunus armeniaca L.) Fruits*. *5*(1), 18–24. https://doi.org/10.14429/dlsj.5.14656

Ngaira, J.K.W. (2004). *Basic facts in contemporary climatology.* Lake Publishers and Enterprises.

Nirmala S, & Subba R. V. V. (2011). *A comparative study of pH modulation and trace elements of various fruit juices on enamel erosion: An in vitro study. 29*, 205–215.

Nisha A P & Radhamany, P. M. (2020). Evaluation of Proximate and Mineral Constituents in Different Commercial Cultivars and Local Varieties of Ananas comosus (L.) Merr. From Kerala. *International Journal of Fruit Science*, *20*(3), 620–634. https://doi.org/10.1080/15538362.2019.1628683

Niwayama, S., & Higuchi, H. (2019). Passion Fruit Quality under Acidic Soil Conditions. *The Horticulture Journal*, *88*. https://doi.org/10.2503/hortj.OKD-169

Norman, C. R., Brye, K. R., Gbur, E. E., Chen PengYin, & Rupe, J. (2016). *Long-term management effects on soil properties and yields in a wheat-soybean double-crop system in eastern Arkansas*. *181*(1), 1–12.

Nour, V., Trandafir, T., & Ionica, M. E. (2011). *Ascorbic acid, anthocyanins, organic acids, and mineral content 0f some black andred currant cultivars*. *66*(5), 353–362.

Nunes, M. C. N. (2008). *(2008). Impact of environmental conditions on fruit and vegetable quality*. *4*(4), 14.

Núñez-Regueira, L., Rodríguez-Añón, J., Proupín-Castiñeiras, J., & Romero-García, A. (2001). Energetic Evaluation of Biomass Originating from Forest Waste by Bomb Calorimetry. *Journal of Thermal Analysis and Calorimetry*, *66*(1), 281–292. https://doi.org/10.1023/A:1012416521652

Nzau, V. M. (2013). *Mainstreaming climate change resilience into development planning in Kenya.* (Climate Change, a Country Report, p. 3). IIED,.

Ojiewo, C., Keatinge, J., Hughes, J., Tenkouano, A., Nair, R., Varshney, R., Siambi, M., Monyo, E., Gangarao, N., & Silim, S. (2015). The Role of Vegetables and Legumes in Assuring Food, Nutrition, and Income Security for Vulnerable Groups in Sub-Saharan Africa. *World Medical and Health Policy*, *7*, 187–210.

Okiei, W., Ogunles,I. M., Azeez, L., Obakachi, V., Osunsami, M., & Nkenchor G. (2009). *The voltammetric and titrimetric determination of ascorbic acid levels in tropical fruit samples. 4*, 276–287.

Oliveira, A.C.G., Seixas, A.S.S., Sousa, C.P., & Souza, C.W.O. (2006). *Microbiological evaluation of sugarcane juice sold at street stands and juice handling conditions in Sao Carlos, Sao Paulo. 22*(5), 1111–1114.

Omid, M., Alimardan, R, & Soltani, M. (2011). Design and Development of a Portable Banana Ripeness Inspection System. *Journal of American Science, 6*. https://www.academia.edu/17149545/Design_and_Development_of_a_Portable_Banana_Ripeness_Inspection_System

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). *Agroforestree database: A tree reference and selection guide version 4.0*. World Agroforestry Transforming Lives and Landscapes with Trees. https://www.worldagroforestry.org/publication/agroforestree-database-tree-reference-and-selection-guide-version-40

Osman, M. (2004). Chemical and nutrient analysis of baobab (Adansonia digitata) fruit and seed protein solubility. *Plant Foods for Human Nutrition*, *59*(1), 29–33.

Osunbitan, J. A., Oyedele, D. J., & Adekalu, K. O. (2005). Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil and Tillage Research*, *82*(1), 57–64. https://doi.org/10.1016/j.still.2004.05.007

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Papadakis, I. E., Protopapadakis, E., Dimassi, K. N., & Therios, I. N. (2005). Nutritional Status, Yield, and Fruit Quality of “Encore” Mandarin Trees Grown in Two Sites of an Orchard with Different Soil Properties. *Journal of Plant Nutrition*, *27*(9), 1505–1515. https://doi.org/10.1081/PLN-200025994

Parkouda C, Diawara B, Ganou L, & Lamien N,. (2007). *Potentialit ´es nutritionnelles des produits de 16 esp`eces fruiti `eres locales au Burkina Faso. 1*, 35–47.

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour Measurement and Analysis in Fresh and Processed Foods: A Review. *Food and Bioprocess Technology*, *6*(1), 36–60. https://doi.org/10.1007/s11947-012-0867-9

Pisoschi, A. M., Danet, A. F., & Kalinowski, S. (2009). Ascorbic Acid Determination in Commercial Fruit Juice Samples by Cyclic Voltammetry. *Journal of Automated Methods and Management in Chemistry*, *2008*, 937651. https://doi.org/10.1155/2008/937651

Pohl, P. (2007). *What do netals tell us about wine*. *26*, 941–949. https://doi.org/10.1016/j.trac2007.07.005

Poole, N., Donovan, J., & Erenstein, O. (2021). Viewpoint: Agri-nutrition research: Revisiting the contribution of maize and wheat to human nutrition and health. *Food Policy*, *100*, 101976. https://doi.org/10.1016/j.foodpol.2020.101976

Rahman, A., Hossain, S., Rahman, M., Hosain, I., Uddin, B., & Khalil, I. (2013). *Syzigium cumini (L.) Seed extract improves memory related learning ability of old rats in eight arm radial maze. 1*(6), 85–94.

Ralph, J., Helmut, S., Berthold, H., & Chris S. (2005). WEST KENYA. In *Farm Management Handbook of Kenya, Natural Conditions and Farm Management Information: Vol. II* (2nd ed.).

Ranganna, S. (2001). *Hand Book of Analysis and Quality Control for Fruits and Vegetable Products.* (7th edition, pp. 594-625.). Tata McGraw Hill Book Co.

Raza, A., Ali, M., Nisar, T., Qaisrani, S., Hussain, R., & Sharif, M. (2015). *Proximate Composition of Jamun (Syzygium cumini) Fruit and Seed*. *15*(7), 1221–1223. https://doi.org/10.5829/idosi.aejaes.2015.15.7.12700

Razafimamonjison, D.E.N.G, Jahiel M., Duclos T., Ramanoelina P., & Danthu P. (2014). *Bud, leaf and stem essential oil composition of Syzygium aromaticum from Madagascar, Indonesia and Zanzibar*. *3*(3), 224–233.

Reid, M.S. (2002). *Maturation and Maturity Indices. In: Kader AA (ed) Postharvest Technology of Horticultural Crops, 3rd. Edn, Univ. Of California, Oakland, CA, USA: ANR Publication 3311, pp: 55-62*.

Reshef, N., Walbaum, N., Agam, N., & Fait, A. (2017). Sunlight Modulates Fruit Metabolic Profile and Shapes the Spatial Pattern of Compound Accumulation within the Grape Cluster. *Frontiers in Plant Science*, *8*, 70. https://doi.org/10.3389/fpls.2017.00070

Reynolds, T. W., Waddington, S. R., Anderson, C. L., Chew, A., True, Z., & Cullen, A. (2015). Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia. *Food Security*, *7*(4), 795–822. https://doi.org/10.1007/s12571-015-0478-1

Rout, G. R., and Sahoo, S. (2015). *Reviews in Agricultural Science*, 3:1-24, doi: 10.7831/ras.3.1

Rokaya, P.R., Baral, D.R., Gautam, D.M., Shrestha, A.K., & Paudyal, K.P. (2016). *Effect of Altitude and Maturity Stages on Quality Attributes of Mandarin (Citrus reticulata Blanco). 7*, 958–966. https://doi.org/doi.org/10.4236/ajps.2016.76091

Sabino LBS, Brito ES, and Silva IJ Jr. "Jabolan- Syzigium Ambolanum." *Exotic Fruits*, 2018, 251-256.

Sahlemedhin, S., & Taye, B. (2000). *Procedures for soil and plant anlysis.* National Soil Research Centre, Ethiopian Agricultural Research Organization,.

Sánchez-Moreno, C., De Pascual-Teresa, S., De Ancos, B., & Cano, M. P. (2006). Nutritional Values of Fruits. In Y. H. Hui (Ed.), *Handbook of Fruits and Fruit Processing* (pp. 29–43). Blackwell Publishing. https://doi.org/10.1002/9780470277737.ch2

Sartaj A., Tariq M., Talat M., Kashif S. A., & Amjed A. (2013). *Influence of CaCl2 on Physico-chemical, Sensory and Microbial Quality of Apricot cv. Habi at Ambient Storage*. *3*(4), 000–000.

Sartaj, A.T.M., Abbasi, K. S., Ali, A., & Hussain, A. (2015). Some compositional and biochemical attributes of jaman fruit (Syzygium cumini L.) from Potowar region of Pakistan. *Research in Pharmacy*, *3*(5).

Sato, S., Peet, M. M., & Thomas, J. F. (2000). Physiological factors limit fruit set of tomato (Lycopersicon esculentum Mill.) under chronic, mild heat stress. *Plant, Cell & Environment*, *23*(7), 719–726. https://doi.org/10.1046/j.1365-3040.2000.00589.x

Seleiman, M.F., Nasser Al-Suhaibani, Nawab Ali, M. Akmal, M. Alotaibi, Y. Refay, T. Dindaroglu, H. H. Abdul-Wajid, and M. L. Battaglia. (2021). Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. *Plants* 10(2): 259. https://doi.org/10.3390/plants10020259.

Seraglio, S. K. T., Schulz, M., Nehring, P., Betta, F. D., Valese, A. C., Daguer, H., Gonzaga, L. V., Fett, R., & Costa, A. C. O. (2018). Nutritional and bioactive potential of Myrtaceae fruits during ripening. *Food Chemistry*, *239*, 649–656. https://doi.org/10.1016/j.foodchem.2017.06.118

Serrem C.A, de Kock, H.L, & Taylor, J. (2011). Nutritional quality, sensory quality and consumer acceptability of sorghum and bread wheat biscuits fortified with defatted soy flour. *International Journal of Food Science & Technology*, *46*(1), 74–83.

Shahnawaz, M., Shahkeela. S., Hussain, M., Ahmad, M., Sher Khan, S., & Arshad, M. (2014). *Significance of physical properties of apple fruit influenced by pre harvest orchard management factors*. *4*(5), 82–89.

Shahnawaz, M., & Sheikh, S. A. (2011). *Physicochemical characteristics of Jamun fruit*. *3*(10), 301–305.

Shakil A., Mia, M. S., Shipon, T. P., Kanan, K. A., & Ahmed, M. (2021). Physicochemical properties, bioactive compounds and total antioxidant activity of Blackberry (Syzygium cumini L.) juice retained by preservatives during storage. *ResearchGate*. https://doi.org/10.1007/s11694-021-00933-7

Sharafeldin, K., & Rizvi, M. R. (2015). *Effect of traditional plant medicines (Cinnamomum zeylanicum and Syzigium cumini) on oxidative stress and insulin resistance in streptozotocin – induced diabetic rats. 72*, 126–134.

Sharma, R., Kishore, N., Hussein, A., & Lall, N. (2013). *Antibacterial and anti-inflammatory effects of Syzygium jambos L. (Alston) and isolated compounds on acne vulgaris. 13*, 292.

Shaver, T.M., Peterson, G.A., & Sherrod, L.A. (2003). *Cropping intensification in dryland systems improves soil physical properties: Regression relations. Geoderma*. *116*, 149–164.

Shilpa, K. J., Krishnakumar, G., & Yildiz, F. (2015). Nutritional, fermentation and pharmacological studies of Syzygium caryophyllatum (L.) Alston and Syzygium zeylanicum (L.) DC fruits. *Cogent Food & Agriculture*, *1*, 1018694. https://doi.org/10.1080/23311932.2015.1018694

Shiri, M. A., Ghasemnezhad, M., Fatahi ,M., J., & Ebrahimi, R. (2016). Enhancing and Maintaining Nutritional Quality and Bioactive Compounds of "Hayward" Kiwifruit: Comparison of the Effectiveness of Different CaCl2 Spraying Times. *Journal of Food Processing and Preservation*, *40*(5), 850–862. https://doi.org/10.1111/jfpp.12663

Sibandze, G. F, van Zyl, R. L., & van Vuuren, S. F. (2010). *The Anti-diarrheal Properties of Breonodia salicia, Syzygium cordatum and Ozoroa sphaerocarpa when used in Combination in Swazi Traditional Medicine. 132*(2), 506–511.

Singh, A. K. (2009). *THE JAMUN (Syzygium cuminii Skeels)*. 28.

Siriwoharn T., Wrolstad R.E., Finn C.E., & Pereira C.B. (2004). Influence of cultivar, maturity, and sampling on blackberry (Rubus L. hybrids) anthocyanins, polyphenolics, and antioxi-dant properties. *Journal of Agriculture and Food Chemistry*, *52*, 8021–8030.

Slavin, J., & Lloyd, B. (2012). *Health benefits of fruits and vegetables*. *3,* 506–516.

Snow, N., McFadden, J., Evans, T. M., Salywon, A. M., Wojciechowski, M. F., & Wilson, P. G. (2011). *Morphological and molecular evidence of polyphyly in Rhomyrtus (Myrtaceae: Myrteae)*. *36*(2), 39–404.

Soloviev P, DaoudaNiang T, Gaye A, & Totte A,. (2004). Variabilit ´e des caract`eres physico-chimiques des fruits de trois esp`eces ligneuses de cueillette r ´ecolt´es au S´en´ egal: Adansonia digitata, Balanites aegyptiaca et Tamarindus indica. *Fruits*, *59*, 109–119.

Sridevi, V., & Giridhar, P. (2013). *Influence of altitude variation on Trigonelline content during ontogeny of Coffee canephora fruit. 2*(1), 62–74.

Stadlmayr, B., Charrondiere, U. R., Eisenwagen, J. R., & Kehlenbeck, K. (2013). . *Nutrient composition of selected indigenous fruits from Sub-Saharan Africa. 93*(11), 2627–2636.

Stiletto, A., & Trestini, S. (2021). Factorsbehind consumers' choices for healthy fruits: a review of pomegranate and its food derivatives. Agricultural and Food Economics, Springer; Italian Society of Agricultural Economics (SIDEA), 9(1): 1- 27.

Sun, J., Chu, Y. F., Wu, X., & Liu, R. H. (2002). *Antioxidant and antiproliferative activities of fruits. 50*, 7449–7454.

Sunderland, T. C. H., Harrison, S. T., & Ndoye, O. (2004). *Commercialisation of non-timber forest products in Africa: History, context and prospects*. CIFOR; Center for International Forestry Research (CIFOR). https://www.cifor.org/knowledge/publication/1483/

Tadesse, S., Abebe, A., & Yohannes, T. (2012). *Natural dye – sensitized solar cells using pigments extracted from Syzigium guineense. 2*(1), 11.

Tehrani, M., Chandran, S., Hossain, A. B. M. S., & Boyce, A. N. (2011). *Postharvest physico-chemical and mechanical changes in jambu air (Syzygium aqueum Alston) fruits*. *5*(1), 32–38.kaleem et al

Tharanathan, R. N., Yashoda, H. M., & Prabha, T. N. (2006). Mango (Mangifera indica L.), "The King of Fruits"—An Overview. *Food Reviews International*, *22*(2), 95–123. https://doi.org/10.1080/87559120600574493

Tian, M., Liang, J., Liu, S., Yu, R., & Zhang, X. (2023). Effects of Watermelon Cropping Management on Soil Bacteria and Fungi Biodiversity. *Agriculture*, *13*(5), Article 5. https://doi.org/10.3390/agriculture13051010

Timilsina, K., & Tripathi, K. M. (2019). *Chemical quality attributes of mandarin (Citrus reticulata Blanco) as affected by altitude and fruit bearing position in*

Kavre, Nepal. *4*(3), 319–325. https://dx.doi.org/10.26832/24566632.2019.0403010

Tryphone, G.M. & Nchimbi-Msolla, S. 2010 Diversity of common bean (*Phaseolus vulgaris* L.) genotypes in iron and zinc contents under screenhouse conditions *Afr. J. Agr. Res.* 5 8 738 747

Tufuor, J.K., Bentum, J.K., Essumang, D.K., & Koranteng-Addo, J.E. (2011). *Analysis of heavy metals in citrus juice from the Abura-Asebu-Kwamankese District, Ghana*. *3*(2), 397–402.

Tyl, C., & Sadler, G. D. (2017). pH and Titratable Acidity. In S. S. Nielsen (Ed.), *Food Analysis* (pp. 389–406). Springer International Publishing. https://doi.org/10.1007/978-3-319-45776-5_22

U.S. EPA. (2007). *Element C. Method 3015A (SW - 846): Microwave Assisted Acid Digestion of Aqueous Samples and Extracts.*

USDA. (2004). *National Nutrient Database for Standard Reference,*.

USFDA. (2013). *United States Food and Drug Administration; 2013. Supporting Document for Action Level for Arsenic in Apple Juice.* http://www.fda.gov/downloads/Food/GuidanceRegulation/GuidanceDocuments RegulatoryInformation/UCM493580.pdf). Link valid on June 8 2016.

Van Wyk, B. E., & Nigel, G. (2000). *People's plants. A guide to useful plants of southern Africa.* (p. 352). Briza publications,.

Velmurugan, A. V., & Swarnam, P. (2017). Nutrient Uptake and Residual Effect of Organics Applied to Vegetable-Rice System in an Acid Soil. *Journal of Plant Nutrition*, *40*, 00–00. https://doi.org/10.1080/01904167.2016.1236944

Verdcourt, B. (2001). Myrtacea. In: Beentje, H. J. (ed.). In *Flora of Tropical East Africa* (p. 89). A. A. Balkema.

Vianna-Silva, T., Resende, E. D., Viana, A. P., Pereira, S. M. F., Carlos, L. A., & Vitorazi, L. (2008). Qualidade do suco de maracujá-amarelo em diferentes épocas de colheita. *Ciência e Tecnologia de Alimentos*, *28*(3), 545–550. https://doi.org/10.1590/S0101-20612008000300007

Walter, K., Don, A., Tiemeyer, B., & , Freibauer, A. (2016). *(2016). Determining soil bulk density for carbon stock calculations: A systematic method comparison. 80*, 579–591.

Wang, S. P., Wang, Y. F., Hu, Z. Y., Chen, Z. Z., Fleckenstein, J., & Schnug, E. (2003). Status of Iron, Manganese, Copper, and Zinc of Soils and Plants and Their Requirement for Ruminants in Inner Mongolia Steppes of China. *Communications in Soil Science and Plant Analysis*, *34*(5–6), 655–670. https://doi.org/10.1081/CSS-120018966

Watkins, C.B. (2003). Ethylene synthesis, mode of action, consequences and control. In: Knee, M. (Ed),. In *Fruit Quality and its biological basis.* (pp. 180–224). Academic press,.

Watson, R., Wright, C. J., McBurney, T., Taylor, A. J., & Linforth, R. S. T. (2002). *Influence of harvest date and light integral on the development of strawberry flavor compounds. 53*(377), 2121–2129.

Wojcik, P., & Wojcik, M. (2001). Growth and nutrition of M. 26 EMLA apple rootstock as influenced by titanium fertilization. *Journal of Plant Nutrition*, *24*(10), 1575–1588.

Ying, J., Guolin, W., Donghui, Z., Zhuqun, H., Zhenxuan, Q., & Biyan, Z. (2019). *Effects of Shading on Carbohydrates of Syzygium samarangense*. *47*(4), 1252–1257. https://doi.org/10.15835/nbha47411637

Zhang, B., Cakmak, I., Feng, J., Yu, C., Chen, X., Xie, D., Wu, L., Song, Z., Cao, J., & He, Y. (2020). Magnesium Deficiency Reduced the Yield and Seed Germination in Wax Gourd by Affecting the Carbohydrate Translocation. *Frontiers in Plant Science*, *11*, 797. https://doi.org/10.3389/fpls.2020.00797

Zhang, H., Chang, M., Wang, J., & Ye, S. (2008). Evaluation of peachquality indices using an electronic nose by MLR, QPST and BPnetwork. *Sensors and Actuators B: Chemical*, *134*(1), 332–338.

APPENDICES

Appendix 1: Physical and Chemical Properties of *Syzygium cuminii* Fruits from Bungoma County

Sample/tree no.	Weight (g)	Length (mm)	Breadth (mm)	Color (L*a*b*) Color intensity(C*)	% Moisture content	% Ash content	PH at 25ºC	TSS (ºBrix at 25ºC)	% Titratable acidity
1	3.23±0.14	24.8±0.15	14.54±1.1	32.66, 60.14, -20.67 C* = 63.59	85.62±1.33	1.25±0.0	3.45 ±0.0	13±0.58	0.79±0.01
2	4.32±1.19	25.83±0.77	13.42±0.63	32.44, 87.7, -22.01 C* = 90.42	86.23±0.61	1.58±0.0	3.52 ±0.0	14.2±0.08	0.68±0.01
3	4.15±1.39	21.23±2.19	14.26±0.89	32.22, 98.23, -35.31 C* = 104.38	86.1±1.83	1.16±0.01	3.47 ±0.0	13±0.4	0.79±0.01
4	4.79±1.13	21.86±2.57	13.43±0.06	32.31, 92.78, -35.98 C* = 99.51	87.5±1.04	2.03±0.01	3.54 ±0.0	15.2 ±0.11	0.64±0.02
5	3.51±1.44	23.52±1	14.73±0.55	31.22, 82.45, -23.05 C* = 85.61	85.76±1.1	1.43±0.01	3.45 ±0.0	13±0.58	0.79±0.01
6	5.95±0.32	27.69±2.58	17.73±1.01	33.14, 87.79, -22.26 C* = 90.57	89.55±0.15	2.74±0.02	3.75 ±0.0	20.9 ±0.04	0.51±0.01
7	4.95±2.14	22.25±0.77	14.34±0.93	33.15, 90.11, -22.23 C* = 92.81	87.7±1.46	2.16±0.0	3.54 ±0.0	15.08±0.02	0.64±0.0

8	5.91±0.48	26.75±1.25	16.11±0.25	33.15, 90.1, -31.89 C* = 95.58	89.23±1.19	2.73±0.02	3.73 ±0.0	20.8 ±0.1	0.51±0.01
9	5.29±1.01	25.57±1.2	16.25±0.48	33.33, 90.13, -31.89 C* = 95.60	88.07±0.39	2.55±0.0	3.59 ±0.0	17.16±0.03	0.53±0.02
10	4.62±0.20	23.63±1.07	14.09±0.73	33.38, 93.67, -34.46 C* = 99.81	87.03±0.33	1.93±0.01	3.54 ±0.0	14.9 ±0.08	0.64±0.01
11	4.98±0.16	29.18±0.75	17.65±0.95	33.21, 99.12, -34.46 C* = 104.94	87.91±0.33	2.22±0.01	3.56 ±0.0	16±0.05	0.57±0.01
12	4.8±1.19	26.47±1.11	15.73±1.19	33.25, 98.42, -34.86 C* = 104.41	87.67±.48	2.15±0.01	3.54 ±0.0	14.7 ±0.07	0.64±0.01
13	3.04±2.84	26.96±2.47	16.44±1.38	30.01, 94.67, 35.4 C* = 101.07	85.31±0.21	1.23±0.01	3.44 ±0.0	12.7 ±0.4	0.85±0.01
14	2.5±0.07	26.18±2.55	15.35±0.8	34.64, 61.18, -21.2 C* = 64.65	82.02±0.28	0.24±0.01	3.35 ±0.0	11.22±0.01	1.06±0.02
15	4.96±1.61	24.04±2.79	15.43±1.99	34.71, 69.67, -21.2 C* = 72.82	85.8±0.81	1.49±0.0	3.56 ±0.0	15.87±0.01	0.59±0.01
16	2.74±0.19	25.45±1.86	15.57±1.15	34, 34, -31.82 C* = 46.57	83.15±0.84	0.91±0.02	3.37 ±0.0	11.49±0.02	0.98±0.01
17	2.86±0.23	24.27±2.84	15.99±0.65	34.17, 34.17, -31.74 C* = 46.64	84.78±0.3	1.15±0.01	3.43 ±0.0	12.4 ±0.0	0.89±0.01

18	4.14±1.39	27.98±1.94	16.91±0.14	34.41, 82.39, -33.2 C*= 88.83	86.16±0.23	1.17±0.01	3.52 ±0.0	14±0.04	0.7±0.01
19	4.8± 1.55	24.78±1.1	16.0±1.07	34.49, 94.28, 34.9 C* = 100.53	87.65±0.34	2.14±0.02	3.54 ±0.0	14.7 ±0.18	0.65±0.01
20	4.71±1.41	25.56±1.76	16.26±1.31	34.42, 94.62, -35.6 C* = 101.09	87.38±0.78	2.02±0.02	3.54 ±0.0	14.31±0.06	0.67±0.01
21	5.61±0.62	25.98±3.42	16.17±1.19	32.69, 88.21, -20.81 C* = 90.63	88.88±0.09	2.72±0.03	3.71 ±0.0	19.98±0.07	0.52±0.02
22	4.32±1.18	25.03±2.89	15.34±1.4	34.98, 99.79, -34.99 C* = 105.75	86.83±0.87	1.73±0.03	3.53 ±0.0	14.2 ±0.08	0.68±0.01
23	2.78±0.18	24.84± 3.71	16±1.73	31.01, 99.11, -34 C* = 100.06	83.26±0.99	1.05±0.04	3.39 ±0.0	11.83±0.15	0.9±0.01
24	2.52±0.18	24.22±3.59	15.93±2.02	31.16,94.12, -35.2 C* = 100.49	82.86±0.98	0.24±0.04	3.36 ±0.0	11.28±0.04	1.04±0.02
25	2.95±0.39	23.55±3.29	16.12±2.19	31.6, 60.89, -34.17 C* = 69.82	84.1 ±0.1	1.12±0.03	3.4±0.0	11.75±0.14	0.9±0.01
26	2.92±0.13	27.91±3.42	15.61±1.96	31.89,62.33, -34.68 C* = 71.32	84.08±0.12	1.08±0.03	3.4±0.0	11.62±0.16	0.91±0.01
27	3.03±0.01	27.49±3.33	15.33±1.82	33.16, 61.39, -34.1 C* = 70.53	84.71±0.28	1.15±0.04	3.41 ±0.0	12.27±0.06	0.89±0.02

28	5.6± 0.13	27.07±3.38	15.45±2.01	32.76, 56.01,-33.28 C* = 65.15	88.77±0.56	2.71±0.02	3.68 ±0.0	17.6 ±0.2	0.52±0.02
29	4.55±0.99	25.02±2.91	15.2±1.44	32.48, 65.01, -33.94 C* = 73.34	86.72±0.85	1.69±0.03	3.52 ±0.0	13.9 ±0.06	0.71±0.01
30	4.98±1.12	25.13±0.78	17.61±0.94	32.65, 72.11, -34.94 C* = 80.13	87.81±0.30	2.22±0.03	3.55 ±0.0	15.3 ±0.04	0.63±0.01
31	2.22±0.03	28.55±2	16.5±0.66	31.46, 68.04, -33.11 C* = 75.69	80.64±0.46	0.19±0.04	3.28 ±0.0	10.7 ±0.04	1.09±0.01
32	2.22±0.02	28.9±3.13	16.96±0.54	31.52, 67.49, -33.23 C* = 75.29	81.24±0.39	0.18±0.02	3.31 ±0.0	11.1 ±0.01	1.07±0.01
33	4.14±1.28	23.94±0.41	14.88±0.76	31.66, 68.54, -33.37 C* = 76.23	83.15±0.66	0.92±0.03	3.49 ±0.0	13.42±0.01	0.78±0.01
34	4.38±0.98	25.15±0.77	15.48±0.30	31.72, 69.62, -33.44 C* = 77.23	86.29±0.22	1.61±0.03	3.52 ±0.0	13.5 ±0.2	0.74±0.0
35	3.11±0.13	20.63±1.94	13.82±1.18	32.08, 70.77, -33.48 C* = 78.29	85.4±0.7	1.21±0.04	3.45 ±0.0	12.6 ±0.04	0.85±0.01
36	2.97±0.40	25.93±2.50	15.6±0.31	33.11, 80.64, -33.52 C* = 87.33	85.3±0.5	1.17±0.02	3.44 ±0.0	12.43±0.01	0.86±0.01
37	5.38±0.97	23.88±0.83	15.38±1.27	34.26, 81.76, -33.57 C* = 88.38	88.49±0.37	2.58±0.03	3.6 ±0.0	16.83 ±0.1	0.53±0.02

38	5.19±1.07	26.83±1.45	14.97±0.86	31.11, 81.76, -33.62 C* = 88.38	87.93±0.41	2.23±0.03	3.57 ±0.0	16.4 ±0.0	0.55±0.03
39	5.42±1.62	24.61±1.19	16±0.74	32.99, 82.48, -33.76 C* = 89.12	88.61±0.12	2.63±0.04	3.64 ±0.0	17.4 ±0.01	0.52±0.01
40	2.97±0.51	26.42±2.14	16.13±0.66	33.22, 89.66, -34.88 C* = 96.2	84.64±0.64	1.13±0.04	3.41 ±0.0	12.2 ±0.0	0.89±0.0

Values reported as means of triplicates ± standard error

Appendix 2: Physical and Chemical properties of *Syzygium cuminii* Fruits from Kwale County

Sample	Weight (g)	Length (mm)	Breadth (mm)	Color (L* a* b*) Intensity (C*)	% Moisture content	% Ash content (DW)	PH at 25°C	TSS /°Brix at 23°C	Titratable acidity
1	4.43±0.36	25.74±2.1	15.41±0.38	34.98, 99.79, -34.99 C* = 105.75	84.81±0.2	2.62±0.0	3.26 ± 0.04	17±0.73	0.67±0.01
2	3.32±0.04	25.56±1.69	15.4±1.03	33.21, 99.12, -34.93 C* =105.09	84.22±0.47	2.26±0.0	3.07± 0.11	12.57± 0.07	0.88±0.01
3	6.87±1.41	30.31±2.86	19.67±0.9	30.18, 79.97, -39.2 C* =89.06	84.46±0.54	3.39±01	3.39± 0.01	19.4± 0.29	0.62±0.02
4	4.5±0.71	30.3±1.9	19.35±1.08	30.18, 79.97, -39.2 C* =89.06	86.13±0.02	2.86±0.01	3.14± 0.0	13±0.53	0.79±0.02
5	4.47±0.04	31.54±3.72	19.45±0.96	28.63, 70.77, -40.95 C* =81.76	85.61±1.09	2.65±0.0	3.22± 0.0	16.5± 0.32	0.68±0.01
6	3.56±0.18	29.99±2.95	19.19±1	24.86, 66.77, -43.23 C* =79.54	86.99±0.51	3.27±0.01	3.2± 0.0	15.71± 0.62	0.68±0.02
7	7.41±1.24	28.93±2.87	15.49±0.99	25.06, 60.44, -43.23 C* =74.31	87.82±0.29	3.57±0.0	3.34± 0.01	15.7± 0.02	0.62±0.0
8	4.38±0.65	22.32±1.09	14.95±1.22	25.01, 80.11, -41.97 C* =90.44	87.74±0.19	2.34±0.0	3.09± 0.01	13±1.04	0.86±0.01

9	4.5±0.89	22.78±1.33	16.53±0.49	34.45, 83.11, -43.63 C* =93.87	86.09±0.06	2.65±0.01	3.19± 0.02	14.9± 0.02	0.69±0.02
10	5.18±1.22	21.58±0.65	18.55±1.69	33.28, 72.14, -33.63 C* =79.59	86.6±0.01	3.14±0.02	3.11± 0.01	13.1± 0.13	0.81±0.01
11	4.97±1.91	23.27±1.29	16.75±0.5	32.88, 63.14, -37.96 C* =73.67	87.36±0.54	3.14±0.01	3.17± 0.0	14.39± 0.22	0.73±0.01
12	5.6±1.91	26.91±3.31	17.1±0.96	37.78, 66.14, -27.95 C* =71.8	87± 0.01	3.27±0.03	3.2± 0.01	14.5± 0.29	0.69±0.02
13	5.19±0.01	22.32±1.09	14.95±1.22	41.83, 52.31, -41.94 C* =67.05	86.73±0.01	3.14±0.0	3.16± 0.01	13.85± 0.06	0.77±0.02
14	7.25±1.49	33.36±0.01	21.02±0.03	42.48, 43.94, -14.7 C* =46.33	88.03±0.01	3.39±0.02	3.29± 0.01	18.7± 0.03	0.63±0.01
15	8.07±1.72	29.51±0.01	17±0.01	42.39, 36.94, -18.99 C* =41.53	85.61±1.27	3.58±0.01	3.48± 0.02	23.43± 0.03	0.56±0.01
16	4.43±0.61	24.17±0.07	16.27±0.08	36.84, 86.88, -16.99 C* =88.53	82.65±0.02	2.6±0.01	2.98± 0.01	11.9± 0.03	0.97±0.02
17	2.89±0.07	33.5±0.01	18.95±0.03	34.18, 60.94, -24.03 C* =65.51	81.5±0.02	1.24±0.01	2.89± 0.02	11.2± 0.03	1.06±0.0
18	3.29±0.0	23.57±0.04	17.13±0.08	32.69, 88.21, -20.81 C* =90.63	84.12±0.36	2.26±0.01	3.04± 0.04	11.87± 0.03	0.97±0.02
19	3.09±0.05	30.31±1.92	19.67±0.9	36.79, 78.25, -17.13 C* =80.1	82.37±0.24	2.21±0.01	2.94± 0.02	11.63± 0.01	0.99±0.0

20	3.09±0.04	28.99±2.95	19.19±1	36.79, 88.25, -46.91 C* =99.94	85.61±1.27	2.16±0.0	2.92± 0.01	11.33± 0.01	1.02±0.02
21	4.47±0.53	23.63±0.3	15.12±0.46	24.11, 99.06,-34.19 C* =104.83	84.15±0.09	2.26±0.01	3.05± 0.01	12.1± 0.02	0.95±0.01
22	2.89±0.89	23.56±0.24	15.62±0.57	25.95, 89.13,-34.29 C* = 95.5	87.84±0.11	3.39±0.01	3.29± 0.01	18.7± 0.01	0.63±0.01
23	4.48±0.64	24.52±1.11	15.5±0.61	26.77, 89.28, -34.33 C* = 95.65	84.46±0.38	2.26± 0.0	3.09± 0.01	12.7± 0.03	0.86±0.01
24	3.23±0.04	23.08 ±0.2	16.33±0.47	27.27, 89.31, -34.42 C* = 95.71	86.85±0.44	2.65±0.01	3.21± 0.01	15.7± 0.01	0.68±0.01
25	3.23±0.03	24.89±0.96	14.58±0.61	28.11, 88.67, -35.82 C* = 95.63	86.29±0.13	3.12±0.01	3.11± 0.0	13±0.58	0.85±0.02
26	4.22±0.71	23.38±0.38	15.75±0.55	29.28, 88.76, -35.99 C* = 95.77	83.78±0.18	2.3± 0.0	3±0.0	11.86± 0.2	0.97±0.02
27	3.23±0.55	23.38 ±0.9	15.74±0.55	30.68, 87.22, -36.16 C* = 94.42	83.91±0.21	2.21±0.01	3.03± 0.01	11.7± 0.02	0.97±0.0
28	2.83±1.11	29.7±0.03	14.25±0.01	31.22, 87.36, -36.73 C* = 94.77	88.34±0.07	3.58 ±0.0	3.47± 0.01	20.12± 0.02	0.58±0.02
29	2.95±0.01	24.16±0.95	13.99±0.02	32.07, 86, -37.01 C* = 93.62	87.74±0.13	3.27±0.02	3.29± 0.0	18.56± 0.07	0.63±0.03
30	3.08±0.52	19.58±1.18	12.94±0.22	33.29, 86.48, -37.33 C* = 94.19	87.82±0.27	3.38±0.01	3.29± 0.01	18.2± 0.06	0.63±0.01

31	5.6±0.02	24.47±2.93	14.77±1.27	34.94, 85.26, -38.22 C* = 93.43	83.45±1.27	2.21 ±0.0	2.99± 0.04	18.53± 0.02	0.97±0.01
32	5.6±0.05	25.13±3.11	14.89±1.17	35.93, 85.63, -38.42 C* = 93.85	81.86±1.96	2.11± 0.0	2.9± 0.0	11.31± 0.08	1.02±0.01
33	4.97±0.14	24.86±3.55	13.63±1.66	36.55, 84.18, -39.02 C* = 92.78	78.74±0.54	1.22±0.01	2.9± 0.0	11.3± 0.25	1.04±0.01
34	8.0 ±1.78	23.67±0.26	15.23±1.25	37.88, 84.36, -39.13 C* = 92.99	88.19±0.10	3.57±0.01	3.4± 0.01	19.6± 0.15	0.61±0.03
35	5.6±1.63	23.23±0.26	15.36±0.60	38.91, 83.57, -40.03 C* = 92.66	87.58±0.17	3.37 ±0.0	3.27± 0.0	17.27± 0.48	0.65±0.01
36	3.39±1.27	24.1±1.4	15.13±0.57	39.44, 83.73, -40.47 C* = 93	87.11±0.33	3.27 ±0.0	3.22± 0.01	14.94± 0.11	0.68±0.03
37	6.15±0.85	22.9 ±0.24	16.07±0.51	40.11, 82.39, -41.26 C* = 92.14	85.29±0.0	2.6 ±0.01	3.26± 0.0	17±0.04	0.67±0.0
38	3.36±1.04	24.89±0.91	14.6 ±0.53	41.21, 82.66, -41.98 C* = 92.71	85.61±0.12	2.63±0.02	3.23± 0.01	16.55± 0.02	0.67±0.02
39	3.25±0.81	23.28±0.45	15.93±0.55	42.74, 76.23, -42.76 C* = 87.4	81.5±0.012	2.3 ±0.0	3.28± 0.0	18.06± 0.26	0.64±0.03
40	5.47±0.63	19.44±1.24	12.17±0.16	34.19, 80.93, -42.85 C* = 91.57	82.5± 0.5	2.21±0.01	2.94± 0.0	11.5± 0.11	1.0±0.29

DW: Dry weight; results reported as means± standard error of triplicate samples

Appendix 3: Nutritional Compositions of *S. Cuminii* fruits from Bungoma County

Sample/ tree no.	(Mg/100g) Carbohydrates	Proteins	Crude fibre	Crude fat	Vitamin C content	Energy (Kcal/100g)
1	16.52±0.0	0.97±0.16	1.31±0.07	0.36±0.03	74.66±0.02	321.53±55.21
2	20.13±0.16	1.47±0.12	0.65±0.02	0.52±0.08	74.66±0.06	348.89±54.47
3	15.93±0.02	1.29±0.25	0.66±0.02	0.33±0.08	76.32±0.02	317.97±50.49
4	23.13±0.01	1.7±0.22	0.56±0.03	0.65±0.08	198±1.15	362.7±50.22
5	6.35±0.0	1.04±0.22	0.93±0.03	0.34±0.07	76.36±0.01	319.04±44.03
6	36.1±0.06	2.96±0.21	0.22±0.03	0.85±0.07	759.47±0.27	387.31±41.34
7	22.94±0.05	1.92±0.21	0.52±0.05	0.64±0.01	498.14±0.01	361.6±40.65
8	31±0.9	2.56±0.2	0.26±0.03	0.84±0.06	802.09±0.02	386.57±39.56
9	25.58±0.34	2.09±0.19	0.35±0.04	0.7±0.06	673.73±0.04	373.44±33.18
10	22.41±0.26	1.57±0.16	0.58±0.04	0.64±0.01	212.36±0.01	360.59±32.48
11	23.96±0.04	1.97±0.14	0.47±0.07	0.68±0.04	530.71±0.01	365.28±31.99
12	21.36±0.23	1.96±0.12	0.54±0.05	0.63±006	196.07 0.01	356.43±30.6
13	15.56±0.05	0.81±0.16	1.57±0.05	0.31±0.04	88.64±0.02	313.95±29.5
14	11.47±0.11	0.45±0.18	1.9±0.04	0.16±0.05	19.81±0.03	261.37±28.49
15	23.66±0.07	1.94±0.17	0.47±0.06	0.67±0.02	529.94±0.01	364.58±24.33
16	12.58±0.42	0.56±0.13	1.85±0.08	0.19±0.06	38.42±0.08	277.44±23.17
17	14.91±0.02	0.71±0.15	1.62±0.08	0.27±0.01	57.36±0.27	306.53±22.88
18	19.38±0.0	1.25±0.14	0.66±0.06	0.42±0.02	76.64±0.1	339.07±16.79

19	21.35±0.02	1.88±0.14	0.53±0.06	0.6±0.04	166.1±0.1	355.27±10.81
20	20.87±0.01	1.63±0.13	0.58±0.02	0.61±0.04	88.64±0.01	354.98±6.97
21	30±0.06	2.47±0.11	0.27±0.06	0.83±0.1	760.82±0.16	382.59±5.88
22	19.89±0.11	1.31±0.12	0.92±0.06	0.42±0.03	164.31±0.0	342.91±4.77
23	13.5±0.05	0.62±0.11	1.81±0.06	0.2±0.71	47.8±0.11	276.15±9.17
24	12.02±0.12	0.53±0.11	1.89±0.3	0.18±0.04	20.5±0.29	288.55±10.57
25	13.57±0.14	0.65±0.1	1.76±0.03	0.19±0.03	45.73±0.04	292.22±13.06
26	13.9±0.3	0.63±0.09	1.78±0.03	0.21±0.03	45.22±0.13	303.88±14.13
27	14.23±0.32	0.68±0.03	1.71±0.04	0.25±0.11	50.22±0.12	382.32±18.15
28	27.58±0.14	2.21±0.1	0.31±0.06	0.8±0.13	759.42±0.2	337.98±18.31
29	14.44±0.23	1.46±0.07	0.6±0.01	0.41±0.1	76.5±0.29	364.09±23.94
30	23.40±0.11	1.96 ±0.06	0.46±0.02	0.66±0.08	525.05±0.04	234.06±25.57
31	10±0.97	0.34±0.08	1.93±0.07	0.1±0.74	17.99±0.01	259.22±28.22
32	10.98±0.27	0.33±0.06	1.91±0.05	0.15±0.08	18.47±0.01	322.94±34.68
33	17.23±.75	1.18±0.05	0.66±0.06	0.37±0.08	76.44±0.02	327.33±36.72
34	17.99±0.24	1.33±0.06	0.62±0.07	0.39±0.09	76.48±0.04	313.79±39.88
35	15.41±0.02	0.93±0.02	1.39±0.8	0.3±0.05	77.86±0.02	308.16±43.55
36	15.17±0.11	0.79±0.05	1.61±0.05	0.29±0.05	60.46±0.2	308.16±34.55
37	25.4±0.03	2.15±0.03	0.35±0.08	0.71±0.08	550.67±0.0	372.75±29.95
38	24.66±0.33	2±0.04	0.39±0.04	0.69±0.05	531.72 0.16	371.66±20.73
39	25.99±0.56	2.16±±0.03	0.32±0.01	0.81±0.05	674.68±0.01	376.13±12.88
40	14±0.44	0.66±0.3	1.75±0.03	0.23±0.04	53.78±0.06	297.42±18.04

Appendix 4: Mineral Composition of *S. cuminii* fruits from Bungoma County

	Concentration (mg/kg sample)								
Sample/ tree no.	Na	P	Ca	Mg	Mn	Fe		Cu	Zn
1	127.2±0.03	857.71±48.2	17±2.4	11.3±0	380.15±0.08	36.27±0.02	41.43±0.01	14.82±0.16	4.09±1.67
2	98.01±0.07	1531.36±19.1	18.71±2.2	13.36±0	469.43±0.07	44.09±0.6	61.06±0.03	17.5±0.01	6.32±0.09
3	127.22±0.03	839.86±50.1	17±1.9	11.6±0	379.05±0.03	36.07±0.02	39.76±0.02	13.58±0.02	4.88±0.41
4	66.11±0.0	1788.63±44.8	21.3±1.8	17.72±8.35	673.35±0.03	66.4±0.23	76.4±0.01	21.09±0.01	8.22±0.02
5	126.69±0.07	788.74±55.1	16.8±1.5	10.64±7.96	375.41±0.02	36.67±0.05	46.22±0.03	15±0.29	5.06±2.06
6	28.73±0.02	2836.25±14.96	45.35±1.4	68±7.32	1641.4±0.05	179.15±0.6	151.81±0.2	33.34±0.16	18.85±0.0
7	71.59±0.0	1727.68±38.7	21.26±1.4	16.74±7.12	647.6±0.23	66.29±0.0	68.72±0.05	21.61±0.1	8.27±0.03
8	26.69±0.01	2718.4±13.78	43.26±0.8	63.75±6.68	1400.92±1.22	176.02±0.01	141.71±0.11	32.27±0.02	18.15±0.01
9	54.67±0.01	2528.09±11.87	35.29±3.1	22.84±3.81	933.39±0.14	92.85±0.08	98.73±0.04	25.46±0.02	13.7±5.59
10	71.59±0.04	1713.23±37.3	21.1±2.3	15.24±2.83	627.39±0.18	54.3±0.6	68.01±0.05	24.69±0.01	7.87±0.01
11	64.19±0.0	1879.48±53.9	24.42±0.28	19.33±2.21	803.78±0.17	84.83±0.14	84.93±0.04	19.41±0.02	10.5±0.06
12	74.55±0.26	1699±35.8	20.25±0.08	15.14±2.2	604.29±0.17	54.21±0.02	66.51±0.05	13.39±0.07	7.51±0.04
13	133.63±0.21	778.94±56.1	16.2±0.04	9.26±1.22	372.29±0.0	35.13±0.07	36.22±0.04	16.74±0.03	4.24±0.03
14	211.19±0.01	479.31±86.08	11.7±0.12	5.47±0.23	175.76±0.17	43.05±0.03	57.81±0.0	24.51±0.02	6.31±0.0
15	65.01±0.02	1845.52±50.5	23.57±0.97	18.35±0.37	714.91±0.12	84.69±0.02	83.24±0.03	10.85±0.09	9.15±0.0

16	177.76±0.02	487.63±85.2	14.53±1.5	5.88±0.49	233.24±0.02	28.05±0.03	12.39±0.09	11.18±0.01	3.17±0.0
17	154.83±0.04	591.06±74.9	15.73±2.0	8.23±0.62	353.01±0.0	32.27±0.05	32.66±0.03	16.62±0.03	3.48±0.02
18	121.07±0.04	1137.44±20.2	18.5±2.5	12.87±2.1	412.86±0.08	42.78±0.17	54.52±0.14	18±0.57	5.96±0.02
19	85.71±0.23	1698.76±35.8	19.68±2.6	15.02±2.4	568.04±0.04	44.7±0.17	66.49±0.02	8.12±0.08	6.62±0.2
20	89.73±0.24	1669.69±32.9	19.22±2.7	14.89±2.64	523.44±0.01	15.32±0.04	10.99±0.0	31.36±0.23	1.12±0.01
21	36.4±0.06	2633.11±12.93	40.32±0.3	27.22±2.85	1380.31±0.02	108.85±0.02	121.65±0.03	18.97±0.22	18.04±0.02
22	109.31±0.18	1400.07±59.6	18.57±0.33	13.11±3.4	422.86±0.18	46.24±0.58	66.49±0.08	10.2±0.05	7.08±0.01
23	168.45±0.03	516.67±82.34	12.15±0.37	5.67±0.36	302.56±0.26	29.94±0.03	26.13±0.08	8.15±0.0	1.42±0.02
24	179.72±0.16	487.08±85.3	14.62±0.42	5.94±0.42	185.59±0.09	27.38±0.01	12.49±0.0	9.78±0.02	1.23±0.0
25	170.23±0.02	495.68±84.4	12.2±0.42	5.76±0.39	283.58±0.26	28.66±0.02	14.21±0.02	9.66±0.05	1.39±0.56
26	175.81±0.01	514.36±82.3	13.4±0.44	5.79±0.48	233.07±0.04	28.11±0.58	14.12±0.02	10.53±0.28	1.24±0.0
27	156.34±0.02	562.74±77.7	16.01±0.5	8.28±0.62	349.22±0.02	32.05±0.03	29.39±0.04	29.21±0.09	2.72±0.01
28	45.56±0.02	2544.53±12.04	39.14±0.52	23.57±7.81	1320.93±1.15	97.73±0.16	120±0.6	16.21±0.05	16.7±0.17
29	121.1±0.07	939.67±40.31	18.45±0.55	12.66±7.42	410.94±0.04	40.38±0.01	51.1±0.06	22.63±0.04	5.77±0.02

30	65.01±0.02	1821.12±48.1	21.50±0.55	17.73±7.28	700.6±0.4	67.05±0.58	81.48±0.01	4.41±0.03	8.29±0.0
31	222.49±0.0	450.73±88.9	10.87±0.50	1.63±0.72	155.92±0.05	10.06±0.02	8.62±0.04	5.02±0.03	0.38±0.05
32	221.3±0.06	472.71±86.7	11.6±0.66	3±0.9	165.74±0.15	10.84±0.03	10.98±0.01	15.87±0.4	1.04±0.02
33	121.5±	892.9±44.7	17.54±0.67	11.93±0.9	387.52±0.03	38.1±0.06	48.95±0.06	15.95±0.03	5.3±0.0
34	121.16±0.02	924.7±41.5	17.9±0.78	12.11±0.72	388.7±0.17	40.24±0.01	52.26±0.02	13.38±0.09	5.49±0.01
35	140±0.88	701.03±63.7	15.6±0.9	7.7±0.68	370.91±0.05	33.06±0.02	36.04±0.02	12.03±0.08	4.09±0.0
36	140±0.06	672.44±66.5	15.7±0.9	8.09±0.89	363.17±0.02	33±0.02	35.65±0.02	25.03±0.02	3.66±0.02
37	59.19±0.01	2470.19±11.3	35.02±0.94	22.64±0.79	877.7±0.06	86.02±0.01	92.5±0.3	24.92±0.04	11.82±0.02
38	59.36±0.02	2429.88±10.89	29.07±0.95	22.2±0.59	800.17±0.02	85.93±0.04	88.63±0.04	28.66±0.02	10.66±0.02
39	47.12±0.01	2528.51±11.88	36.5±0.96	23.48±0.39	1250.38±0.01	94.03±0.1	105.52±0.01	28.66±0.01	15.93±0.03
40	166.26±0.02	549.22±79.12	11.8±0.1	5.59±0.57	323.75±0.03	31.98±0.01	27.53±0.03	10.21±0.02	2.51±0.0

Cr, Cd were not detected by the ICP OES, Their Limit of detection (LOD for Cr = 0.01mg/L)

Appendix 5: Nutritional Composition of *S. cuminii* fruits from Kwale County

Sample/tree no.	**(Mg/100g)**					**Energy (Kcal/100g)**
	Carbohydrates	**Proteins**	**Crude fibre**	**Crude fat**	**Vitamin C content**	
1	23.83±2.3	3.34	0.66	0.69±0.38	529.58±035	365.63±5.3
2	15.38±1.5	3.01	1.62	0.32±0.09	95.53±0.0	317.82±5.18
3	28.61±2.6	2.58	0.33	0.83±0.08	940.42±0.21	382.56±5.04
4	17.65±1.8	2.56	0.59	0.41±0.03	134.35±0.02	327.94±4.83
5	22.42±2.2	2.44	0.64	0.66±0.05	255.16±0.03	357.32±4.31
6	21.96±2.1	2.31	0.95	0.65±0.08	252.14±0.08	357.33±3.93
7	21.53±2.1	2.31	0.29	0.62±0.04	498.66±0.56	354.98±4.26
8	16.88±1.6	2.27	0.69	0.37±0.04	114.67±0.02	324.14±3.84
9	20.33±2	2.25	0.61	0.47±0.02	218.8±011	343.97±3.36
10	17.49±1.4	2.21	0.55	0.39±0.01	126.88±0.6	323.39±0.26
11	18.56±1.1	2.19	0.57	0.43±0.07	164.31±0.02	337.99±3.1
12	19.43±1.9	2.11	0.39	0.45±0.07	166.1±0.02	347.12±3.14
13	18.37±1.2	2.08	0.41	0.42±0.06	136.5±0.03	331.33±2.73
14	25.55±2.5	1.94	0.54	0.79±0.06	902.21±0.32	373.57±2.74
15	38.2±1.8	1.78	0.32	0.87±0.07	965.24±0.15	387.56±2.31
16	15.21±1.5	1.72	0.67	0.28±0.05	87.8±0.06	309.68±2.32
17	10.97±1	1.63	1.94	0.13±0.02	76.24±0.0	235.15±2.07
18	14.85±1.3	1.58	1.64	0.24±0.05	85.92±0.02	310.78±1.47
19	14.17±1.4	1.55	1.83	0.21±0.04	76.64±0.0	288.55±9.73

20	12.69±1.2	1.52	1.83	0.2±0.04	75.58±0.01	277.15±1.29
21	15.23±1.2	1.51	1.83	0.31±0.02	88.64±0.03	315.37±3.75
22	26.02±2.5	1.33	1.84	0.85±0.01	895.61±0.01	377.33±0
23	16.61±1.6	1.32	0.64	0.35±0.03	97.24±0.01	316.98±6.3
24	14.37±0.9	1.26	1.94	0.22±0.3	230.34±0.01	295.42±0
25	16.87±1.8	1.16	0.63	0.36±0.06	120.81±0.05	317.97±1.01
26	14.66±1.7	1.06	0.22	0.23±0.03	82.2±0.01	299.55±1.63
27	14.63±1.5	1.02	1.73	0.22±0.03	82.13±0.01	297.48±1.73
28	31.5±3.1	0.91	1.97	0.86±0.01	950.04±0.01	386.1±1.64
29	26±2.3	0.9	1.93	0.74±0.03	894.84±0.19	376.81±1.89
30	24.86±2.4	0.88	1.87	0.72±0.04	851.43±0.02	367.83±2.46
31	25.81±2.6	0.84	0.41	0.74±0.02	138.72±0.03	372.66±2.35
32	12.08±1.2	0.78	0.47	0.19±0.02	76.5±0.0	264.57±3.47
33	11.22±1.1	0.77	0.41	0.16±0.02	76.46±0.0	259.22±3.68
34	31.24±3.1	0.76	0.27	0.85±0.01	949.62±0.22	384.63±3.88
35	23.94±2.3	0.73	0.48	0.7±0.01	760.04±0.0	365.23±4.57
36	21.48±2.4	0.67	1.36	0.55±0.02	226.69±0.0	348.91±5.47
37	23.19±2.3	0.61	0.38	0.66±0.02	532.22±0.06	361.6±5.71
38	23.11±0.9	0.54	1.44	0.69±0.02	310.77±0.06	361.64±6.97
39	24.02±2.4	0.42	1.66	0.71±0.01	802.53±0.0	366.85±9.09
40	13.22±1.3	0.41	0.47	0.2±0.03	74.72±0.02	279.54±10

Appendix 6: Mineral Composition of *S. cuminii* Fruits from Kwale County

Sample/ tree no.	Concentration (mg/100g sample)								
	Na	K	P	Ca	Mg	Mn	Fe	Cu	Zn
1	14.09±0.1	1802.13±43.9	21.87±0.42	13.05±0.31	531.87±0.07	17.99±0.0	64.96±0.07	9.91±0.05	5.27±0.0
2	39.9±0.11	715.94±6.46	16.65±0.56	6.33±0.36	246.12±0.4	7.65±0.03	35.92±0.05	4.31±0.02	2.17±0.02
3	10.84±0.03	2633.89±12.71	40.33±1.8	16.18±0.67	832.17±0.03	68.9±0.07	90.99±0.06	13.9±0.06	8.97±0.04
4	30.22±0.0	901.77±46.6	19.2±0.31	7.64±0.23	301.74±0.15	8.32±0.02	52.09±0.03	5.57±0.02	2.71±0.0
5	14.94±0.03	1709.28±34.66	21.38±0.91	11.94±0.2	362.27±0.02	10.26±0.02	61.94±0.03	9.52±0.02	4.81±0.09
6	15.25±0.01	1708.55±34.64	21.11±0.12	11.3±0.14	359.94±0.3	9.92±0.04	60.24±0.07	8.88±0.01	4.47±0.02
7	14.85±0.13	1702±33.97	21.76±0.53	12.78±0.29	412.18±0.02	15.13±0.05	64.37±0.02	9.85±0.09	5.05±0.03
8	32.06±0.02	841.67±52.15	18.75±0.35	6.61±0.33	284.4±0.23	8.27±0.02	43.93±0.04	5.11±0.0	2.4±0.02
9	16.65±0.04	1421.32±59.18	19.83±0.24	10.19±0.03	325.53±0.02	9.62±0.05	56.09±0.05	7.79±0.0	3.6±0.02
10	31.61±0.03	861.64±50	18.99±0.33	7.17±0.27	289.49±0.3	8.29±0.02	48.78±0.01	5.11±0.0	2.69±0.02
11	22.79±0.0	944.56±41.7	19.47±0.28	8.37±0.15	309.46±0.02	8.77±0.02	56.03±0.03	7.11±0.01	3.3±0.03
12	18.06±0.02	1141.17±22.09	19.64±0.28	8.94±0.09	319.37±0.01	9.5±0.02	56.09±0.05	7.59±0.03	3.56±0.02
13	25.36±0.02	931.65±43.55	18.05±1.8	7.82±0.21	303.06±0.02	8.4±0.0	52.4±0.02	6.2±0.01	2.72±0.01
14	11.0±1.15	2532.16±11.7	38.97±1.66	15.28±0.53	828.26±0.07	36.27±0.02	90.05±0.03	10.38±0.04	8.56±0.02
15	10.47±0.02	2911.45±15.49	45.65±2.3	20.7±0.97	846.26±1.14	74.0±1.15	196.87±0.23	14.07±0.03	10.09±0.04
16	42.09±0.01	598.04±7.66	16.36±0.59	6.24±0.37	235.19±0.04	7.56±0.03	33.54±0.03	4.3±0.0	1.97±0.01
17	146.8±0.11	462.38±8.9	11.31±0.1	2.87±0.7	185.59±0.09	7.29±0.01	5.19±0.0	2.49±0.0	0.11±0.01
18	47.59±0.0	570.46±7.99	15.44±0.68	6.07±0.38	230.0±0.58	7.540.03	25.17±0.02	4.22±0.02	1.58±0.02
19	65.14±0.08	501.11±8.6	13.09±0.1	5.47±0.44	212.62±0.01	7.39±0.02	16.42±0.03	3.79±0.0	1.26±0.01

20	93.03±0.02	491.07±8.7	12.87±0.94	4.8±0.51	203.12±0.07	7.34±0.01	14.9±0.01	3.71±0.17	1.04±0.02
21	41.64±0.03	688.31±6.75	17.15±0.53	6.33±0.36	245.66±0.22	7.65±0.0	35.68±0.01	4.3±0.0	2.12±0.02
22	10.99±0.0	2587.42±12.25	37.11±1.48	15.35±0.54	561.94±0.36	63.07±0.02	90.29±0.0	11.25±0.0	8.91±0.0
23	39.25±0.03	783.44±57.8	17.82±0.47	6.35±0.35	349.34±0.38	8.01±0.01	38.3±0.02	5.05±0.03	2.17±0.02
24	15.34±0.2	531.68±8.3	20.66±0.16	11.17±0.12	341.29±0.0	9.8±0.11	60.13±0.06	7.9±0.06	3.98±0.01
25	38.57±0.01	792.81±56.9	18.06±0.42	6.59±0.33	276.86±0.08	8.2±0.01	40.89±0.1	5.11±0.0	2.26±0.07
26	54.21±0.02	551.19±8.1	14.87±0.74	5.95±0.4	228.33±0.01	7.52±0.02	29.39±0.04	4.3±0.0	1.69±0.0
27	57.91±0.05	521.4±8.4	13.65±0.86	5.74±0.42	223.22±0.0	7.45±0.05	16.47±0.02	3.82±0.0	1.29±0.0
28	10.51±0.03	2866.13±15.03	43.32±2.1	17.93±0.8	840.04±0.07	76.19±0.0	1053.33±0.03	26.18±0.01	13.2±0.06
29	11.01±0.01	2500.55±11.38	35.77±1.3	15.24±0.53	548.92±0.02	31.04±0.05	75.4±0.03	10.33±0.0	8.23±0.02
30	11.96±0.02	1933.64±57.1	30.06±7.77	14.95±0.5	543.4±0.06	28.3±0.0	73.9±0.06	10.33±0.02	7.98±0.0
31	25.24±0.03	2456.37±10.94	19.44±0.28	7.91±0.2	308.5±0.06	8.63±0.02	54.22±0.02	6.7±0.17	3.12±0.08
32	122.13±0.01	483.288.7	12.16±0.1	2.91±0.7	200.26±0.02	7.31±0.02	8.1±0.0	2.92±0.01	0.67±0.02
33	106.14±0.01	482.06±8.8	12.34±0.99	3.81±0.61	186.89±0.06	7.33±0.01	6.12±0.0	3.31±0.0	1.0±0.3
34	10.63±0.04	2708.44±13.46	40.69±1.84	16.61±0.66	836.29±0.0	73.19±0.02	92.65±0.03	13.49±0.0	10.01±0.0
35	12.41±0.02	1866.21±50.4	24.31±2.02	13.73±0.38	538.26±0.05	20.33±0.01	68.81±0.05	10.15±0.02	6.27±0.02
36	16.17±0.02	1542.88±18.09	20.43±0.18	10.87±0.09	328.31±0.02	9.8±0.11	59.02±0.01	7.9±0.06	3.76±0.01
37	13.73±0.04	1734.86±37.34	22.69±0.4	13.1±0.32	507.6±0.23	18.26±0.02	66.3±0.17	9.92±0.05	5.69±0.0
38	14.73±0.01	1711.64±34.75	21.63±0.66	12.54±0.26	395.66±0.02	12.54±0.04	62.46±0.02	9.79±0.0	5.03±0.02
39	11.98±0.01	1869.02±50.6	25.64±3.35	14.59±0.46	540.07±0.02	20.3±0.18	66.59±0.0	10.33±0.0	7.32±0.02
40	67.25±0.01	492.01±8.7	13.07±0.92	5.1±0.48	205.61±0.01	7.38±0.01	15.11±0.01	3.73±0.04	1.06±0.02

Cr, Cd were not detected by the ICP OES, Their Limit of detection (LOD for Cr = 0.01mg/L)

Appendix 7: Characterization of Soils from Bungoma County

Sample/ tree no.	**Altitude (m)**	**pH**	**Porosity (%)**	**Bulk density (g/cm^3)**	**Particle density (g/cm^3)**	**Minerals (mg/kg)**					
						Na	**Mg**	**Mn**	**Cu**	**Zn**	**Ti**
1	1757	3.23±0.14	64 ±1	0.74±0.01	2.38±0.0	8.37±0.02	34.93±0.04	85.93±0.04	0.94±0.03	7.1±0.06	0.53±0.01
2	1766	5.6±0.0	60 ±2	0.78 ±001	2.43±0.0	6.69±0.0	62.3±0.17	60.52±0.01	0.53±0.01	5.82±0.02	0.75±0.04
3	1768	5.99 ±0.0	65 ± 2	0.73±0.01	2.36±0.0	8.85±0.4	34.63±0.41	88.54±0.41	0.95±0.41	7.11±0.41	0.51±0.41
4	1762	5.20 ±0.0	56 ± 2	0.86±0.02	2.5±0.0	4.19±0.0	90.77±0.13	46.26±0.15	0.46±0.03	5.32±0.09	2.09 0.01
5	1485	5.78±0.05	64 ± 1	0.75± 0.0	2.39±0.01	7.99±0.0	35.12±0.02	80±2.89	0.91±0.05	6.7±0.09	0.49 0.01
6	1587	4.53±0.11	50 ± 1	1.06±0.00	2.69±0.01	0.01±0.0	1075±43.3	10.06±0.02	0	1.08±0.05	92.85±0.03
7	1639	5.19±0.01	56 ± 1	0.87± 0.0	2.5±0.0	1.98±0.4	129.69±0.44	39.65±0.41	0.46±0.41	5.27±0.02	2.08 ±0.41
8	1693	4.88±0.01	51 ± 2	1.04±0.01	2.69±0.0	0.33±0.01	578±4.62	15.12±0.02	0	1.09±002	92.85±0.02
9	1722	5.03±0.05	53 ± 2	0.92±0.00	2.65±0.0	1.63±0.02	272±2.89	28.78±0.01	0.25±0.03	3.89±0.0	36.67±0.02
10	1549	6.01±0.0	57 ± 1	0.82 ± 0.0	2.49±0.0	4.46±0.02	81.53±0.02	46.26±0.15	0.47±0.02	5.46±0.02	1.47 ±0.02
11	1648	5.21±0.2	55 ± 2	0.88± 0.0	2.56±0.0	1.8±0.42	243.1±0.41	33.06±0.41	0.41±0.41	4.73±0.05	32.27±0.41
12	1615	5.35±0.0	57 ± 1	0.84±0.00	2.5±0.02	4.71±0.17	81.16±0.02	47.78±0.13	0.48±0.01	5.51±0.05	1.23 ±0.04
13	1597	6.0±0.0	65 ± 3	0.73± 0.0	2.37±0.0	8.87±0.07	32.1±0.06	108.86±0.02	1.01±0.02	7.99±0.1	0.48 ±0.02
14	1569	5.66±0.01	60 ± 3	0.78±0.01	2.44±0.0	6.71±0.05	61.26±0.02	66.41±0.12	0.62±0.01	6.28±0.02	0.21 ±0.02
15	1579	5.13±0.01	55 ± 3	0.89±0.01	2.63±0.0	1.81±0.41	230±3.49	33.85±0.41	0.45±0.41	5.03±0.41	15.19±0.41
16	1619	6.36±0.01	67 ± 3	0.69±0.00	2.35±0.01	17.39±0.0	28.9±0.06	155.38±0.01	1.24±0.02	9.93±0.04	0.23 ±0.02

17	1602	6.19±0.0	67 ± 1	0.7 ± 0.01	2.36±0.0	14.71±0.02	29.13±0.05	141.59±0.0	1.19±0.0	8.97±0.02	0.46 ±0.03
18	1602	5.68±0.0	60± 1	0.78±0.02	2.44±0.0	6.94±0.03	53.98±0.01	66.3±1.1	0.74±0.03	6.29±0.0	0.62 ±0.01
19	1605	5.39±0.01	59 ± 2	0.79 ± .00	2.48±0.0	5.85±0.4	62.58±0.41	58.6±0.47	0.52±0.41	5.72±0.41	0.99 ±0.41
20	1654	6.74±0.01	72± 2	0.61±0.00	2.27±0.0	26.6±0.23	24.63±0.21	185.25±0.14	1.86±0.02	20.46±0.03	0.77 ±0.02
21	1667	4.89±0.0	52 ± 1	0.92±0.01	2.66±0.0	1.03±0.02	576.89±0.0	15.33±0.19	0.74±0.04	2.24±0.14	54.88±0.07
22	1672	5.38±0.0	59 ± 1	0.8 ±0.00	2.49±0.0	5.04±0.02	71.98±0.01	49.23±0.13	0.52±0.02	5.86±0.02	0.7 ±0.06
23	1631	6.5±0.0	71± 1	0.62±0.03	2.66±0.01	23.49±0.4	27.02±0.41	180.46±0.41	1.86±0.41	18.54±0.41	0.4 ±0.41
24	1601	6.61±0.0	71± 2	0.62±0.02	2.28±0.0	24.970.02	25.73±0.04	184.88±0.01	0.19±0.0	18.86±0.02	0.22 ±0.01
25	1788	6.5±0.0	70± 1	0.66±0.01	2.3±0.01	23.49±0.0	27.12±0.09	180.09±0.0	0.51±0.01	14.81±0.05	0.24 ±0.02
26	1710	6.5±0.01	69± 1	0.67±0.01	2.3±0.0	21.41±0.03	28.45±0.05	179.72±0.16	1.77±0.02	14.54±0.03	0.25 ±0.01
27	1684	6.4±0.0	68± 2	0.68±0.02	2.32±0.01	17.41±0.4	28.83±0.41	176.74±0.43	1.83±0.41	13.2±0.42	0.45 ±0.41
28	1631	4.9±0.05	52± 3	0.94±0.01	2.68±0.0	1.13±0.07	544.3±0.23	27.33±0.19	1.76±0.02	2.27±0.02	40.24±0.14
29	1523	5.69±0.00	62± 1	0.77± 0.0	2.43±0.22	7.21±0.02	52.55±0.03	66.5±0.29	1.75±0.02	6.3±0.01	0.55 ±0.03
30	1630	5.18±0.01	56± 2	0.88±0.02	2.63±0.02	1.88±0.01	138.7±0.17	38.46±0.02	1.34±0.01	5.03±0.02	3.03 ±0.02
31	1441	6.87±0.0	77± 1	0.53± 0.0	2.26±0.39	54.2±0.4	10.5±0.42	190.77±0.41	0.22±0.41	20.7±0.44	0.05 ±0.41
32	1275	6.75±0.00	74± 1	0.6± 0.01	2.26±0.36	54.2±0.11	21.67±0.02	188.93±0.04	0.76±0.02	20.5±0.32	0.05 ±0.01
33	1470	5.73±0.0	63± 3	0.75± 0.0	2.41±0.24	7.82±0.03	36.22±0.13	78.46±0.02	0.45±0.03	6.61±0.06	0.53 ±0.01
34	1490	5.70±0.0	62± 2	0.77± 0.0	2.43±0.0.21	7.63±0.01	36.29±0.0	70.77±0.13	1.88±0.01	6.42±0.03	0.54 ±0.01
35	1695	6.120.0	65± 1	0.74±0.01	2.38±0.25	9.06±0.4	30.58±0.41	101.98±0.41	1.86±0.41	8.33±0.41	0.47 ±0.41
36	1523	6.13±0.0	66± 2	0.72±0.02	2.36±0.3	9.35±0.03	30.6±0.03	124.6±0.23	1.86±0.0	9.91±0.05	0.47 ±0.03
37	1349	5.04±0.0	54± 3	0.89± 0.0	2.66±0.0	1.72±0.01	270.31± .02	29.23±0.13	0.9±0.02	3.98±0.01	36.81±0.11
38	1729	5.09±0.03	54± 2	0.81±0.01	2.65±0.01	1.78±0.01	260.31±0.01	32.28±0.01	0.88± .01	4.71±0.17	34.22±0.13

39	1624	5.02±0.01	53± 3	0.92±0.02	2.67±0.0	1.58±0.4	.53± 0.41	28.11±0.41	1.17±0.41	3.72±0.41	40.24 0.41
40	1527	6.41±0.0	69± 1	0.68±0.03	2.35±0.28	18.84± 0.02	28.66±0.02	179.16±0.48	1.18±0.01	14.49±0.02	0.44 ±0.03

All values reported as Means ± Standard error of triplicates

Cd, Cr, Zn and Cu were not detected. Instrument detection levels were as follows; Cd (0.001), Cr (0.003), Zn (0.01) and Cu (0.02) mg/L.

Appendix 8: Characterization of Soils from Kwale County

Sample/ tree no.	Altitude (m)	PH	Porosity (%)	Particle density (g/cm^3)	Bulk density (g/cm^3)	Mineral content (mg/kg)					
						Na	Mg	Mn	Cu	Zn	Ti
1	14	4.31±0.05	52±1	2.79±0.0	1.28±0.0	1.17±0.02	103.96±0.02	45.64±0.21	0.13±0.02	0.3±0.03	48.74±0.44
2	15	6.04±0.03	45±0	2.56±0.1	1.08±0.0	6.45±0.03	13.77±0.13	18.96±0.02	0.82±0.05	1.7±0.02	17.76±0.14
3	14	3.82±0.0	59±1	3.12±0.0	1.51±0.0	0.23±0.41	152.55±0.48	61.61±0.41	0	0	139.72±0.44
4	16	5.53±0.01	59±0	2.58±0.1	1.11±0.0	3.83±0.1	21.72±0.05	25.06±0.03	0.67±0.02	1.5±0.03	19.27±0.15
5	10	4.35±0.01	55±0	2.7±0.0	1.26±0.0	1.25±0.14	91.32±0.18	38.3±0.17	0.19±0.03	0.93±0.02	37.69±0.18
6	11	4.5±0.0	56±1	2.65±0.0	1.23±0.0	1.58±0.01	91.080.01	37.39±0.0	0.23±0.02	0.94±0.02	37.06±0.03
7	12	4.32±0.01	55±0	2.73±0.0	1.27±0.0	1.18±0.41	103.82±0.42	42.85±0.42	0.17±0.41	0.63±0.41	36.57±0.48
8	412	5.67±0.01	60±1	2.58±0.1	1.1±0.0	5.84±0.03	19.09±0.05	20.97±0.04	0.7±0.06	1.54±0.03	18.36±0.21
9	398	5.11±0.01	57±1	2.63±0.02	1.17±0.0	1.69±0.01	53.87±0.07	32.39±0.0	0.38±0.01	1±0.23	25.41±0.05
10	57	5.57±0.02	59±1	2.59±0.1	1.12±0.0	5.17±0.02	19.27±0.15	22.68±0.0	0.68±0.01	1.53±0.02	18.49±0.02
11	56	5.32±0.02	58±1	2.61±0.04	1.15±0.0	2.6±0.41	46.22±0.43	27.95±0.41	0.55±0.41	1.23±0.43	22.19±0.42
12	55	5.17±0.01	57±0	2.63±0.02	1.21±0.0	2.41±0.05	46.93±0.04	31.75±0.14	0.49±0.03	1.11±0.0	23.29±0.17
13	389	5.42±0.01	59±0	2.62±0.03	1.15±0.0	3.61±0.05	33.28±0.16	25.65±0.03	0.63±0.04	1.47±0.02	19.56±0.25
14	412	3.92±0.0	48±0	3±0.0	1.45±0.0	0.27±0.02	134.71±0.17	55.22±0.45	0	0.11±0.0	97.88±0.07
15	413	3.8±0.01	35±1	3.29±0.0	1.58±0.0	0.12±0.41	298.66±0.45	66.88±0.41	0	0	369.23±0.43
16	416	6.16±0.0	70±1	2.55±0.1	0.95±0.0	6.58±0.01	10.64±0.21	15.69±0.31	0.92±0.05	2.15±0.09	16.81±0.11
17	411	7.65±0.01	100±0	2.5±0.15	0.67±0.0	15.4±0.23	2.02±0.05	1.57±0.24	2.78±0.01	5.78±0.01	0
18	408	6.37±0.0	73±0	2.55±0.1	0.94±0.01	6.67±0.19	7.38±0.01	13.83±0.1	1.08±0.02	2.41±0.0	16.77±0.13

19	386	6.71±0.0	75±1	2.54±0.11	0.81±0.0	7.67±0.45	5.22±0.3	11.64±0.46	1.19±0.41	2.69±0.41	16.42±0.47
20	25	7.12±0.01	85±2	2.53±0.12	0.7±0.09	11.39±0.0	4.09±0.01	6.44±0.25	1.44±0.03	3.15±0.09	0.15±0.03
21	63	6.15±0.01	64±1	2.56±0.1	1.05±0.0	6.46±0.02	12.03±0.04	17.28±0.01	0.9±0.06	1.87±0.02	17.09±0.0
22	27	3.85± 0.0	46±3	3.06±0	1.48±0.0	0.25±0.02	141.23±0.13	58.77±0.13	0	0.06±0.01	124.09±0.05
23	39	5.87±0.01	62±1	2.56±0.1	1.08±0.0	6.27±0.41	13.98±0.41	19.55±0.48	0.79±0.42	1.64±0.41	17.94±0.41
24	150	4.98±0.01	56±0	2.68±0	1.24±0.0	1.59±0.24	68.12±0.07	35.77±0.13	0.24±0.02	0.97±0.02	16.49±0.28
25	8	5.69±0.01	61±0	2.57±0.1	1.09±0.0	5.92±0.05	17.15±0.09	19.99±0.0	0.78±0.02	1.63±0.02	18.34±0.2
26	41	6.37±0.01	70±1	2.55±0.1	1.03±0.0	6.61±0.22	9.45±0.26	15.55±0.26	0.98±0.01	2.2±0.1	16.75±0.02
27	40	6.55±0.02	74±0	2.55±0.1	0.92±0.08	7.2±0.41	6.31±0.44	13.38±0.41	1.18±0.41	2.46±0.41	16.52±0p.49
28	69	3.8 ± 0.01	25±2	3.29±0	1.93±0.0	0.090.0	301.68±0.18	93.82±0.1	0	0	318.66±0.2
29	61	3.93±0.01	50±3	2.85±0	1.34±0.0	0.6±0.23	128.17±0.1	54.1±0.06	0.01±0.0	0.16±0.01	86.87±
30	382	3.94±0.01	50±0	2.9±0	1.35±0.0	0.61±0.03	118.43±0.02	51.96±0.02	0.08±0.01	0.17±0.01	75.22±0.13
31	265	5.39 ±0.0	58±0	2.63±0.12	1.16±0.0	3.24±0.43	30.78±0.42	27.74±0.43	0.6±0.41	1.45±0.03	80.93±0.41
32	74	7.73±0.01	98±0	2.5±0.15	0.69±0.03	13.04±0.02	2.89±0.0	2.35±0.2	2.74±0.03	4.86±0.02	0.15±0.0
33	252	7.33±0.01	89±1	2.52±0.13	0.69±0.04	12.71±0.05	3.11±0.06	3.52±0.01	1.88±0.01	4.17±0.02	0.03±0.0
34	20	3.81±0.01	44±1	3.23±0	1.56±0.0	0.23±0.02	153.69±0.0	66.39±0.0	0	0	281.84±0.03
35	51	3.99±0.01	50±1	2.9±0	1.35±0.0	0.89±0.41	113.17±0.41	49.63±0.55	0.09±0.41	0.27±0.41	56.49±0.5
36	332	5.11±0.01	57±2	2.65±0	1.23±0.0	1.65±0.03	61.85±0.09	35±1.15	0.3±0.11	0.97±0.02	32.31±0.18
37	303	4.18±0.01	52±0	2.8±0	1.32±0.0	0.99±0.06	105.91±0.05	48.43±0.02	0.13±0.01	0.28±0.01	40.79±0.12
38	295	4.34 ±0.0	55±0	2.77±0	1.27±0.0	1.19±0.11	93.02±0.05	39.15±0.09	0.17±0.02	0.86±0.02	39.28±0.16
39	48	3.98 ±0.0	50±1	2.91±0	1.4±0.0	0.67±0.41	113.77±0.43	51.03±0.41	0.08±0.41	0.21±0.41	63.79±0.42
40	22	6.79 ± 0.0	75±0	2.94±0	0.91±0.09	11.14±0.02	4.71±0.17	6.57±0.01	1.43±0.04	2.78±0.01	16.23±0.13

Appendix 9: Journal Paper 1

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Physicochemical and nutritional properties of *Syzygium cumini* (L.) skeels fruits grown in varied microclimates in Kenya

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Wild fruits contribute significantly to food security, thus becoming an important global discussion. This study evaluated the physicochemical and nutritional properties of *Syzygium cumini* (L.) Skeels fruits from two microclimates in Kenya as essential contributors to the human diet. Analysis was done using standard methodologies including the use of inductively coupled plasma - optical emission spectrometer for elemental analysis and high-pressure liquid chromatography for the determination of Vitamin C. The T-test showed significant differences in the fruit breadth, pH, total ash, sodium, calcium, manganese, copper, and zinc. The Pearson correlation matrix showed a small positive association between total soluble solids and titratable acidity with altitude, a medium positive correlation with rainfall, and a strong positive correlation between sunshine and skin colour intensity. Larger fruits contained substantial amounts of protein and crude fiber with a significant increase in energy values in fruits with high crude fat and carbohydrates, all correlating positively with the microclimate conditions; altitude, and rainfall. This study exemplifies the potential of *Syzygium cumini* as an alternative feed supplement to strengthen food security. It provides information on the variation of the physicochemical and nutritional composition of the fruits with climatic conditions, for the industries to employ the best strategies in obtaining marketable products.

Key words: Food security, fruit quality, microclimate, nutritional, physicochemical, *Syzygium cumini*

Appendix 10: Journal Paper 2

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Effect of Soil Properties on the Physical and Nutritional Content of Syzygium Fruits

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ABSTRACT

This study was undertaken to determine the effect of Soil pH, porosity, bulk and particle density, magnesium, manganese, sodium, copper, zinc, and titanium on the physicochemical and nutritional content of *Syzygium cumini* fruits. Multistage sampling was used to select the counties, identify, sample and collect fruit trees. Analysis was done using 40 soil and fruit samples each per county using standard methodologies. Fruit parameters were evaluated by measuring juice pH, total soluble solids, titratable acids, vitamin C, crude fat and fiber, proteins, fruit maturity, carbohydrates, energy, sodium, magnesium, manganese, calcium, iron, copper, and zinc. Results showed that, Syzygium fruits preferred a soil pH from 5.3 to 6.9 which was significantly different between the two counties. Titanium was significantly high in Kwale soil samples giving 57.53±8.37 mg/kg. Particle density caused an increase in bulk density, which in turn increased fruit weight, pH, and ash content. Proteins had a weak positive correlation with soil magnesium, 0.11 and very strongly correlated with carbohydrates, 0.99. Mature fruits had significantly higher protein and carbohydrate contents of 2.96 and 36.1 mg/100 g respectively. The physicochemical and nutritional content of *Syzygium cumini* fruits were highly influenced by soil properties.

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