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Evaluation of proximate composition, selected minerals and physicochemical properties of fifteen local mchare cooking bananas

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EVALUATION OF PROXIMATE COMPOSITION, SELECTED MINERALS AND PHYSICOCHEMICAL PROPERTIES OF FIFTEEN LOCAL *MCHARE* COOKING BANANAS

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

This study investigated the proximate composition, selected minerals potassium (K), calcium (Ca), iron (Fe) and zinc (Zn) and some physicochemical properties of fifteen *Mchare* cooking bananas mainly consumed in northern Tanzania. Analyses were conducted using the standard methods to ascertain their potential in food-based strategies in order to improve nutrition-sensitive agriculture, address hidden-hunger. Data were subjected to analysis of variance and means were compared. There were significant differences in all parameters assessed. Results further indicated that the moisture content ranged from 65.53 to 74.44 g/100 g; ash 0.66 to 1.45 g/100 g; fat 0.1 to 0.6 g/100 g; fibre 0.9 to 2.8 g/100 g; carbohydrate 21.6 to 30 g/100 g. Mineral content ranged from 306 to 469 mg/100 g; 2.6 to 6 mg/100 g; 0.4 to 0.8 mg/100 g and 0.1 to 0.2 mg/100 g for K, Ca, Fe and Zn, indicating potential nutritional significance. The total titratable acidity (TTA) ranged from 1.5 to 2.3%, total soluble solids (TSS) 1.0 to 2.0 °Brix while pH ranged from 5.4 to 6.0 suggesting a substantial contribution to the sensory attributes of bananas, which is an important sensory attribute to consumers. Cooking bananas could, therefore, play a key role in contributing to alleviating hidden-hunger and food insecurity through developing new food recipes.

Keywords: *Mchare* cultivars, nutritional composition, minerals, physicochemical parameters

DECLARATION

I, Joachim Dotto, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concomitantly submitted for degree award in any other institution.

Signature ……. Date: ……..

Joachim Dotto

The above declaration is confirmed by:

Signature: …….. Date: …….

Dr. Athanasia Matemu (Supervisor 1)

Signature: …….. Date: ……...

Prof. Patrick Ndakidemi (Supervisor 2)

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CERTIFICATION

The undersigned certify that they have read the dissertation titled, “Evaluation of Proximate Composition, Selected Minerals and Physicochemical Properties of Fifteen Local *Mchare* Cooking Bananas” and recommend for examination in fulfillment for the requirements for the award of Master’s in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

AA, AB	Diploid Banana Hybrids
AAA, AAB, ABB	Triploid Banana Hybrids
AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
EA	East Africa
EAHB	East African Highland Cooking Banana
FAO	Food and Agriculture Organization
FHIA	Honduran Foundation for Agricultural Research
Fig.	Figure
HSD	Honestly Significant Difference
IITA	International Institute of Tropical Agriculture
INIBAP	International Network for The Improvement of Banana and Plantain
M	Molarity
N	Normality
n	Number of Replications
NM-AIST	Nelson Mandela African Institution of Science and Technology
p	p - Value
PHQL	Postharvest Quality Losses
RDA	Recommended Daily Allowance
SE	Standard Error
TDF	Total Dietary Fibre
TFCT	Tanzania Food Composition Tables
TSS	Total Soluble Solids
TTA	Total Titratable Acidity
USA	United States of America
USD	United States Dollar
WVC	World Vegetable Centre

CHAPTER ONE

INTRODUCTION

1.1. Background of the Problem

With a production of 145 million metric tons worth approximately USD 30.8 billion globally, banana (*Musa spp*.) is one of the world's most important staple food and cash crops. Food and Agriculture Organization Statistics (2014) reports banana as the world's most popular fruit in terms of international trade. In fact, it is one of the most produced and consumed fresh fruit worldwide (Affognon, Mutungi, Sanginga, & Borgemeister, 2015). Bartoshuk and Klee (2013) reported that different varieties grown in various parts of the world have markedly different sensory characteristics. The world main banana producers are India (27.6 mil. tons), China (12.1 mil. tons), Uganda (9 mil. tons), the Philippines (8.6 mil. tons), Brazil (6.9 mil. tons) and Ecuador (6.0 mil. tons), making banana a significant contributor to the world economy (Sheth, 2017; Statistica, 2016). While developed countries consider banana mainly as a dessert food, in many developing countries banana is a staple food cooked as an essential meal. Furthermore, it contributes notably to food security and income generation to more than 70 million Africans (Adeniji, Tenkouano, Ezurike, Ariyo, & Vroh-Bi, 2010).

The literature review shows that there are various types of banana unique to Africa and these can be eaten fresh, cooked, fried, processed as baby food, juice or beer (Chandler, 1995). Cooking bananas represent a major food source and a major income source for smallholder farmers (D. Karamura, Karamura, & Tinzaara, 2012). In fact, the East African Highland cooking Banana (EAHB) and plantain make up over 50% of all bananas grown in Africa (Kilimo-Trust, 2012). The people living in the Eastern and Central Highlands of Africa consume more bananas than anyone else in the world, deriving up to 12% of their daily calories from the crop (Karamura *et al.*, 2012). In the lowland of the Congo basin, farmers grow a greater diversity of banana plantains than any other place in the world (Lejju, Robertshaw, & Taylor , 2006). Moreover, these perennial plants are the backbone of many farming systems as they produce fruits all-year-round, protect the soil from erosion and survive floods, drought and civil conflicts (D. Karamura, Karamura, & Gold, 1996).

Perrier *et al.* (2011) reported that nearly all African countries produce substantial amounts of bananas, however only a few exports them. Despite the fact that East Africa is one of the

leading regions of banana production in Africa, most of the produced crop is for local consumption and sale rather than export (Price, 2006). In countries such as Uganda, Tanzania, Burundi and Rwanda, the per capita annual consumption is estimated to be over 100 kilograms and the highest in the world (Fungo & Pillay, 2011). Although Uganda is the largest banana producer in Africa (Ssonko & Muranga, 2017), the country consistently remains as one of many smaller exporters of banana in the continent, with the crop being used mostly for local consumption (Kilimo-Trust, 2012). West African countries, on the other hand, according to BananaLink (2015) they produce nearly all of Africa's banana exports, with Cameroon and Côte d'Ivoire being the two largest exporters of dessert and cooking bananas to European countries. Diop and Jaffee (2005) reported that banana production in these two countries has grown hastily over the past two decades and that they contribute to approximately 4.1% banana exports in the global market.

It has been documented that bananas are rich in carbohydrates, vitamins and dietary fibres. Although they contain 75% water, also contain alkali-forming minerals, lots of potassium and little protein and fat (Haslinda, Cheng, Chong, & Aziah, 2009). Additionally, the ripe bananas are easy to digest and the food of choice for many professional athletes because they provide quick energy and provide potassium lost during exercise (Kachru, Kotwaliwale, & Balasubramanian, 1995), it has also for long been considered as the best food for babies. Several studies have reported the nutritional and sensory attributes of local ripe bananas (Ohizua *et al.*, 2017; Pareek, 2016; Suntharalingam, 1990) but published data on the same attributes of the unripe local banana varieties is few in Eastern Africa.

In the East Africa region, cooking bananas are an essential staple food and they are important in addressing the problem of food insecurity. Bananas provide a household income of about USD 1244 annually to more than 4 million smallholders, this is one of the maximum smallholder revenue-generating agricultural produce in the area (Mgenzi, Mshaghuley, Staver, & Nkuba, 2008). Nutritionally, bananas supply about ten percent of the energy intake and vital micronutrients to over 70 million people in Eastern Africa (Belayneh, Workneh, & Belew, 2014). For instance, banana consumption per person in Tanzania and Uganda is among the highest in the global rankings (Kilimo-Trust, 2012). The two countries collectively produce over 50% of all bananas grown in Africa (Jacobsen, 2014). Banana production in Tanzania is estimated to be about 3.7 million metric tons per annum on about 403 000 hectares. Kilimanjaro and Kagera regions alone contribute to over 60% of country annual banana production (Kilimo-

Trust, 2012). Other banana-producing regions in Tanzania are Mbeya (12%), Kigoma (7%), Arusha (7%) and Tanga (3%) (Larsen *et al.*, 2009). The country positions fourth in banana production in Africa (Mbwika, 2009).

Hardisson *et al.* (2001) suggested the importance of evaluation of physicochemical and sensory analysis of local banana cultivars as a preliminary strategy for breeding. This information is warranted since it advises on fruit quality and which quality characteristics among cultivars are important and preferable to the consumers. Current studies show limited information regarding these important attributes of the local *Mchare* cooking bananas. Therefore, there is a need to investigate the proximate composition, mineral profile and physicochemical quality attributes of *Mchare* bananas.

1.2. Statement of the Problem

Humans are faced with several food choices each day and make decisions on what food to eat based on several criteria (Mela, 1999). Despite the recent applications of advanced agricultural technology in food production, low preferences given to some accessible and available food crops is still a challenge in many developing countries (Ouma & Jagwe, 2010). In sub-Saharan Africa, cooking bananas offer great potential as a staple food and of recently as a cash crop. It is largely consumed in the Great Lakes Region i.e., Uganda, Tanzania, Burundi and Kenya. Although, many existing varieties are still overlooked as sources of food (Kilimo-Trust, 2012). Of specific interest in this study, was *Mchare* banana family largely grown and consumed in the northern zone of Tanzania. Tens of preferred cooking bananas in this zone belong to this family, making it a popular choice among country-northern residents. Considerable studies have been done aiming at the improvement of these banana cultivars focusing on the desirable agronomic characters such as disease resistance and high-yielding traits (Bakry, Carreel, Jenny, & Horry, 2009; Buddenhagen, 1990; Osei, Asante, Agyeman, Adebayo, & Adu-Dapaah, 2014; Pillay & Tenkouano, 2011). However, there is a lack of consistent practical information about the nutritional and physicochemical quality parameters of this popular banana family. Furthermore, consumers' preferences differ greatly in many varieties of a banana being produced. This ultimately leads to low economic value and substantial post-harvest losses. Unknown nutritional values of the local banana cultivars have been largely implicated. Additionally, a limited nutritional and quality information of local banana cultivars reduces the effectiveness of developing new improved banana cultivars with qualities that are acceptable

by the farmers and consumers. Evidently, the need to evaluate the nutritional values and associated physicochemical parameters of different banana varieties cannot be overemphasized. This study, therefore, seeks to analyse the proximate composition, selected mineral and physicochemical properties of the fifteen (15) banana cultivars of *Mchare* family.

1.3. The Rationale of the Study

Consumer quality traits, such as nutritional, sensory and physicochemical parameters of foods are becoming increasingly important in current plant breeding programs (Ferris, Ortiz, & Vuylsteke, 1999; Fonsah & Chidebelu, 2011). Sensory and physicochemical properties of any food have to be tailored in due course to meet the requirements of the end-users. Regardless how natural and nutritive a food is, if it does not appeal to its consumers, it is uncertain to do well in nowadays' elastic market (Adeniji *et al.*, 2010; Belayneh *et al.*, 2014; Ferris *et al.*, 1999). Based on the importance of cooking bananas as a source of food to local communities especially in Tanzania, the need to evaluate food attributes that promote preferential consumption cannot be overlooked (De-Langhe, Karamura, & Mbwana, 2001). The purpose of the present study was, therefore, to analyze the proximate composition, selected minerals, that is potassium (K), calcium (Ca), zinc (Zn) and iron (Fe) and the selected physicochemical quality parameters of 15 banana cultivars of *Mchare* family. The *Mchare* cultivars included *Mlelembo Mchare, Huti white*, *Kahuti*, *Ijihu inkundu*, *Makyughu* 1, *Makyughu* 2, *Mchare laini*, *Huti* green, *Akondro mainty*, *Njuru*, *Muraru Mchare, Majimaji*, *Muraru*, *Muraru* white and *Muraru* red which predominantly consumed in northern Tanzania.

1.4. Objectives of the Study

1.4.1. General Objective

To determine the proximate composition, selected minerals and physicochemical quality attributes of fifteen cooking bananas of *Mchare* family (*Musa spp*.).

1.4.2. Specific Objectives

i. To determine and quantify proximate composition (moisture, ash, crude protein, crude fat, dietary fibre, carbohydrate and energy value) of fifteen cooking bananas of *Mchare* family.

ii. To determine and quantify concentrations of selected minerals (K, Ca, Zn and Fe) in the fifteen cooking bananas of *Mchare* family.

iii. To determine the selected physicochemical quality parameters of the fifteen cooking bananas of *Mchare* family [the total soluble solids (TSS), pH, total titratable acidity (TTA)].

1.5. Research Questions

i. What is the proximate composition of *Mchare* cooking bananas?

ii. What is the mineral profile of *Mchare* cooking bananas?

iii. What are the physicochemical properties of *Mchare* cooking bananas?

1.6. Significance of the Study

i. Information presented in this study may be vital to local farmers and food processors as a reliable selection tool for *Mchare* cooking bananas for development of banana-related food products, to breeders for developing new improved cultivars that can be readily adopted by local farmers and consumers. It also might be used to ascertain the potential of cooking bananas in food-based strategies in order to improve nutrition-sensitive agriculture, address hidden hunger and food security.

ii. The study carries the potential to maximize the use of underutilized local banana varieties by local communities. It might also stimulate researchers to pay attention to the underutilized varieties as an affordable and sustainable food source if identified to have potential nutritional and sensory properties. In other words, banana cultivars that contain genes specific for desirable characteristics may be considered for further studies in improving nutritional and sensory qualities in breeding programs/projects.

1.7. Delineation of the Study

This study focused on the evaluation of proximate composition, selected dietary minerals and physicochemical properties of fifteen (15) local bananas of *Mchare* family in Arusha. These bananas are *Mlelembo Mchare*, *Huti white*, *Kahuti*, *Ijihu inkundu*, *Makyughu* 1, *Makyughu* 2, *Mchare laini*, *Huti green*, *Akondro mainty*, *Njuru*, *Muraru Mchare*, *Majimaji*, *Muraru*, *Muraru* white and *Muraru* red. The samples for research materials were obtained at unripe green stage one of maturity in 2018 from two agricultural sites; (a) International Institute of Tropical Agriculture (IITA) and (b) World Vegetable Centre (WVC) both located in Arusha which represented the population. This study did not cover *Mchare* family members other than mentioned above. Similarly, the other non-*Mchare* banana varieties were not within the scope of this research. In this regard, the information reported in this document should not be used to refer all *Mchare* bananas and/or non-*Mchare* bananas.

CHAPTER TWO

LITERATURE REVIEW

2.1. Impact of Banana on Food Security in East Africa

Kilimo-Trust (2012) reported that banana (*Musa spp*.) is one of the most important staples and nutritional food in East Africa, it plays a central role in addressing food security to over 35 million people and reliable source of income for small-holder farmers in the local market. Bananas provide an annual income of about USD 1500 to about 4 million small-holder households. This is one of the major smallholder income-generating agricultural produce in the region (Mgenzi *et al.*, 2008). Banana is a practically non-seasonal crop that reliably grown in the region. Tanzania and Uganda alone produce over 50% of all bananas in Africa (Jacobsen, 2014). In fact, banana consumption per capita in Tanzania (100 Kg/year) and Uganda (350 Kg/year) are amongst the highest in the global rankings while banana production is estimated to be about 4 and 9 million metric tons per annum, respectively (Kilimo-Trust, 2012).

Banana is a climacteric fruit that is consumed in the ripe state. Affognon *et al.* (2015) observed that large quantities of fruit are lost during commercialization due to poor post-harvest practices. These bananas are produced primarily for local consumption and sale and rarely for export (BananaLink, 2015). A large number of unripe banana rejections or post-harvest losses are used as raw materials for domestic artisanal flour preparation (Aurore, Parfait Fahrasmane, 2009). They have the potential of being used as staple food in many developing countries and many researchers have studied applications of cooking banana flour as ingredients in various food products (Hoffmann *et al.*, 2016; Ohizua *et al*., 2017; Salih *et al.*, 2017; Savlak, Türker, & Yeşilkanat, 2016; Wang, Zhang, & Mujumdar, 2012).

Aurore *et al.* (2009) figured out that cooking bananas denote an alternative source of carbohydrates due to the relatively high starch content of the pulp, hemicellulose and lignin levels, as well as the low cost of the fruit that may allow the preparation of cooked recipes with appealing sensory and functional features. Previous studies have shown that cooking banana remains, among other crops, the forerunner of food security in the highland regions of Tanzania, central and some other parts of Uganda, Rwanda and Eastern Democratic Republic of Congo, where the crop has been staple food for local residents consuming about 70% of harvested bananas in their households (De-Langhe *et al.*, 2001; Smale & Tushemereirwe,

2007). Secondary banana products such as beer (*Lubisi*, *Tonto*, *Waragi*, *Mulamba*, *Mbege*), wine, banana crisps, chips, cooked dried bananas, juice, banana flour composites for making bread, chapattis and pastries) account for only about 30% (Carter *et al.*, 2010). Furthermore, banana is a key commercial crop and/or a major source of raw materials for not only food, beverage and handicraft industries but also the crop has great cultural and social implication (Ndunguru, 2009).

Bananas remain to be one of the reliable staple foods in East Africa. The nutritional benefits of spending a dollar on banana are comparatively higher than other popular food crops such as maize, rice, cassava and wheat. Bananas are rich in antioxidants, potassium, energy and vitamin C (Caballero, 2012). The other nutrients found in the fruit are vitamin B_6, protein, dietary fibre, riboflavin and niacin (Haslinda, Cheng, Chong, & Aziah, 2009; Suntharalingam, 1990). Potassium in banana is important in controlling the blood pressure. Magnesium, among other health benefits, helps in treating depression as helps in the relaxation of muscles and vitamin B_6 helps to have a good sleep (Lescot, 2000). Other advantageous benefits of banana consumption include weight loss, vision improvement, improvement of digestion and stronger bones (Ohizua *et al*., 2017). Table 1 compares nutritional benefits one USD on various food crops in East Africa with reference to banana.

Table 1: Comparative Nutrition Benefits of Spending USD 1 on Food Crops in East Africa

Nutrient	Unit	Banana	Rice	Sweet Potato	Cassava	Maize Grain	Sorghum Grain	Wheat	Beans
Energy	kcal	2745	3066	3233	5312	7446	8068	3449	5851
Proteins	g	29	60	59	45	192	269	100	414
Total fibre	g	52	11	113	60	55	150	136	437
Iron	mg	13	7	23	9	55	105	39	144
Potassium	mg	11224	966	12668	8997	5855	8330	4094	24703
Zinc	mg	3	9	11	11	45	27	31	49
Vitamin A	µg	1260	0	26651	33	0	0	0	0
Vitamin C	mg	414	0	90	684	0	0	0	79
Vitamin D	IU	16	0	0	0	0	0	0	0

Modified table adopted from Kilimo-Trust Banana Analysis Survey, 2012

In their findings, De-Langhe *et al.* (2001) reported that some communities of banana farmers in East Africa such as *Chagga*, *Haya* and *Nyakyusa* in Tanzania and *Buganda* in central and some other parts of Uganda, Kisii, central and eastern regions of Kenya have consistently

categorised the banana as one of their most essential crops since they produce fruits all-year-long, a property that places it above others as a food and income security crop. However, not all local communities substantially grow and prefer cooking bananas as a staple food, for example, *Sukuma*, *Kuria* and *Jita* in Tanzania are among them. The banana plant is beneficial in several aspects, being a perennial crop with a root network and broad leaves they maintain soil structure and provides a soil cover throughout the year hence reducing land degradation (Mohapatra, Mishra, & Sutar, 2010). This feature makes the banana crop a central element in environmental conservation. Banana has multi-purpose usages such as food, snacks, feedstuff, industrial spirits, soft and alcoholic drinks and a number of crafts, medicinal and therapeutic potential (Neumann & Hildebrand, 2009; Nguthi, Onyango, Muniu, Muthamia, & Njuguna, 1999). Studies have shown that banana produces a relatively cheapest carbohydrate and they are able to grow in a wide environmental spectrum and farming systems such as pure-stand, livestock-crop, intercropping and farming systems (Ouma & Jagwe, 2010).

From the above description of the impact of cooking in the region, it can be noticed how much the crop is important for human nutrition and other uses. There is a need to prioritize banana crops in reluctant banana-growing areas in agriculture system in the region in order to feed the rapidly increasing population. This calls for a need to addressing the importance of banana in solving food security and hidden hunger. This might also raise political awareness in the integration, consolidation and rationalization of governments' policies of banana-growing countries and regions.

2.2. An Overview of Banana Cultivars in East Africa

There are countless types of banana native to East Africa and these can be consumed fresh, fried, boiled and processed to be served as baby food, soft and/or alcoholic drinks (Bugaud, Alter, Daribo, & Brillouet, 2009; Salih *et al.*, 2017). Banana cultivars have been given several names which is a depiction of both their morphological variations and of the socio-linguistic diversity of the people naming them in numerous vernacular tongues around the globe (Karamura, 1999). The commonly grown cultivars are the East Africa Highland bananas (*Musa* AAA-EA), *Cavendish* subgroup bananas, AAB banana cultivars, *Musa* AB banana cultivars and ABB cultivars with numerous vernacular names (Table 2).

Table 2: Some of the Clones of Cooking Bananas in East African Countries

Tanzania	Uganda	Kenya	Rwanda	Burundi
Engumba	*Engumba*	*Ngongia*	*Ingumba*	*Ingumba*
Kisubi	*Ensika, Insika*	*Ngoromora*	*Inshika*	*Ishikazi*
Entalibwambuzi	*Ensowe,*	*Maffukha*	*Nakitembe*	*Makara*
Mchare, or Mshare	*Entukura, Emburasika*	*Munjuu*	*Injumbura*	*Ingamatayiri*
Illalyi	*Kibiddebidde*	*Enjobo*	*Bakurura*	*Bakurura*
Kipungara	*Nakawere*	*Muraru*	*Inzirabu shera*	*Inzirabu*
Ndizi Bukoba	*Bogoya Omumyufu*	*Uganda* Red	*Indemera*	*Igitsiri*
Kimalindi	*Kizungu* white	*Kamunyilya*	*Ingote*	*Inyamaizi*
Ndyali	*Bofulo*	*Mjenga*	*Inyamaizi*	*Igihuna*
Busilya	*Ekijungu*	*Kamunyilya*	*Inzinga*	*Inzinga*
Matoke	*Matooke*	*Matoke*	*Matoke*	*Matoke*

Modified Table adopted from Karamura *et al*. (2012).

East African Highland Bananas (EAHBs) are a subgroup of triploid (AAA-EA) bananas that considerably provide immediate nutrients and long run can address food security issues in Eastern Africa. Until recently, there has been no reliable evidence about their inherent variation, populace network and evolutionary account. They show some phenotypic variations, however, Kitavi *et al.* (2016) recently reported that all EAHB cultivars are genetically identical having descended from the first prototype brought to the African continent. East African Highland Bananas are by far the most widely distributed in the region stretching from the Eastern Democratic Republic of Congo to the Southern fringes of the Ethiopian highlands and down to Mbeya in Southern Tanzania (Karamura, 1999).

They are believed to be indigenous to this region with no clear similarity elsewhere in the world (Kitavi *et al.*, 2016). Altitude is the leading key reason accountable for group distribution (Perrier *et al.*, 2011). In Tanzania, mature green EAHB fruits are well known as *Embirabire, Enzinga, Endeishya, Matoke, Ndizi za kupika* and *Ekitoke Kisamunyu*. It is in this group to which *Mchare* banana family belongs (Karamura *et al.*, 2012). In Uganda, the EAHBs are known as *Kibiddebidde*, *Lwezinga*, *Nakawere*, *Nakhaki* and *Nakinyika*; in Rwanda and Burundi green EAHB are famously known as *Mbirabire*, *Bakurura*, *Ingumba Inyamunyu, Inzirabu shera* and *Insira* are usually cooked, steamed or boiled before consumption (Karamura *et al.*, 2012). The increasing population density and related land crumbling tied together with growing pest harms and destruction of available natural resources are all collectively limiting the

throughput of AAA-EA farming schemes (Onyango, Karamura, Keeley, Manshardt, & Haymer, 2009).

Cavendish bananas fit the AAA genome group, i.e., the cultivars that possess three copies of each gene-bearing chromosome (Vézina, 2018). *Cavendish* bananas are some of the fairly studied banana cultivars. This AAA typical group, which includes *Lacatan*, Red Banana, *Gros Michel* and *Cavendish* bananas, is the most widely grown group of edible bananas. Unlike EAHBs, *Cavendish* dessert bananas are sweet and grow better in lower altitudes below 1000 metres above sea level usually along coastal regions (Hippolyte *et al.*, 2012). *Gros Michel* exceptionally found around the Lake Victoria region at a marginally higher altitude range and now creates an important cooking banana in the area (Lejju *et al.*, 2006). Bananas in this group being sweet fruits, some parts around the Great Lake region. Consumers mainly use the crushed ripe bananas usually mixed with millet flour or other cereal flour for fermentation. The hazy beer produced has long been distilled locally where residents use the beverage as a refreshment drink (Karamura *et al.*, 2012). In East Africa, the clones in this group recognized as *Enkundi, Ng'ombe, Kiguruwe, Kimalindi, Israeli, Omutsiri, Kiise, Ntotomya, Giant Cavendish* and *Malindi* (Karamura, 1999). Most cultivars of this group are prone to black leaf streak and Panama disease, while they are usually relatively resistant to weevil plague (Perrier *et al.*, 2011; Vézina, 2018). These banana cultivars serve as dessert food and they are also important for local sales but exports remain low (Kilimo-Trust, 2012).

AAB banana cultivars is a lowland cultivar growing best below 700 metres above sea level and grow scarcely above 1000 metres above sea level (De-Langhe, 1986b). Most of the clones of this group are identified, however, are yet to be investigated nutritionally (De-Langhe *et al*., 2001). The typical examples in this group are *Nkonjwa, Prata, Gonja, Ndizi ya kuchoma, Mzuzu* in Tanzania. *Ngongia* in Kenya. *Makemba, Mzuzu* or *Misheba* in Democratic Republic of Congo. *Muzuzu* in Burundi. *Umushaba* in Rwanda and *Gonja, Gonje, Wette* and *Adeke* in Uganda (Karamura *et al*., 2012). Cultivars in this group are also called plantains that are usually roasted and sometimes cooked. The AAB cultivars, however in Kagera region of Tanzania, it still does well where they are grown extensively but not intensively, plantain is a major food in the coastal regions and low plains of East Africa as well (De-Langhe *et al*., 2001). Plantains appear to be predominantly susceptible to weevil occurrence. Likewise, Pratas is grown widely in the identical ecological ranges, however in Burundi, yet perform better at high altitude (De-Langhe *et al*., 1986b). *Musa* AAB "*Apple*" banana is another clone in this group that is popular

in the region. *Apple* bananas are widely grown in the traditionally known banana produced areas. In Tanzania for example, *Apple* bananas are known as *Kisukari Kubwa* are largely produced in Morogoro, Kagera, Kilimanjaro, Zanzibar and Usambara mountain ranges in the north-eastern region of the country while in Kenya, *Apple* bananas are grown in Western, Nyanza and Central Provinces. Other regions in East Africa are Rwanda and Wakiso, Masaka, Luweero and Bushenyi Mubende districts in Uganda. In Rwanda, they are well known as *Kamaramasenge* and in Uganda as *Sukari* or *Sukari Ndiizi* (De-Langhe, 1986a; Karamura *et al.*, 2012). The AAB bananas are grown for sustenance reasons and local market.

ABB banana cultivars are a group of banana cultivars belonging to the three subgroups, namely *Pisang Awak, Monathan* and *Bluggoe* (Karamura, 1999). Furthermore, Karamura *et al.* (2012) reported that there are nearly 13 to 14 other cultivars belonging to this group. Very little is exposed about this group in terms of both nutritional value and agronomic potentials. The plants are moderately flexible regarding ecological conditions, even though they grow optimally in regions below 1000 metres above sea level (Price, 2006). In Southern Tanzania for example, the ABB cultivars like *Ndyali, Busilya* and *Ndizi nyama* have been accepted for use as cooking bananas. Again, it is very widely spread and often an important food crop. Furthermore, most cultivars in this group were later adopted as beer bananas in Uganda and Rwanda, generally because of their capability to increase production regardless of unfavouring growing conditions (Karamura *et al.*, 1998). The cultivars are, therefore, the backbone for the local beer industries. The ABB bananas display good environmental tolerance, believed to be hardly affected by the soil nematodes, black Sigatoka and weevil attack (Karamura, 1999) may be advantageous to local beverage industry owners.

AB banana cultivars are another group of banana cultivars with a genome category comprising all the cultivars that possess a double set of chromosomes, one contributed by *Musa acuminata* and the other by *Musa balbisiana* (Kitavi *et al.*, 2016; Simmonds & Shepherd, 1955). So far, however, little attention has been paid to this banana group. The most common cultivars include *Ndizi Kisukari, Kipakapaka Ndogo, Ganda, Kipukucha, Subi, Gisubi kagogo, Kasubi, Kasukari, Barwokole* and *Kisubi*. Some varieties like *Ndizi Kisukari, Gisubi kagogo, Kasukari* are primarily dessert bananas, not to mention its high juice-yielding property (Staver & Capra, 2017) while *Kisubi/Kasubi* is harsh in flavour, this restricts them to both beer and juice processing (Karamura *et al.*, 1998). Currently, farming of the AB bananas remains dispersed across the East Africa region (Ndunguru, 2009).

A number of banana accessions other than those mentioned above have been imported into the region along with improved varieties such as Honduran Foundation for Agricultural Research (FHIA) hybrids that are optimistic indeed (Ndayitegeye *et al.*, 2017; Rowe & Rosales, 1993). Other improved banana cultivars are being developed by the International Institute of Tropical Agriculture (IITA) in Tanzania and Uganda and Biodiversity International for evaluation and improvement purposes across East Africa. Another group of cultivars "endemic" to the area have yet to be characterised (Onyango *et al.*, 2009), they comprise the *acuminata* species all over Kilimanjaro region and two *acuminata* wild sorts in Zanzibar assemblage (Karamura *et al.*, 2012). These cultivars are believed to be peculiar from the EAHBs of the Great Lakes Zone but the key differences among them are not yet clearly understood. Apart from the *acuminata* spices of Zanzibar Islands in Tanzania, the characteristics of divergent materials in the region's collections have yet to be studied (Karamura *et al.*, 2012; Karamura, 1999).

From the above overview, it can be noticed that there is a huge and wide diversity of banana cultivars in East Africa but only a few of them have been studied. As indicated earlier, more work is necessary to characterise not only desirable agronomic characteristics but also the biochemical, sensory and physical quality parameters of under-privileged cultivars across the region for public nutrition welfare and food security stability. Some cultivars, as noted above, are resistant/tolerant to harsh environmental conditions, this advantage may be a breakthrough if used appropriately in fighting against agronomic threats yet addressing the food security even more effectively.

2.3. Nutritional Value and Health Benefits of Cooking Bananas

Bananas and plantains are available in most tropical domestic farmyards and are readily acceptable and preferable. In fact, bananas with sweet potatoes are often the first solid foods fed to infants in most East African families (Davies, 1995). There are numerous procedures for preparing cooking bananas, which differs across different ethnical groups (Onyango *et al.*, 2009). Bananas have substantial quantities of carbohydrate content and have low-fat contents (Table 3) making them particularly useful in low-fat diets. Bananas, including plantains, are also a good source of many vitamins (A, B's and C) and minerals (K, Ca, Mg, P and Mn) (Haslinda *et al.*, 2009). The low sodium and high potassium contents of the fruit are of sound implication in dietary terms and are recommended for better cardiovascular health (Elmadfa,

2005). However, as it is generally known, the protein level is relatively low to the major staple food crops such as maize, sorghum, wheat and in this case cooking bananas (Caballero, Trugo, & Finglas, 2003). Despite the nutrient density of banana; Reis, Viana, Jesus, Santos, and Oliveira (2016) reported that the method of preparation may affect the nutritional value of the banana recipe. For instance, if fried, the oil used considerably boosts its energy value. However, cooking may also destroy bioactivity and availability of vital heat-sensitive food components such as vitamins and the like (Pareek, 2016). Nevertheless, this is not the case with ripe bananas.

Other minerals such as calcium, iron, zinc and copper (Table 3) found in cooking bananas can help to optimize the metabolism by providing a stable, complex carbohydrate base for energy generation in the body (Elmadfa, 2005). Although fresh green bananas are a good source of vitamin C, almost 65% is lost during the preparation of banana products such as recipes, flour, drinks and snacks (Suntharalingam & Ravindran, 1993). Other less known advantages of banana consumption include vision improvement, bone strengthening and weight loss (Caballero, 2012). Biochemical characteristics of cooking banana suggest nutrients essential for human health.

Table 3: Estimate of Proximate Composition of Cooking Banana Genotypes

Parameter	Quantity (g/100 g DM)
Carbohydrate	16.1 – 80.0[2,4,5]
Moisture content	1.0 – 27.7[1,2]
Crude protein	0.4 – 4.2[3,4,6]
Crude fat	1.1 – 4.7[2,4,6]
Dietary fibre	6.0 – 7.5[1,2,5]
Total ash	2.4 – 11.7[1,2,5]

[1]Anuonye *et al*. (2012); [2]Aurore *et al.* (2009); [3]Deshmukh *et al.* (2009); [4]Haslinda *et al.* (2009); [5]Savlak *et al.* (2016) and [6]Schmidt *et al*. (2015).

Tapsell *et al.* (2016) reported that one of the recent dietary trends in nutrition and health is to consume low-carbohydrate food products. Consumers are demanding foods showing two main properties: the first one deals with the traditional nutritional aspects of the food, whereas, as a second feature, additional health benefits are expected from its regular ingestion (American Diabetes Association, 2012). There has been a substantial discussion about the metabolic effects of limiting carbohydrate intake in weight and diabetes control (Anderson, Kendall, &

Jenkins, 2003; Franz *et al*., 2002). However, the American Diabetes Association (2012) has noted that weight and metabolic improvements can be achieved with low carbohydrate and low fat. Cooking bananas are rich in fibrous carbohydrates, which can offer the named benefits. In a rapidly changing world, with altered food habits, sedentary and stressful lifestyles, it is more and more recognized that a healthy digestive system is essential (Brouns, Kettlitz, & Arrigon, 2002). In the case of cooking bananas, the parenchymatous tissues and cell walls supply the dietary fibres. In the digestive tract, for example, fibre exercises a safeguarding effect that links excess of acid in the stomach and stimulates the intestinal evacuation (Slavin, 2013). Moreover, it provides a favourable environment for the growth of the beneficial intestinal flora (Drzikova, Dongowski, Gebhardt, & Habel, 2005). Fibre can also bind cholesterol and get rid of it. More importantly, fibre plays a central role in the preclusion and management of diabetes, obesity, atherosclerosis and cardiovascular diseases (Peters *et al.*, 2003; Terry *et al.*, 2001). Some carbohydrates in cooking bananas can speed up the calorie-burning process in the body, thanks to the short-chain fatty acids found in them (Hijova & Chmelarova, 2007). Researchers have found that this type of fatty acids can improve the body's ability to absorb nutrients, particularly calcium (Jenkins *et al.,* 1998).

Table 4 shows potassium as the principal mineral in banana. Some other essential minerals found in a banana are Fe, Zn, Ca, sodium (Na) and magnesium (Mg). Fresh green banana is a good source of vitamin C, but almost 65% is lost during the preparation of banana products such as recipes, flour, drinks and snacks (Suntharalingam & Ravindran, 1993).

Table 4: Estimate of Mineral Contents of Cooking Banana Genotypes

Element	Quantity (mg/100g DM)
Potassium	259.0 – 733.9[1,4]
Magnesium	21.2 – 106.0[2,5,6]
Calcium	10.1–132.4[3,4,5]
Sodium	0.1 – 23.9[2,6]
Iron	0.3 – 12.2[3,4]
Zinc	0.7 – 2.8[1,6]
Copper	0.1 – 2.1[2,4,5]

[1]Arvanitoyannis and Mavromatis (2009); [2]Aurore *et al*. (2009); [3]Deshmukh *et al*. (2009); [4]Hardisson *et al*. (2001); [5]Haslinda *et al.* (2009) and [6]Suntharalingam *et al*., (1993).

The carbohydrate, protein fractions, mineral concentration, vitamins and other functional potentials of the under-privileged cooking banana non-*Mchare* varieties like *Gonja*, *Kimalindi*, *Ekitoke*, *Ingumba*, *Insira*, *Ntotonya*, *Enkundi* and many more cultivars need further investigations. Such information might be a breakthrough in crop improvement and nutrition-sensitive agricultural activities leading to nutrients (such as vitamins, carbohydrate and minerals) increase in bananas that are greatly solicited currently in combating hidden hunger in developing countries. It is also noted that the biochemical composition of banana peels have not adequately studied as either human food, animal feed or medicinal extracts, this may be due to their limited usages.

2.4. Physicochemical Characteristics of Cooking Banana Cultivars

Systematized study of the physicochemical characteristics of foods and food products is a relatively new scientific arena (Salih *et al.*, 2017). Physicochemical properties are of great interest to food scientists and farmers because of their close connection with the quality of the produce or product, not to mention their influence on the sensory and processing characteristics of foods (Baiyeri, Aba, Otitoju, & Mbah, 2011; Belayneh *et al.*, 2014). Since cooking bananas are inherently perishable, it is expected that substantial-quality losses ranging from a slight loss of quality to total spoilage may occur at any point in the value chain (Affognon *et al.*, 2015). According to Prusky (2011), quality of cooking banana changes rapidly after harvest and thus substantially affects the acceptability by the consumers. Firstly, fruit selection is based on physical appearance, colour, gloss size and then by texture, pH, total soluble solids (TSS) content and total titratable acidity (TTA). These parameters supply important information to the consumers in recognizing fruits with appealing sensory quality and draw special attention to researchers (Drogoudi, Michailidis, & Pantelidis, 2008). The presence of various oxo-acids identified as malic and oxalic, contribute to the acidity and pH hence influence the taste of the cooked banana.

The TSS concentration of the fruit, on the other hand, is commonly obtained by measuring the °Brix of the fruit pulp. Table 5 shows the average ranges of TSS of cooking banana. Brix offers a clue of how much sugar is concentrated in the pulp (Alkarkhi, Bin-Ramli, Yong, & Easa, 2011) and it is influenced by minerals, fats, proteins, carbohydrates and organic acids present in the pulp (Jayasena & Cameron, 2008). It represents at least 10% of the unripe fresh banana weight and increases as fruit mature and ripen to produce less acidic and sweeter pulps

(Hoffmann *et al.*, 2016). While Zn, Mg and Fe all increase TSS substantially, nitrogen and K have a negligible effect on TSS (Hasani, Zamani, Savaghebi, & Fatahi, 2012). However, it is reported that Molybdenum (Mo) induces a decrease in TSS and may also help improve the ascorbic acid content of the fruit (Kazi, Ismail, & Joshi, 2012).

Fruit properties like pH, TSS and TTA among others are also of utmost interest for researchers in studying behaviours of fruits under different experimental settings (Belayneh *et al.*, 2014). The presence of various oxo-acids identified as malic and oxalic, contribute to the acidity and pH hence influence the taste of the cooked bananas. Table 5 summarizes the average ranges of physicochemical properties of cooking banana varieties.

Table 5: Ranges of Physicochemical Properties of Unripe Banana Genotypes

Parameter	Quantity	Unit
pH	4.7 – 6.5[3,4,5]	-
TSS	0.5 – 2.7[3,4,5]	%
Viscosity	35.7 – 47.5[1]	mPa s
TTA	1.9 – 2.2[3]	%
Ascorbic acid	1.4 – 33.5[1,3]	mg/100g

[1]Alkarkhi *et al.* (2011); [2]Arvanitoyannis & Mavromatis (2009); [3]Belayneh *et al.* (2014); [4]Bugaud *et al.* (2009); [5]Savlak *et al.* (2016).

Thorough understanding of the inherent properties of cooking banana is essential for the development of better hybrids and novel food products that meet consumers' expectation. Important developments about these properties might include significant efforts in determining them as well as their prediction based on composition to meet dietary and sensory demands.

2.5. Sensory Characteristics and Consumers' Preferences Banana Cultivars

Sensory quality is a superficially clear but elusive concept and sensory evaluation is necessary to acquire information on claimed facets of food quality to which no other objective technique can be employed (Lawless & Heymann, 2010; Meilgaard, Carr, & Civille 2006). Sensory attributes play an important part in how consumers discern the quality and preferences of a produce or food product (Green-Petersen, 2010). Certainly, colour and taste are some of the central parts of the human regular sensory practice. For example, a particular food should have a specific colour and taste feature to be appealing and palatable to the consumer (Caballero *et*

al., 2003). Like any other food, cooked banana stimulates biological and emotional responses accustomed to knowledge, environment, education and traditional practices (Lawless & Heymann, 2010). The impression of the dullness of food is related to habitually and involuntarily with sub-standard or inferiority. In contrast, natural and bright colours give the sensory feeling of nutritious, high-quality, beneficial foodstuff (Costell, Tárrega, & Bayarri, 2010). For this reason, banana consumers are not only concerned with the nutritional value of the food, but also the amount of inherent ingredients that improve the consumers' sensory demand like colour and flavour (Callaghan, Weisbord, Dew, & Pyle, 2012), not to mention their ability to show outstanding health effects (Grashorn, 2005). The appearance and inherent flavours of cooked banana, therefore, serves as one of the leading criteria on which consumers base their choices while purchasing the produce. Caballero *et al.* (2003) noted that sensory attributes of food may cause a reduction in the contentment of the given food after it is consumed on regular basis and an increase to a substantial food intake if that property is changed by the successive presentation of different foods. In light of this, sensory evaluation plays a significant role in the quality control of not only developed banana hybrids but also banana food products (Wang, Sun, Pu, & Cheng, 2017).

A range of factors, along with sensory attributes and beliefs about the nutritional and socio-economic value of the foods also influences food choice. Nevertheless, it is even more challenging to conclude the relative importance of beliefs about the sensory aspects of foods (Nestle *et al.*, 1998). Consumer food preference is considered as a function of the interactive combination of the individual, person's culture and beliefs, sensory characteristics of the food, previous exposure to it and subsequent expectations or the situation in which the food is consumed (Caballero *et al.*, 2003; Vabø & Hansen, 2014). Furthermore, East African banana producers grow cultivars preferred by local communities in terms of sensory attributes, a phenomenon known as varietal compartmentalization (Kilimo-Trust, 2012). However, such compartmentalized varieties are not appropriate for sale to communities with different banana varietal alternatives. Kilimo-Trust (2012) reported that this has hindered the growth of the banana trade and with urbanization, not all types of bananas have won popularity in East Africa's major urban centres. Cooking bananas gained their tremendous popularity in the East African region probably due to their appealing sensory properties (Onyango *et al.*, 2009). These properties are attributed by several inherent compounds that have a significant effect on consumer sensory quality. Among other bioactive components in cooking banana, the most prominent ones are phenolic compounds which show numerous and notorious health benefits

such as high antioxidant activity and useful physiological functionalities (Bujor, Giniès, Popa, & Dufour, 2018; Carocho & Ferreira, 2013). However, these compounds may reduce the palatability of cooked bananas, largely due to the noticeable bitter and astringent taste (Pu *et al.*, 2018). It is claimed that higher-molecular-weight (> 430) polymers appear to be astringent and phenolic polymers of lower molecular weight are more likely to be bitter (Drewnowski & Gomez-Carneros, 2000). As the molecular weight increases to approximately ten units, tannins gradually become more astringent and less bitter (Bravo, 1998). It has been reported that the sensation of astringency increases significantly with the increase of tannin concentration with a tendency to mask perceived bitterness (Villamor, 2012). These particular components are commonly linked to reduced preferences of unripe banana (Muñoz-González *et al.*, 2018) and can influence the taste of cooked bananas hence lower eating quality (Suárez-Estrella, Torri, Pagani, & Marti, 2018).

Sensory properties, mainly colour, aroma and taste, are major factors affecting quality perception and consumer's acceptance of any food. Appearance and colour form initial quality features attracting consumers. Nonetheless, the flavour (the overall blend of both nasal and oral stimulation) may have the largest impact on acceptability and desire to consume it again. As outlined above, cooking bananas contain compounds that are in some cases not appealing to consumers. Because of limited information resources available so far, this review emphasizes more palatability studies focusing on the analysis of flavour compounds and carrying out a sensory evaluation of under-utilized banana cultivars. This is necessary to identify inherent compounds responsible for un-appealing flavours and reveal the consumer acceptability of cooked banana. In addition, sensory information on under-utilized bananas may be useful for the improvement of these cultivars to more palatable sensory attributes that may help in reducing the compartmentalized banana cultivars and diversify their usage. Further work is required to establish this.

2.6. The Role of Breeding in Improving the Quality of Cooking Bananas

Crop plants have been bio-engineered in order to have different but desired characteristics. Thanks to plant breeding technologies which developed from the artificial selection methods based on phenotypes over decades. To meet the needs of the fast-growing population in East Africa and elsewhere, yield improvement has been a key emphasis in breeding and some other genetic manipulation of food crops (Opara, Jacobson, & Al-Saady, 2010; Rowe & Rosales,

1993; Smale & Tushemereirwe, 2007). The demand for better quality crops and fruits that are rich in nutrients and which can endure the needs of the regional and global supply chain is growing quickly (Gordon *et al.*, 2017). Although food production has expanded over the recent decades, nutrient deficiency poses a new challenge to people that lack physical and/or economical access to a balanced diet and rely on staple food crops with low levels of micronutrients and essential amino acids (Dwyer & Drewnowski, 2017). For examples, recently, considerable researches by International Institute of Tropical Agriculture (IITA) in Tanzania and Uganda and Biodiversity International across East Africa have focused their programs on improvement of banana cultivars with respect to agronomic traits e.g., high yielding and disease or pest-resistant traits through breeding and other biotechnological techniques (Karamura *et al.*, 2012). These are some of the remarkable efforts in addressing food security and hunger in the region, however, due to public awareness to nutrition quality parameters, such as nutritional value, taste, colour, texture, to mention a few, are becoming increasingly important in current banana consumers in the region (Christinck & Weltzien, 2013; Fan & Pandya-Lorch, 2012).

From the short review above, this suggests that it is very important to include both nutritional and sensory quality aspects in future banana breeding programs. Advances in biotechnology make it possible to study these complex, multifactorial traits and come up with the possible solutions. The breeding for nutrition and sensory quality should aim to make more nutritious and appealing food, readily available and accessible and of course, the increase food production and diversity. Studies have shown the potential to exploit the genetic variation and breeding in fruit concentration of iron, zinc and other trace minerals without the general negative effect on yield of adding new desirable traits (Kumssa *et al.*, 2017; Moreira, Moraes, & Dos-Reis, 2018). The use of biotechnological techniques, such as molecular marker-aided selection, will notably increase the speed and prospects of realization for breeding to improve not only the agronomic features but also the nutritional value and sensory quality of cooking bananas. Apart from the development of hybrids that are resistant to pests and diseases, fruit sensorial evaluations are imperative in the course of selecting new cultivars. Banana fruits must have flavour, shape, texture, colour, size and aroma that meet consumers' requirements (Dadzie & Orchard, 1996). Evaluations provide valuable information that may help the future improvement of food crop through breeding or genetic programs.

Therefore, it is suggested that the future attention to banana breeding should be geared towards designing genetic strategies and developing breeding materials to meet the following requirements. Sustaining banana nutritional value and sensory quality throughout the post-harvest supply chain as a means to preclude or reduce nutrient deficiency and food loss. Maintaining quality at increased production and yield and achieving desirable quality banana under sub-optimal growing conditions. These are important issues for future research.

Banana cultivars for cooking are of great importance in food security affairs in Tanzania and in Africa at large, making this crop an object of common interest. Full characterisation of its nutrient value, physicochemical attributes and concentration of useful bioactive compounds especially from under-exploited cultivars is necessary. The banana family has a wide range, with many accessions and cultivars grown, nevertheless, in future the genetic engineering and breeding technologies has to help improve nutritional and sensory qualities from this banana diversity whenever possible. Thus, banana cultivars that contain genes specific for desirable and useful characteristics may be considered for developing targeted nutritional, sensory and agronomic qualities for bananas. It is therefore essential that researchers, donors, farmers, consumers and traders are made aware of the importance of this crop in the region, in order to ensure that a level of resources commensurate with its importance is directed towards its improvement in the future for public nutritional welfare.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

3.1.1. Chemicals and Reagents

Table 6: Chemicals and Reagents Used in the Study

Chemical/Reagent	Manufacturers
Sulphuric acid (H_2SO_4), 98%	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
Nitric acid (HNO_3), 68%	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
Hydrochloric acid (HCl), 36% and 0.02 N HCl solution	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
Perchloric acid ($HClO_4$), 70%	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
4% Boric acid (H_3BO_3)	Merck Chemicals (Pty) Ltd, 259 Davidson Road, Wadeville, Gauteng, RSA
Sodium hydroxide (NaOH), 40% and 0.1 N NaOH solution	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
pH buffers 4, 7 and 10	Loba Chemie Pvt. Ltd, 107, Wodehouse Road, Jehangir villa, Mumbai-400005. India
Kjeldahl Selenium tablets	Sigma-Aldrich, Co.3050 Spruce Street, St. Louis Mo 63103 USA.
Petroleum ether (C_6H_{14})	Gato Perez, 33-P.I.Mas d'En Cisa. 08181 Sentimenat SPAIN. Made in Spain.
Filter paper	Thomas Scientific, Swedesboro, USA
Standard solutions for K, Ca, Fe and Zn	Merck Chemicals (Pty), 259 Davidson Road, Wadeville, Gauteng, RSA
Ultrapure water (Milli-Q Type 1)	UPW-PP1463, National Chemist Office, Headquarter Dar es Salaam, Tanzania
Phenolphthalein (POP) indicator	Loba Chemie Pvt. Ltd, 107 Wodehouse Road, Jehangir villa, Mumbai-400005. India
Ethyl alcohol/Ethanol (C_2H_6O), 95%	Merck Chemicals (Pty), 259 Davidson Road, Wadeville, Gauteng, RSA

3.1.2. Laboratory Equipment

Table 7: Laboratory Equipment Used in the Study

Equipment	Model and manufacturer
Air oven	Memmert, Mode 023583i31, Germany
Centrifuge machine 5000 and 7000 rpm	Universal 320 Hettich-Zentrifugen, Germany and Eppendorf Centrifuge 5430 R, Germany
Water bath	S/N A114120801-64 Wagtech Project
pH meter	Greisinger Model GMH 3500, Regenstauf, Germany
Atomic absorption spectrometer (AAS)	Thermo Scientific® iCE 3500, Waltham, USA
Semi-auto titrator	Titronic Nr 00679531, Germany
Cool box	Cool box S/N 14728341 Made in China
Analytical balance	S/N 8332140269 Made in China
Freezer	Thermo Scientific® iCE i700, Waltham, USA
Kjeldahl system	Behrotest® InKjel System, Behr Labor-Technik, Dusseldorf, Germany
Muffle furnace	Thermo Fisher Scientific®, Waltham, USA
Soxhlet system	KIKA-WERKE Co. KS 501 Digital made in Germany
Total Dietary Fiber Assay Kit	Megazyme™
Hand-held Refractometer (0 – 32% Brix)	Erma™ Refractometer, Tokyo, Japan
Chopping knives and slicer	Gato Perez, 33-P.I.Mas d'En Cisa. 078341 Sentimenat, Spain
Gloves	Made in China
Refrigerator	Thermo Scientific® iCE 2300, Waltham, USA
Plastic bags for waste collection	Loba Chemie Pvt, 107 Wodehouse Road, Jehangir villa, Mumbai-400005. India
Safety goggles	Merck Chemicals (Pty), 259 Davidson Road, Wadeville, Gauteng, RSA
Blender	Loba Chemie Pvt, 107 Wodehouse Road, Jehangir villa, Mumbai-400005. India
Grinder	Erma™ Grinder, Tokyo, Japan

3.2. Experimental Materials and Study Site

Fifteen local cooking bananas of *Mchare* family included *Mlelembo Mchare, Huti white, Kahuti, Ijihu inkundu, Makyughu* 1, *Makyughu* 2, *Mchare laini, Huti green, Akondro mainty, Njuru, Muraru Mchare, Majimaji, Muraru, Muraru* white and *Muraru* red (Fig. 1) obtained at unripe green stage one of maturity (Aurore *et al.*, 2009). This was achieved with the help from IITA field experts. Mentioned varieties were collected from two research centres, the

International Institute of Tropical Agriculture (IITA) and the World Vegetable Centre (WVC) in the Arusha region of Tanzania were used for the study. The cultivars were chosen based on the consumption popularity among consumers in the northern zone of the country and secondly, due to the demand of an ongoing IITA breeding program that currently is developing new *Mchare* cultivars with improved agronomic traits, also with similar or improved nutritional and physicochemical quality parameters.

3.3. Sampling and Research Design

Banana samples of healthy, clean fingers at the matured green stage, from the banana orchard at NM-AIST and Tengeru research units, were randomly collected/harvested early in the morning from a farm of about two hectares. Then from the middle part of banana bunches of every single variety, fingers were collected as experimental samples. Newly collected banana samples were then used to carry out the entire analytical test and evaluation. From each sample set, a laboratory sample was prepared (peeling, chopping and grinding) and frozen at -20 °C (Dadzie & Orchard, 1997) for subsequent nutritional analyses. The analyses were done in triplicate for each variety, also the blank for each parameter was simultaneously run.

Figure 1: *Mchare* banana family depicting the diversity in fruit morphology. A: *Njuru*, B: *Muraru* red, C: *Muraru*, D: *Muraru* white, E: *Akondro mainty*, F: *Muraru Mchare*, G: *Mlelembo Mchare*, H: *Mchare laini*, I: *Makyughu* 2, J: *Makyughu* 1, K: *Majimaji*, L: *Kahuti*, M: *Ijihu inkundu*, N: *Huti* white and O: *Huti* green. *Source*: Images compiled from the International Institute of Tropical Agriculture (IITA), Arusha, Tanzania.

3.4. Proximate Composition, Mineral Analysis and Energy Estimation

3.4.1. Determination of Moisture Content

The moisture content of banana samples was analysed by the oven method according to Association of Official Analytical Chemists (AOAC), (2012), where 1 g of sample was heated at 105 °C for 24 h in a forced-air oven (Memmert, Germany). The difference in weight before and after drying was recorded as moisture content and used to estimate the water percentage of a given mass of the sample by using equation (*i*).

$$\%Moisture = \frac{weight\ of\ water\ in\ the\ sample\ (g)}{initial\ weight\ of\ the\ sample\ (g)} \times 100\% \quad \text{..... Eqn. i}$$

3.4.2. Determination of Ash Content

Ash content was determined by the change in weight as described by AOAC (2012), which involved burning off moisture and all organic components of 1 g sample at 500°C in a Muffle Furnace (Thermo Fisher Scientific, Waltham, USA) overnight. The ash content obtained by weighing the incinerated sample and estimated using equation (*ii*).

$$\%\ Ash = \frac{weight\ of\ ashed\ sample\ (g)}{initial\ weight\ of\ the\ sample\ (g)} \times 100\% \quad \text{..... Eqn. ii}$$

3.4.3. Determination of Crude Protein

Crude protein content was measured by the Kjeldahl method using Behrotest® InKjel System (Behr Labor-Technik, Dusseldorf, Germany) according to AOAC (2000) standard method. The method involved digestion of 0.5 g ground dried sample in 10 mL of conc. Sulphuric acid (H_2SO_4) catalyzed by Kjeldahl Selenium tablets at 400 °C for 1 h to liberate the organically bound nitrogen (N) in the form of ammonium sulphate ($[NH_4]_2SO_4$). The ammonia gas (NH_3) in the digest was then diluted with 40 mL of 40% Sodium hydroxide (NaOH) then distilled off into a 20 mL of 4% Boric acid (H_3BO_3) receiver solution and then titrated with standard 0.02 N Hydrochloric acid (HCl). Sample protein per cent was estimated using equations (*iii*) and (*iv*), respectively. A conversion factor of 6.25 was used to convert total nitrogen to percentage crude protein.

$$\%\ N = HCl\left(\frac{mol}{ml}\right) \times \frac{corrected\ acid\ vol.used\ (mL)}{initial\ weight\ of\ the\ sample\ (g)} \times 14\ \left(\frac{gN}{mol}\right) \times 100\% \ldots\ldots\ldots\ldots \text{Eqn. iii}$$

$$\%\ Protein\ = \%N \times 6.25^{*} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. iv}$$

*6.25 is the protein conversion factor

3.4.4. Determination of Crude Fat

Crude fat was determined by Soxhlet extraction method according to AOAC (2012). Crude fat was extracted from the sample powder with 40% petroleum ether (C_6H_{14}) as the solvent, soon after extraction, the solvent was evaporated off to get the fat extract. The difference between the initial and final weight of the extraction flask was recorded as the crude fat content. At time intervals of 20 – 30 min, the extracting solution was tapped to the boiler, to begin the cycle for the second time. Ether extract (fat) was obtained by calculating the mass of oil removed using equation (*v*).

$$\%\ Crude\ fat\ = \frac{weight\ of\ fat\ extract\ (g)}{initial\ weight\ of\ the\ sample\ (g)} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. v}$$

3.4.5. Determination of Total Dietary Fibre

Dietary fibre was determined by an enzymatic-gravimetric technique using AOAC Method 2009.01, where soluble and insoluble fibres were both quantified in the assessment. Three test portions of 10 g of each homogenized and dried sample set were defatted with petroleum ether. Defatted samples were subjected to enzymatic digestion (α-amylase, protease, amyloglucosidase) to breakdown simple sugars, protein units and starch molecules. Phosphate buffer, containing an α-amylase enzyme (pH 6.0 ± 0.2, 50 mL) was added to the sample and incubated at 95 - 100 °C to achieve gelatinization in a water bath for 30 min. The sample mixture was then cooled to room temperature and pH was adjusted to 7.5 ± 0.2, this was followed by adding protease enzyme to remove protein materials from the sample and incubated at 60 °C for 30 min. The sample mixture was again cooled and the pH adjusted to 4.0 – 4.6. Digestion ended up by adding amyloglucosidase enzyme to remove starch molecules from the sample mixture and incubated at 60 °C for 30 min. At 60 °C 280 mL 95% ethyl alcohol (C_2H_5OH) was added to the mixture to allow the precipitation process for 60 min. The residues (soluble and insoluble fibres) were collected in pre-weighed crucibles before they were filtered,

solvent-washed, dried and weighed. One remained test portion was analyzed for protein content, using 6.25 as the conversion factor while the second test portion was incinerated in a Muffle Furnace at 525 °C for 5 h to quantify ash content. The amount of residue, protein and ash was recorded for each sample set. The total dietary fibre (TDF) content was calculated using the equation (*vi*) below.

$$\%\ TDF\ = \frac{weight\ of\ residual - protein - ash - blank\ (g)}{initial\ weight\ of\ the\ sample\ (g)} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots \textit{Eqn. vi}$$

3.4.6. Determination of Available Carbohydrate and Energy Value

Available carbohydrate concentration was calculated as the difference between 100% and the sum of the percentages of moisture, crude protein, crude fat, ash and dietary fibre contents. The energy value was calculated using the Atwater's conversion factors whereby the total grams of protein concentration and carbohydrate content multiplied by a factor of 4 kilocalories per gram of the sample and total lipid content was multiplied by a factor of 9 kilocalories per gram (AOAC, 2012).

3.4.7. Determination of Selected Minerals' Concentrations

The mineral concentrations of the sample materials were evaluated using the technique described by Onwuka (2005). Potassium (K), calcium (Ca), iron (Fe) and zinc (Zn) element concentrations were measured by Atomic Absorption Spectrophotometer (AAS) (Thermo Scientific iCE 3500, Waltham, USA). One gram of each sample was weighed into a 150 mL Erlenmeyer flask and 20 mL of the acid mixture [containing 325 mL conc. Nitric acid (HNO_3), 40 mL Perchloric acid ($HClO_4$) and 10 mL of conc. Sulphuric acid (H_2SO_4)] was added. The content was mixed and heated gently in a digester at a medium heat under a fume hood and heating continued until dense white fume appeared. Heating continued for 40 seconds and then allowed to cool followed by the addition of 50 mL of distilled water. The solutions were filtered using filter paper (Thomas Scientific, Swedesboro, USA) into a 100 mL volumetric flask and made up to mark with distilled water. The resultant solutions were read on the AAS. The instrument was adjusted with commonly used standards (K 2, 6, 10 ppm; Ca 5, 15, 30 ppm; Fe 2, 4, 10 ppm; Zn 2, 4, 6 ppm) and samples were analysed at corresponding wavelength. The required hollow cathode lamp corresponding to the required mineral and holders in the lamp

compartment was installed to determine the concentration of each mineral. The dilution factor for potassium and calcium was 50 and 20, respectively while for iron and zinc was 1.

3.5. Analysis of Physicochemical Quality Parameters of the Selected Cooking Bananas

3.5.1. Determination of Total Soluble Solids

Total Soluble Solids (TSS) was assessed by grinding 50 g of flesh matter of banana samples, which was taken from the cross-sectional part of the banana fruit, into 70 mL ultra-pure water for about 5 min in a blending machine. The slurry sample was then centrifuged to get 50 mL of clear liquid, which was used for analysis. Using a pipette, a single droplet of the filtrate was carefully positioned on a prism of a well-calibrated hand-held refractometer (Erma Refractometer 0 – 32% Brix, Tokyo, Japan) equipped with automatic temperature compensation system at 25 °C, according to Dadzie and Orchard (1997) and reported as °Brix.

3.5.2. Determination of pH

The clear liquid obtained from procedures in section 3.5.1 above was used to measure the pH values of the fruits. The pH values of the fresh fruits were determined by the potentiometric method using a digital pH Meter at 25 °C (Greisinger Model GMH 3500, Regenstauf, Germany).

3.5.3. Determination of Total Titratable Acidity

For each sample, 6 g of clear fruit supernatant prepared in section 3.5.1 above was weighed into a 100 mL beaker. Total acidity of the filtrate for each sample was estimated by titrating it against a standard solution of sodium hydroxide 0.1 N NaOH to an endpoint of 8.2 (measured with the potentiometer) and the millilitres (mLs) of NaOH used was recorded. The total titratable acidity (TTA) was calculated and reported as per cent malic acid (predominant acid) using the following formula.

$$\%\ Acidity = \frac{(mL\ of\ NaOH\ used)\times(0.1M\ NaOH)\times(0.067)}{initial\ weight\ of\ the\ sample\ (g)} \times 100\% \quad \text{.....Eqn. vii}$$

0.067 is the milliequivalent factor for Malic acid.

3.6. Statistical Analysis

Data collected from analyses and experimental runs were subjected to Analysis of Variance (ANOVA) and reported as a mean ± standard error (SE) of the three replicates. A Tukey's Honestly Significant Difference (HSD) test at $p = 0.05$ was employed to test statistical differences between means using Statistica 10 for Windows (TIBCO Software Inc., 3307 Hillview Avenue Palo Alto, CA 94304 USA). For more details, kindly look at the appendices.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Proximate Composition of the Selected Cooking Bananas

The results of the proximate composition are summarized in Table 8. There were significant varietal differences in all parameters analysed. Moisture content for *Majimaji* was notably highest of all varieties while *Huti* green had the lowest moisture content. The mean moisture content for the studied bananas ranged from 65.53 to 74.44 g/100 g. These findings were in line with previous results reported by Aurore *et al.* (2009) for unripe bananas (63.00 – 74.00 g/100 g). In contrary, the moisture content, in the current study, was lower than the findings of *Grand Naine* cultivars grown with bio-fertilizer reported by Vazquezshy *et al.* (2012) which ranged from 77.77 to 78.86 g/100 g. The moisture level of foods or food products provides a clue of its freshness and shelf life (Annor, Asamoah-Bonti, & Sakyi-Dawson, 2016). Food stuffs with more moisture level are susceptible to increased microbial damage and reduced shelf life, which may result in its decomposition (Baiyeri *et al.*, 2011). The level of moisture content in any raw food crop is greatly dependent on the genetic factors of individual variety and the site factors (e.g., soil) (Thompson, 2011). This explains why there may have been differences in the moisture content observed between the studied banana cultivars. For more statistical details look at Appendices 1 and 2.

A significant varietal difference in the total ash content of the assessed varieties was also observed (Table 8). The ash content ranged from 0.66 to 1.45 g/100 g. The lowest ash content was 0.66 g/100 g for *Makyughu* 2 which may indicate lower mineral concentration (Kumssa *et al*., 2017). In contrast, *Ijihu inkundu* exhibited the highest ash content value signifying high mineral levels of cooking bananas (Table 8). The present results tie well with the previous conclusion reached by Ohizua *et al*. (2017) who found the ash content of the unripe banana flour to be 1.09 g/100 g, which is in line with average ash content for the *Mchare* bananas. According to Vazquezshy, Karina, Adriano-Anaya, Salvador-Figueroa, and Ov (2012) and Pragati, Genitha, and Ravish (2014), it was revealed that ash content values for cooking bananas range from 2.89 to 2.93 g/100 g and 3.52 to 3.75 g/100 g, respectively, which were higher than the present findings. This varietal variation might be attributed to the different varietal ability to absorb minerals. For more statistical details look at Appendices 3 and 4.

Table 8: Proximate Composition and Energy Value of 15 *Mchare* Cooking Bananas (g/100 g)

Variety	Moisture	Total Ash	Protein	Fat	Total fibre	Carbohydrate[#]	Energy value (kcal)
Mlelembo M.	66.62±0.17^{fgh}	1.12±0.01^{d}	0.61±0.01^{g}	0.14±0.01^{ef}	2.30±0.10^{ab}	29.19±3.46^{abc}	120.77±0.32^{b}
Huti White	71.69±0.13^{abcd}	0.91±0.01^{e}	0.73±0.01^{efg}	0.39±0.03^{bcde}	2.29±0.08^{ab}	23.99±0.45^{abcd}	102.76±0.34^{f}
Kahuti	72.00±1.56^{abc}	1.17±0.01^{cd}	0.69±0.01^{efg}	0.44±0.02^{abc}	2.29±0.76^{ab}	22.55±1.91^{bcd}	96.47±0.47^{g}
Ijihu Inkundu	67.72±0.28^{efgh}	1.45±0.02^{a}	0.91±0.05^{def}	0.22±0.01^{def}	1.65±0.15^{bc}	28.05±0.70^{abcd}	117.21±0.45^{c}
Makyughu 1	69.64±0.43^{cde}	0.87±0.04^{e}	0.80±0.06^{defg}	0.15±0.03^{ef}	2.70±0.10^{ab}	25.84±1.08^{abcd}	108.68±0.57^{e}
Makyughu 2	65.97±0.22^{gh}	0.66±0.01^{f}	1.75±0.01^{a}	0.53±0.03^{ab}	2.47±0.20^{ab}	28.75±0.75^{abcd}	128.62±0.09^{a}
Mchare laini	66.52±0.37^{fgh}	1.32±0.01^{ab}	1.29±0.04^{bc}	0.38±0.05^{bcde}	0.92±0.01^{c}	29.57±1.19^{ab}	127.18±0.90^{a}
Huti Green	65.53±0.48^{h}	1.28±0.02^{bc}	0.90±0.06^{def}	0.30±0.06^{cde}	2.03±0.05^{abc}	29.96±2.22^{a}	126.63±0.62^{a}
Akondro M.	70.59±0.04^{bcde}	1.30±0.05^{bc}	1.34±0.05^{b}	0.12±0.01^{f}	2.48±0.06^{ab}	24.17±0.99^{abcd}	102.52±0.48^{f}
Njuru	73.43±0.14^{ab}	0.85±0.01^{e}	0.66±0.04^{fg}	0.60±0.15^{a}	2.13±0.03^{ab}	22.33±0.90^{cd}	96.97±0.42^{g}
Muraru M.	71.37±0.42^{bcd}	0.86±0.02^{e}	1.03±0.03^{cd}	0.30±0.06^{cde}	1.89±0.07^{abc}	24.55±1.06^{abcd}	105.96±0.54^{e}
Majimaji	74.44±0.25^{a}	0.92±0.01^{e}	0.76±0.03^{efg}	0.09±0.01^{f}	1.86±0.12^{abc}	21.59±1.69^{d}	90.22±0.26^{h}
Muraru	68.76±0.59^{defg}	0.89±0.03^{e}	1.51±0.04^{ab}	0.42±0.03^{bcd}	1.64±0.07^{bc}	26.78±0.71^{abcd}	116.71±0.60^{c}
Muraru Wh.	69.34±0.59^{cdef}	0.90±0.02^{e}	0.84±0.04^{defg}	0.48±0.03^{ab}	2.16±0.03^{ab}	26.28±0.60^{abcd}	112.99±0.28^{d}
Muraru Red	70.78±0.89^{bcd}	0.94±0.05^{e}	0.94±0.03^{de}	0.18±0.01^{def}	2.79±0.07^{a}	24.37±0.55^{abcd}	102.61±0.56^{f}
F statistics	23.30***	78.55**	47.71***	10.79***	4.81***	4.03***	446.8**

Values are mean ± SE. *Number of replications = 3*. Values are on a dry weight basis except for moisture content whose values are on a wet basis. **, *** = significant at $p \leq 0.01$ and at $p \leq 0.001$, respectively. *Mlelembo M.* – *Mlelembo Mchare*, *Muraru M.* – *Muraru Mchare*, *Muraru* Wh. - *Muraru* White. [#]Carbohydrate content was calculated by difference. Means with different superscript letters within columns are significantly different from each other by Tukey's test at $p = 0.05$.

Table 8 summarizes results of the protein content of *Mchare* banana varieties. The protein content of the varieties varied significantly and ranged from 0.61 to 1.75 g/100 g. Likewise, Ashokkumar, Elayabalan, Shobana, Sivakumar, and Pandiyan (2018) and Ohizua *et al*. (2017) recorded that the dried and dehydrated unripe banana flour contained 0.80 – 3.10 g/100 g, which was actually higher than 0.8 – 1.06 g/ 100 g reported by Vazquezshy *et al*. (2012). The value of crude protein content was highest for the *Makyughu* 2 (1.75 g/100 g) and lowest for *Mlelembo Mchare* (0.61 g/100 g). The mean value of crude protein for the studied bananas (0.98 g/100 g) is lower than other starchy staples. One hundred grams of the cooking banana supply roughly 6% of the Recommended Daily Allowance (RDA) for protein, see Appendices 5 and 6 for more detailed information. Protein is required for the human body to supply an adequate amount of required amino acids (Ashokkumar *et al*., 2018). The crude protein level of the studied samples was also relatively lower when compared with other sources of protein-rich foods such as, beans, gourd seeds and soybeans which ranges between 22.8 – 34.0% (Carocho & Ferreira, 2013). This suggests that consumers should consume protein-rich foods to supplement the protein deficit in bananas.

The fat content of the studied bananas ranged from 0.09 to 0.60 g/100 g with significant variation between *Mchare* bananas (Table 8). The present values are lower than of the previous studies (2.34 g/100 g and 1.03 – 1.44 g/100 g) reported by several studies (Ohizua *et al.,* 2017; Pragati *et al.*, 2014; Vazquezshy *et al*., 2012). Similar values for unripe banana (0.20 g/ 100 g) was reported by Lukmanji *et al.* (2008). *Njuru* had the highest value of fat content followed by *Makyughu* 2, *Muraru* white, *Kahuti* and *Muraru*. These may be good sources of fat-soluble vitamins and might also contribute substantially to the caloric level of cooked banana recipes. *Majimaji*, on the other hand, had the lowest value. The variation in the crude fat content of the cooking bananas may be due to the genetic differences in varieties and ecological reasons (Annor *et al.*, 2016). Despite the fact that the amounts of fat were generally low, variations among the varieties were statistically significant. For more statistical details look at Appendices 7 and 8. One hundred grams of the evaluated bananas can provide not more than 4% of the RDA for fat. Banana-based foods and other low-fat diets can help lose weight and reduce the risk of serious medical conditions, including heart disease and diabetes.

The dietary fibre results of the varieties studied were significantly different. The fibre content of the studied bananas ranged from 0.92 to 2.79 g/100 g (Table 8). Findings from this study are

in sparing agreement with the dietary fibre content of unripe *Cavendish* banana flour which ranged from 2.34 g/100 g and 2.75 g/100 g and 2.96 g/100 g (Anggraeni & Saputra, 2018; Ohizua *et al*., 2017). *Muraru* red was found to have the highest fibre content (2.79 g/100 g) followed by *Makyughu* 1 (2.70 g/100 g), *Akondro mainty* (2.48 g/100 g) and *Makyughu* 2 (2.47 g/100 g) while *Mchare laini* had the lowest fibre content of 0.92 g/100 g (Appendices 9 and 10). In addition, there was no significant different between *Majimaji*, *Muraru Mchare* and *Huti* Green. Dietary fibre plays a central role in human nutrition. It has been associated with increased removal of impending mutagens. Also helps control blood sugar levels. Maintains bowel health, not to mention lowering of the cholesterol levels (Drzikova *et al.*, 2005). A hundred grams of the studied banana might deliver 12% of the recommended allowance for dietary fibres. Tapsell *et al.* (2016) reported that one of the recent dietary trends in nutrition and health is to consume low-fat and high-in-fibre food products. Consumers demand foods which show two main properties: (a) traditional nutritional aspects of the food and (b) additional health benefits expected from the regular ingestion (American Diabetes Association, 2012). Some of the studied bananas are rich in fibrous carbohydrates, which offers the named benefits.

Table 8 also presents the carbohydrate contents of the evaluated banana varieties. Results revealed a significant varietal difference ($p < 0.001$) in the mean values of both carbohydrate and energy value. The carbohydrate content ranged from 21.59 to 29.96 g/100 g. The content of carbohydrate was the second most abundant among all proximate parameters analysed, preceded by moisture content. While *Huti* green had highest values of carbohydrate tailed by *Mchare laini* and *Mlelembo Mchare*; *Huti* White, *Ijihu inkundu*, *Akondro mainty*, *Muraru* red, *Muraru* white, *Muraru Mchare*, *Muraru* and *Makyughu* 1 and 2 were not statistically different. *Majimaji* had the lowest value. A similar pattern of results was obtained by Aurore *et al.* (2009) for the unripe bananas in a range from 21.80 to 32.00 g/100 g. One hundred grams of the assessed bananas can provide roughly 17% of the RDA for carbohydrate. This suggests that studied bananas may be used to fight against food security in banana-growing regions. Moreover, some carbohydrates in cooking bananas are reportedly able to speed up the calorie-burning process in the body due to the available inherent short-chain fatty acids (Hijova & Chmelarova, 2007). Additionally, this type of fatty acids can improve the body's ability to absorb nutrients, particularly calcium (Jenkins *et al.*, 1998). For more statistical review look at Appendices 11, 12, 13 and 14.

4.2. Mineral Content

Results for K, Ca, Fe and Zn concentration is presented in Figs. 2 – 5. Significant variations ($p < 0.001$) in mineral concentrations were observed. Potassium was found to be the most abundant element in all the varieties studied with the mean value of 410 mg/100 g (Fig. 2). On the other hand, *Akondro mainty* had the highest Ca and Fe concentrations (Figs. 3 and 5), whereas *Makyughu* 1, *Majimaji*, *Njuru* and *Akondro mainty* had the highest non-significant K content (Fig. 2) while *Ijihu inkundu* had the highest Zn content followed by *Akondro Mainty, Makyughu* 1 and *Huti* green (Fig. 4). The high levels of K obtained in this study make these cultivars useful to people with cardiovascular compromised conditions (Daniells, 2003).

There was wide variability in Ca content between *Akondro mainty* (6.07 mg/100 g) and the rest of the bananas which ranged from 2.59 to 4.55 mg/100 g (Fig. 3 and Appendices 15 - 22). The exceptional physiological ability of *Akondro mainty* to absorb the mineral may explain the observed variation (Zhang *et al.*, 2010). Calcium is very important in the formation of strong bones and teeth, for blood clotting, growth, cell metabolism and heart function. Similar values for K, Ca, Zn and Fe of unripe bananas was 465 mg/100 g, 2.00 mg/100 g, 0.10 mg/100 g and 0.60 mg/100 g, respectively (Lukmanji *et al.*, 2008). The average value obtained for Zn was rather the lowest of all the elements of interest in this study. The levels of K, Zn and Fe show a similar pattern with the findings from other studies on unripe *Cavendish* bananas (Ashokkumar *et al.*, 2018; Aurore *et al.*, 2009). Furthermore, Ohizua *et al.* (2017) reported Fe content value of 1.26 mg/100 g for unripe *Burro* bananas, higher than the values from the present study. Generally, Fe serves as a carrier of oxygen to the tissues from the lungs by thrombocyte's haemoglobin and as an integrated part of important enzyme systems in various tissues. Zinc, on the other hand, is present in all body tissues and fluids and is also an essential component of a large number of enzymes and it plays a central role in the immune system. Several studies reported comparatively higher Ca levels in other unripe varieties as well as in plantains as opposed to the present study (Ashokkumar *et al*., 2018; Aurore *et al*., 2009). Of specific importance, while focusing on the nutritional significance from staple food crops is the contribution of micronutrients, which are widely reported to be deficient and causing severe public health concerns in low-income communities in Tanzania and Africa in general (Tanzania Demographic Health Survey - Malaria Indicator Survey (TDHS-MIS), 2016). Deficiencies of Fe and Zn are core public health concerns, especially for child and maternal health (Black *et al.*, 2013).

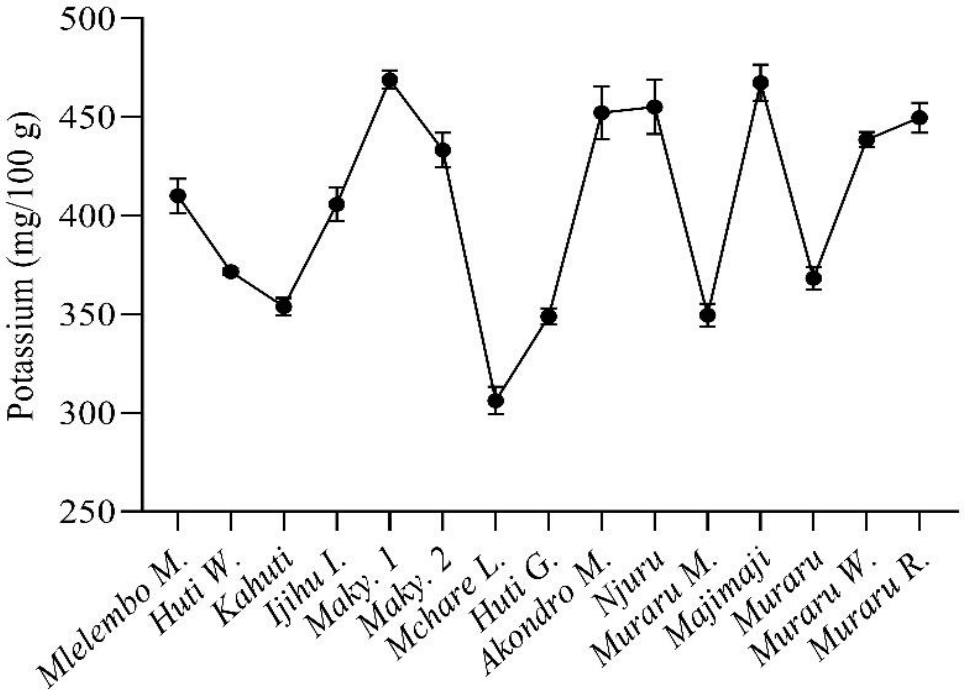

Figure 2: Potassium (K) contents of the studied *Mchare* family varieties

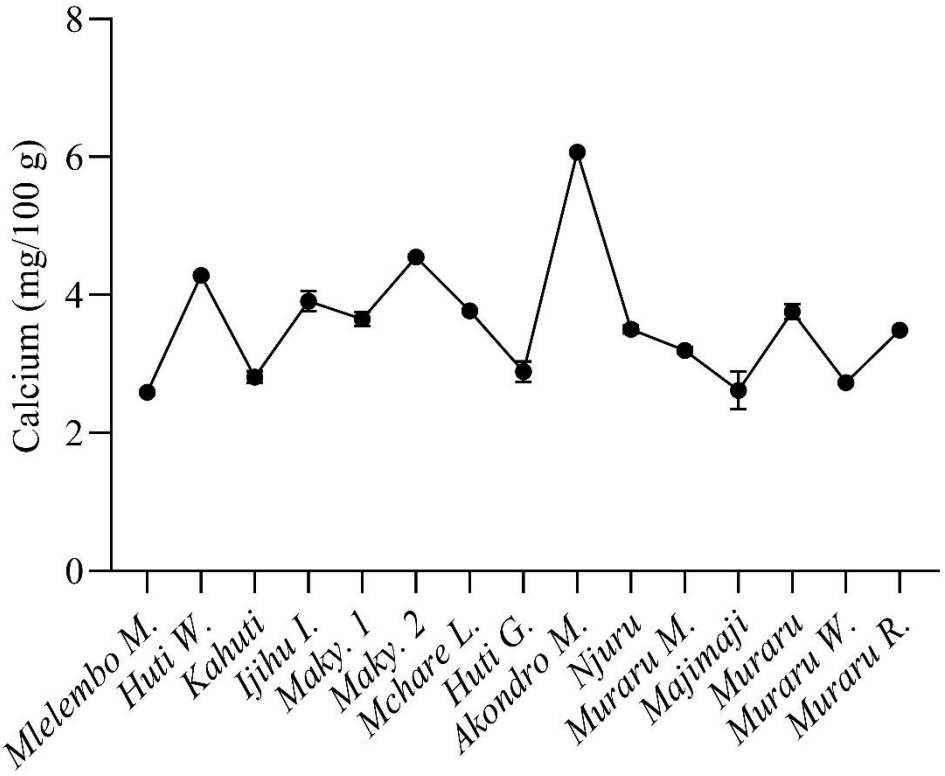

Figure 3: Calcium (Ca) contents of the studied *Mchare* family varieties

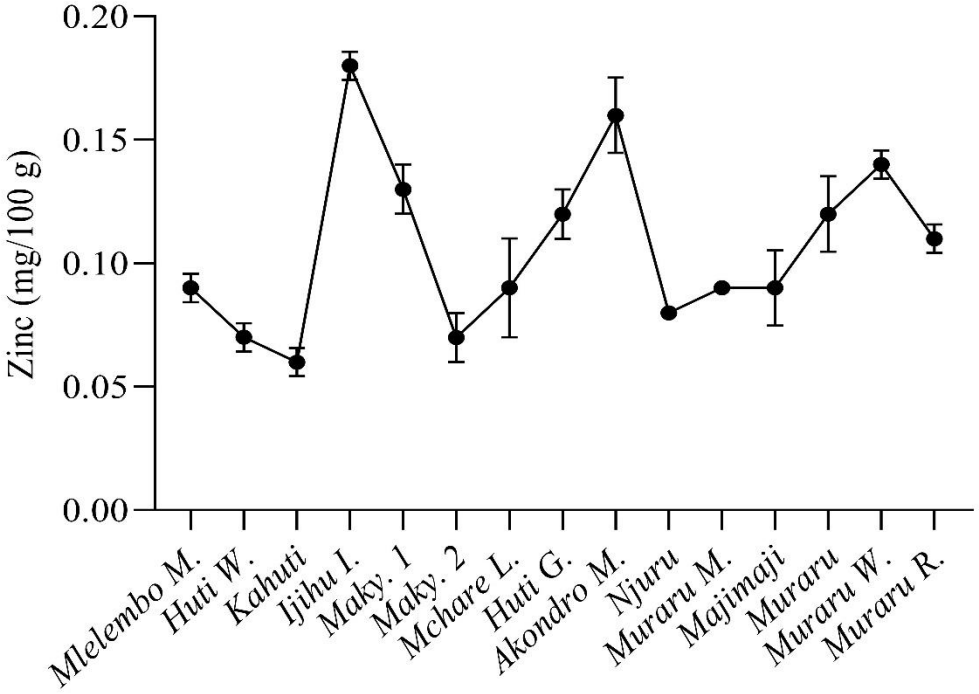

Figure 4: Zinc (Zn) contents of the studied *Mchare* family varieties

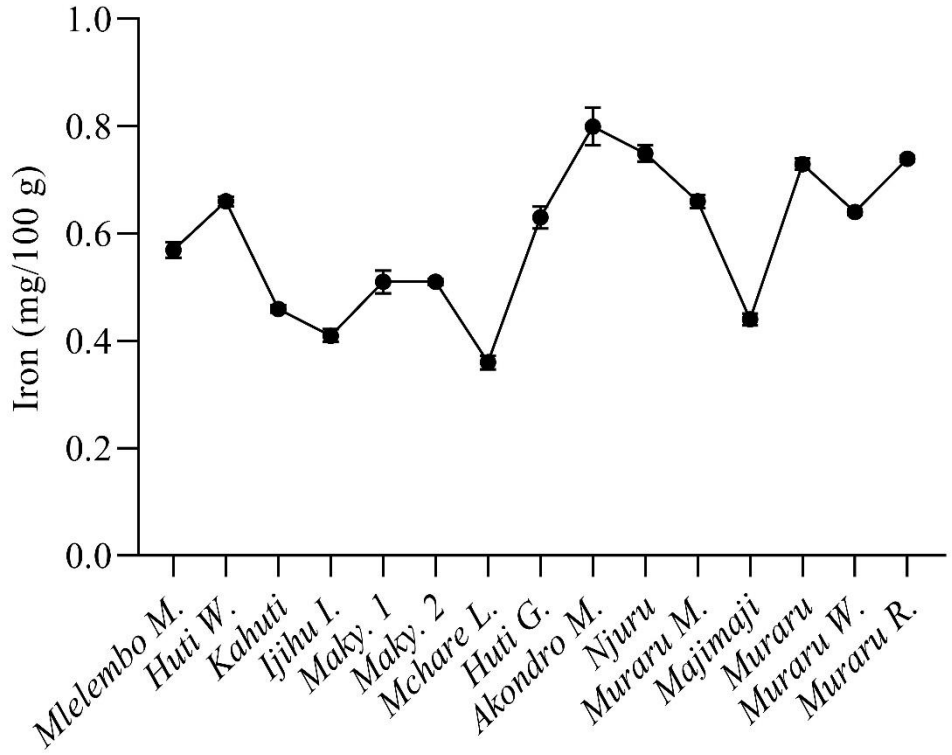

Figure 5: Iron (Fe) contents of the studied *Mchare* family varieties

Cooking bananas generally contain little amount Zn and Fe (Figs. 4, 5 and Appendices 15 - 22). Moreover, Frossard *et al.* (2000) and Njoumi *et al.* (2018) suggested that bioavailability of these minerals and other nutrients like protein from other sources such as beans, legumes, edible insects, poultry and meat is likely to be higher than from the cooking bananas. Therefore, banana-based diets could receive a boost with the addition of the mentioned sources to the diets to make them nutrient balanced.

4.3. Physicochemical Quality Parameters

Total soluble solids (TSS), total titratable acidity (TTA) and pH were the physicochemical parameters of interest in this study and results are summarized in Figs. 6 – 8 and detailed in Appendices 23 and 24. A significant varietal difference ($p < 0.001$) in the mean values of TSS was observed. The TSS values for the *Mchare* bananas were observed in a range from 1.3 to 1.9 °Brix (Fig. 6). A similar finding (1.14 to 2.38 °Brix) was reported by Chandler (1995) for unripe *Musa acuminate* spp. The TSS values of the present study were significantly lower than for the unripe *Cavendish* bananas (2.00 – 6.00 °Brix and 3.66 – 6.30 °Brix) as recorded by Liew and Lau (2012) and Aquino *et al.* (2017), respectively. While *Mlelembo Mchare* and *Majimaji* had equal highest TSS value, there was no observed significant difference between *Ijihu Inkundu, Akondro mainty, Kahuti, Njuru, Makyughu* 1 and 2, *Muraru Mchare, Mchare laini, Muraru* White, *Huti* Green, *Muraru* red and *Huti* White (Fig. 6 and Appendix 24). In principle, TSS indicates soluble solid content of the fruits. High TSS has been linked with high sucrose concentration in fruit pulp, also together with dry matter and some other factors, TSS influences the taste of cooked bananas (Ohizua *et al*., 2017). Contrary to the present study, Ferris *et al.* (1999) and Muchui *et al.* (2010) established that the TSS genotypic variation in banana fruit at the unripe mature stage is not significant, however, it became more apparent as the fruit ripened. Therefore, for tastier bananas, consumers are advised to cook semi-ripen or consume ripen bananas. Dadzie and Orjeda (1998), suggested that any variation in TSS values in banana pulp might be due to differences in textural and chemical contents which could influence the TSS values of banana at unripe green stage one of maturity.

On the other hand, the TTA values for the *Mchare* bananas under study were statistically different (Fig. 7 and Appendix 26). *Akondro mainty* had the highest value of TTA, followed by *Muraru Mchare, Ijihu inkundu* and *Kahuti* while *Muraru* white had the lowest value. However, no statistically notable difference between *Mchare laini, Njuru, Mlelembo Mchare,*

Makyughu 2, *Majimaji*, *Muraru* and *Muraru* white was observed (Fig. 7 and Appendix 25). High level of acidity indicates that the varieties contain a high amount of malic acid in its pulp and vice versa. The pulp TTA values are consistent with Dadzie and Orjeda (1998) with malic acid content ranging from 1.5 to 2.5% at harvest for plantain hybrids and Honduran Foundation for Agricultural Research bananas (or FHIA bananas). Furthermore, the TTA parameter is essential for sensory attributes in cooked banana recipes. The TTA measures the total hydrogen ion concentration (both dissociated and undissociated), which is more relevant to the flavour than pH (Friesen, 2017). Similarly, banana varieties had a significant difference in pulp pH values in a range of 5.4 to 5.8 (Fig. 8 and Appendix 28). *Mchare laini* and *Huti* green both had equal highest pH values, succeeded by *Makyughu* 2 whereas *Mararu* white had the lowest pH value. Meanwhile, no significant difference was found between *Muraru* red, *Makyughu* 1, *Mlelembo Mchare*, *Njuru*, *Muraru*, *Ijihu inkundu* and *Huti* white (Fig. 8). According to Dadzie and Orjeda (1998), the pH paralleled the values for banana fruits at a maturity stage. This further proves the nature of the fruit samples used in the current study. The pH may, therefore, be used as a maturity indicator for banana harvesting (Dadzie & Orchard, 1997). Furthermore, both pH and titratable acid parameters are indicators for the number of organic acids and inherent salts contained in a fruit (Pareek, 2016), the higher the value of the parameter, the higher the number of acids and salts. Adding to that, Daniells (2003) reported that both parameters affect gel formation during the cooking process, hence they determine the final texture and mouthfeel of the cooked bananas. See Appendices 27 and 28 for more statistical description.

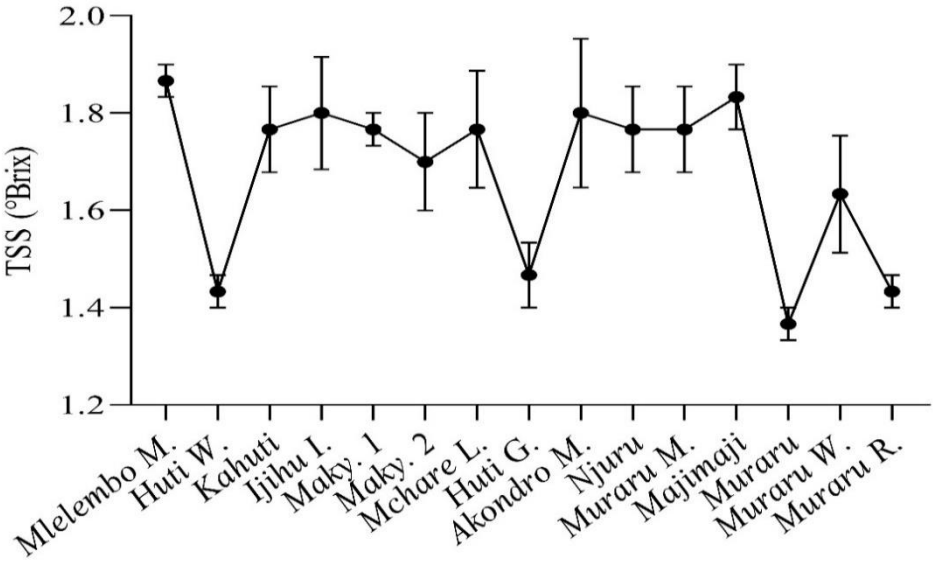

Figure 4: Total soluble solids (TSS) contents for the studied *Mchare* banana varieties

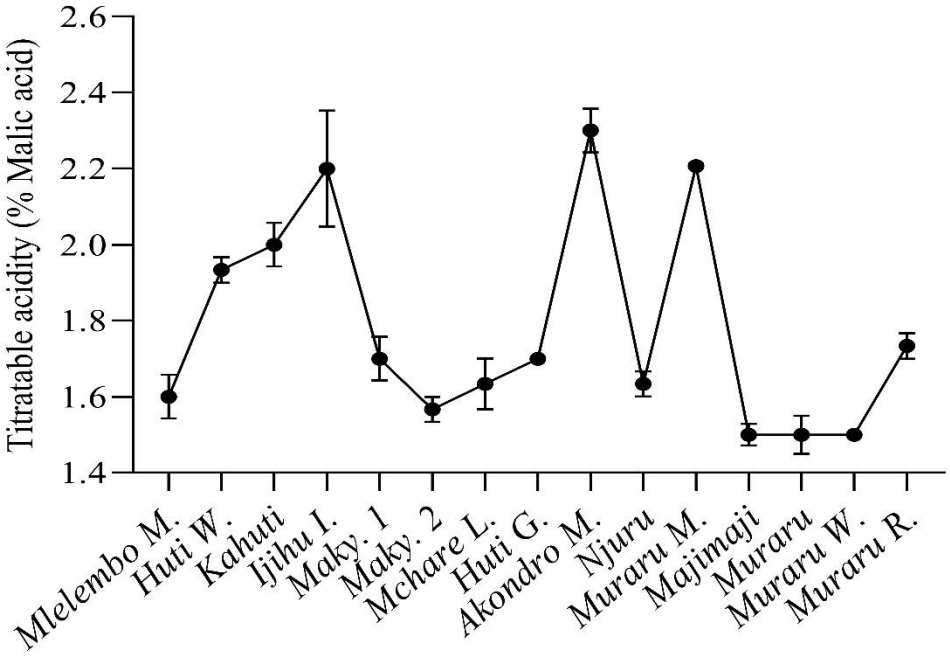

Figure 5: Total titratable acidity (TTA) contents for the studied *Mchare* family varieties

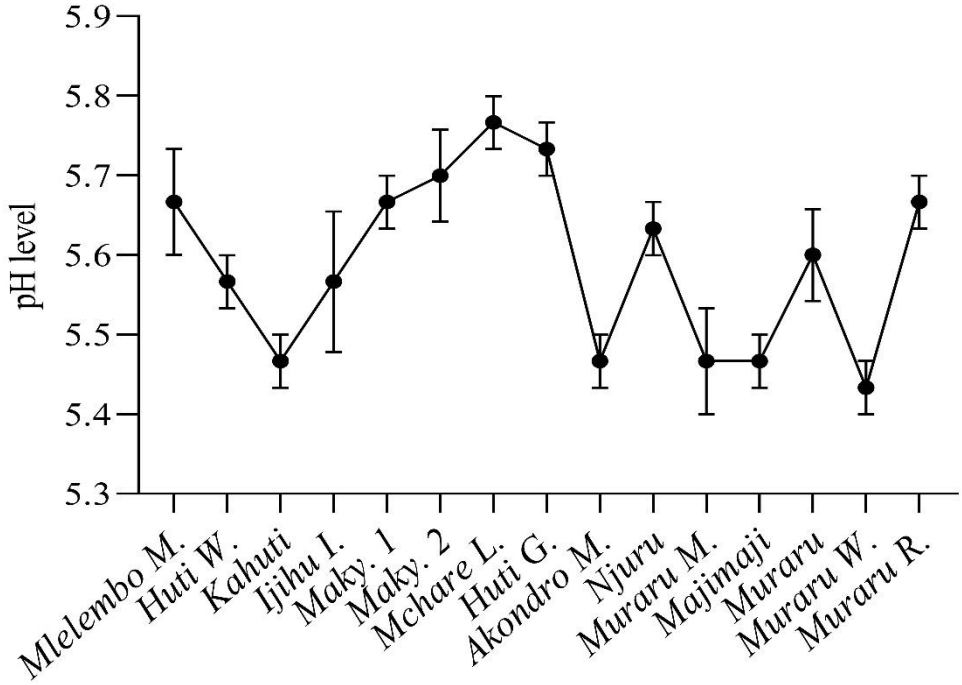

Figure 6: pH levels for the studied *Mchare* family varieties

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main goal of the current study was to determine the proximate composition and selected minerals and physicochemical quality parameters of 15 cooking bananas of *Mchare* family mainly consumed in northern Tanzania. Generally, these findings indicated that *Akondro mainty* had superior values for nutritional and physicochemical characteristics tailed by *Njuru*, *Makyughu* 2, *Mchare laini*, *Majimaji*, *Ijihu inkundu*, *Huti* green, *Muraru* red and *Makyughu* 1 in that order. Likewise, *Makyughu* 1 had the highest proportion of K concentration while *Akondro mainty* had the highest content of Ca and Fe. The highest fat content was observed in *Njuru*, *Makyughu* 2 contained the highest level of protein whereas the water content highest in *Majimaji*. The highest carbohydrate content was observed in *Huti* green while the highest dietary fibre content was found in *Muraru* red. In terms of green matured fruit, the physicochemical quality was found to be significant amongst the tested varieties. *Akondro mainty* had the highest TTA content, *Mlelembo Mchare*, *Makyughu* 2 and *Mchare laini* had the highest pH and *Ijihu inkundu* had the highest TSS values. This study has provided a deeper insight into understanding the important attributes of *Mchare* bananas. It may act as a reliable selection tool of *Mchare* cooking bananas as food commodity and cash crop for banana producers and businessmen in northern Tanzania for the development of banana-related food products. Moreover, these findings might be important to breeders for developing new improved cultivars that could be readily adopted by local farmers and consumers. Findings from the present study could also be crucial to be considered in the national food composition database of Tanzania for enhancing its value.

5.2. Recommendations

Cooking bananas have been one of the potential commodities which serve as both food and cash crop to the local farmers in the northern zone of Tanzania. As a cash crop, bananas provide reliable revenue to the farmers, which in turn improve their livelihood. Despite banana production being increased as of late due to the nutritional and economic reasons for the crop in the region, a number of possible future studies are apparent. It would be interesting to explore the consumer preferences and sensory evaluation of the *Mchare* family. This would provide

important information necessary for breeding programs for nutritional, organoleptic and agronomic improvements of the banana varieties, which actually meet consumers' requirements. Following the findings of the present study, it is advised that the banana varieties listed down might be considered in the ongoing or future breeding programs for a balanced improvement of both desirable nutritional and physicochemical attributes. *Akondro mainty, Njuru, Makyughu* 2*, Mchare laini, Majimaji, Ijihu inkundu, Muraru* red*, Kakyughu* 1, *Huti* white, *Muraru Mchare* and *Kahuti*.

In addition, further work could also assess the postharvest quality losses (PHQL) of the cooking bananas. Banana value chain actors have relished good harvests in recent times, though the good harvests from banana-growing regions have not been translated into projected profit, due to quality loss of the fruits and puzzling consumers' preferences, thus leading to significant nutritional and economic losses. Besides reducing the total amount of available food, PHQL reduces quality and represent an unacceptable waste of scarce resources. The postharvest quality losses might also exaggerate farmers' poverty by eroding income generation along the food value chain. Evidently, the need to assess the postharvest quality losses of local cooking bananas cannot be overemphasized.

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LIST OF APPENDICES

Appendix 1: ANOVA Table for Moisture Content

Univariate Tests of Significance for Moisture level (Spreadsheet 1). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	218158.4	1	218158.4	223332.8	0.000000
Variety	318.5	14	22.8	23.3	0.000000
Error	29.3	30	1.0		

Appendix 2: Descriptive Statistics for Moisture Content

Variety	N	Moisture level Mean	Moisture level Std. Dev.	Moisture level Std. Err.	Moisture level -95.00%	Moisture level +95.00%
Total	45	69.62733	2.811676	0.419140	68.78261	70.47205
Mlelembo M.	3	66.62333	0.290230	0.167564	65.90236	67.34430
Huti white	3	71.69000	0.216564	0.125033	71.15203	72.22797
Kahuti	3	72.00000	2.695125	1.556031	65.30494	78.69506
Ijihu inkundu	3	67.72000	0.480416	0.277369	66.52658	68.91342
Makyughu 1	3	69.64000	0.745050	0.430155	67.78919	71.49081
Makyughu 2	3	65.97000	0.380000	0.219393	65.02603	66.91397
Mchare laini	3	66.52000	0.640234	0.369639	64.92957	68.11043
Huti green	3	65.53000	0.832106	0.480416	63.46293	67.59707
Akondro M.	3	70.59000	0.070000	0.040415	70.41611	70.76389
Njuru	3	73.43000	0.236432	0.136504	72.84267	74.01733
Muraru M.	3	71.37000	0.735459	0.424617	69.54302	73.19698
Majimaji	3	74.44667	0.440038	0.254056	73.35355	75.53978
Muraru	3	68.76000	1.017988	0.587736	66.23118	71.28882
Muraru Wh.	3	69.34000	1.017988	0.587736	66.81118	71.86882
Muraru red	3	70.78000	1.535285	0.886397	66.96614	74.59386

Appendix 3: ANOVA Table for Ash Content

Univariate Tests of Significance for Ash level (Spreadsheet 2). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	47.67872	1	47.67872	24325.88	0.00
Variety	2.15548	14	0.15396	78.55	0.00
Error	0.05880	30	0.00196		

Appendix 4: Descriptive Statistics for Ash Content

Variety	N	Ash level Mean	Ash level Std. Dev.	Ash level Std. Err.	Ash level -95.00%	Ash level +95.00%
Total	45	1.029333	0.224331	0.033441	0.961937	1.096730
Mlelembo M.	3	1.120000	0.017321	0.010000	1.076973	1.163027
Huti White	3	0.910000	0.010000	0.005774	0.885159	0.934841
Kahuti	3	1.170000	0.017321	0.010000	1.126973	1.213027
Ijihu inkundu	3	1.450000	0.026458	0.015275	1.384276	1.515724
Makyughu 1	3	0.870000	0.070000	0.040415	0.696110	1.043890
Makyughu 2	3	0.660000	0.017321	0.010000	0.616973	0.703027
Mchare laini	3	1.320000	0.017321	0.010000	1.276973	1.363027
Huti green	3	1.280000	0.026458	0.015275	1.214276	1.345724
Akondro M.	3	1.300000	0.091652	0.052915	1.072325	1.527675
Njuru	3	0.850000	0.020000	0.011547	0.800317	0.899683
Muraru M.	3	0.860000	0.036056	0.020817	0.770433	0.949567
Majimaji	3	0.920000	0.017321	0.010000	0.876973	0.963027
Muraru	3	0.890000	0.052915	0.030551	0.758552	1.021448
Muraru Wh.	3	0.900000	0.036056	0.020817	0.810433	0.989567
Muraru red	3	0.940000	0.085440	0.049329	0.727755	1.152245

Appendix 5: ANOVA Table for Protein Content

Univariate Tests of Significance for Protein content (Spreadsheet 3). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	43.57152	1	43.57152	5678.304	0.000000
Cultivar	4.80288	14	0.34306	44.708	0.000000
Error	0.23020	30	0.00767		

Appendix 6: Descriptive Statistics for Protein Content

Variety	N	Protein level Mean	Protein level Std. Dev.	Protein level Std. Err.	Protein level -95.00%	Protein level +95.00%
Total	45	0.984000	0.338213	0.050418	0.882389	1.085611
Mlelembo M.	3	0.610000	0.020000	0.011547	0.560317	0.659683
Huti white	3	0.730000	0.017321	0.010000	0.686973	0.773027
Kahuti	3	0.690000	0.026458	0.015275	0.624276	0.755724
Ijihu inkundu	3	0.910000	0.253574	0.146401	0.280086	1.539914
Makyughu 1	3	0.800000	0.100000	0.057735	0.551586	1.048414
Makyughu 2	3	1.750000	0.017321	0.010000	1.706973	1.793027
Mchare laini	3	1.290000	0.065574	0.037859	1.127104	1.452896
Huti green	3	0.900000	0.100000	0.057735	0.651586	1.148414
Akondro M.	3	1.340000	0.079373	0.045826	1.142828	1.537172
Njuru	3	0.660000	0.062450	0.036056	0.504866	0.815134
Muraru M.	3	1.030000	0.043589	0.025166	0.921719	1.138281
Majimaji	3	0.760000	0.052915	0.030551	0.628552	0.891448
Muraru	3	1.510000	0.065574	0.037859	1.347104	1.672896
Muraru Wh.	3	0.840000	0.060828	0.035119	0.688896	0.991104
Muraru red	3	0.940000	0.043589	0.025166	0.831719	1.048281

Appendix 7: ANOVA Table for Fat Content

Univariate Tests of Significance for Fat content (Spreadsheet 4). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	4.493520	1	4.493520	619.0047	0.000000
Cultivar	1.096080	14	0.078291	10.7850	0.000000
Error	0.217778	30	0.007259		

Appendix 8: Descriptive Statistics for Fat Content

Variety	N	Fat level Mean	Fat level Std. Dev.	Fat level Std. Err.	Fat level -95.00%	Fat level +95.00%
Total	45	0.316000	0.172802	0.025760	0.264085	0.367915
Mlelembo M.	3	0.140000	0.010000	0.005774	0.115159	0.164841
Huti white	3	0.390000	0.052915	0.030551	0.258552	0.521448
Kahuti	3	0.440000	0.026458	0.015275	0.374276	0.505724
Ijihu inkundu	3	0.220000	0.017321	0.010000	0.176973	0.263027
Makyughu 1	3	0.150000	0.043589	0.025166	0.041719	0.258281
Makyughu 2	3	0.530000	0.051856	0.029939	0.401184	0.658816
Mchare laini	3	0.380000	0.079373	0.045826	0.182828	0.577172
Huti green	3	0.300000	0.095394	0.055076	0.063028	0.536972
Akondro M.	3	0.120000	0.017321	0.010000	0.076973	0.163027
Njuru	3	0.600000	0.264575	0.152753	-0.057241	1.257241
Muraru M.	3	0.300000	0.100000	0.057735	0.051586	0.548414
Majimaji	3	0.090000	0.017321	0.010000	0.046973	0.133027
Muraru	3	0.420000	0.052915	0.030551	0.288552	0.551448
Muraru Wh.	3	0.480000	0.036056	0.020817	0.390433	0.569567
Muraru red	3	0.180000	0.017321	0.010000	0.136973	0.223027

Appendix 9: ANOVA Table for Fibre Content

Univariate Tests of Significance for Fibre level (Spreadsheet 5). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	199.7963	1	199.7963	1422.556	0.000000
Cultivar	9.4543	14	0.6753	4.808	0.000153
Error	4.2135	30	0.1404		

Appendix 10: Descriptive Statistics for Fibre Content

Variety	N	Fibre content Mean	Fibre content Std. Dev.	Fibre content Std. Dev.	Fibre content -95.00%	Fibre content +95.00%
Total	45	2.107111	0.557342	0.083084	1.939667	2.274555
Mlelembo M.	3	2.300000	0.173205	0.100000	1.869735	2.730265
Huti white	3	2.290000	0.135277	0.078102	1.953952	2.626048
Kahuti	3	2.290000	1.317308	0.760548	-0.982374	5.562374
Ijihu inkundu	3	1.650000	0.259808	0.150000	1.004602	2.295398
Makyughu 1	3	2.700000	0.173205	0.100000	2.269735	3.130265
Makyughu 2	3	2.476667	0.341223	0.197005	1.629021	3.324312
Mchare laini	3	0.920000	0.013748	0.007937	0.885849	0.954151
Huti green	3	2.030000	0.092892	0.053631	1.799242	2.260758
Akondro M.	3	2.480000	0.103058	0.059501	2.223989	2.736011
Njuru	3	2.130000	0.043589	0.025166	2.021719	2.238281
Muraru M.	3	1.890000	0.115326	0.066583	1.603515	2.176485
Majimaji	3	1.860000	0.209724	0.121084	1.339018	2.380982
Muraru	3	1.640000	0.118216	0.068252	1.346335	1.933665
Muraru Wh.	3	2.160000	0.051962	0.030000	2.030920	2.289080
Muraru red	3	2.790000	0.117898	0.068069	2.497124	3.082876

Appendix 11: ANOVA Table for Carbohydrate Content

Univariate Tests of Significance for Fibre level (Spreadsheet 6). Sigma-restricted Parameterization Effective Hypothesis Decomposition

Effect	SS	DF	MS	F	p
Intercept	30104.97	1	30104.97	5250.144	0.000000
Cultivar	323.40	14	23.10	4.029	0.000666
Error	172.02	30	5.73		

Appendix 12: Descriptive Statistics for Carbohydrate Content

Variety	N	Fibre content Mean	Fibre content Std. Dev.	Fibre content Std. Err.	Fibre content -95.00%	Fibre content +95.00%
Total	45	25.86502	3.355549	0.500216	24.85690	26.87314
Mlelembo M.	3	29.19000	5.986586	3.456357	14.31850	44.06150
Huti white	3	23.99000	0.779487	0.450037	22.05365	25.92635
Kahuti	3	22.55000	3.312062	1.912220	14.32238	30.77762
Ijihu inkundu	3	28.05000	1.211175	0.699272	25.04128	31.05872
Makyughu 1	3	25.84000	1.868411	1.078728	21.19861	30.48139
Makyughu 2	3	28.75500	1.303607	0.752638	25.51666	31.99334
Mchare laini	3	29.57000	2.066339	1.193002	24.43693	34.70307
Huti green	3	29.96000	3.843720	2.219173	20.41167	39.50833
Akondro M.	3	24.17000	1.720822	0.993517	19.89524	28.44476
Njuru	3	22.33000	1.564124	0.903047	18.44450	26.21550
Muraru M.	3	24.55000	1.835708	1.059847	19.98985	29.11015
Majimaji	3	21.59000	0.800192	0.461991	19.60221	23.57779
Muraru	3	26.78000	1.227570	0.708738	23.73055	29.82945
Muraru Wh.	3	26.28000	1.036803	0.598598	23.70444	28.85556
Muraru red	3	24.37030	0.945677	0.545987	22.02111	26.71949

Appendix 13: ANOVA Table for Energy

Univariate Tests of Significance for Energy (Spreadsheet 7). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	549346.3	1	549346.3	562566.7	0.00
Cultivar	6108.1	14	436.3	446.8	0.00
Error	29.3	30	1.0		

Appendix 14: Descriptive Statistics for Energy

Variety	N	Energy level Mean	Energy level Std. Dev.	Energy level Std. Err.	Energy level -95.00%	Energy level +95.00%
Total	45	110.4884	11.81043	1.760595	106.9402	114.0367
Mlelembo M.	3	120.7733	0.56889	0.328448	119.3601	122.1865
Huti white	3	102.7567	0.58389	0.337112	101.3062	104.2071
Kahuti	3	97.4667	0.81739	0.471923	95.4361	99.4972
Ijihu inkundu	3	117.2100	0.78352	0.452364	115.2636	119.1564
Makyughu 1	3	108.6800	0.98504	0.568712	106.2330	111.1270
Makyughu 2	3	128.6233	1.88580	1.088766	123.9388	133.3079
Mchare laini	3	127.1833	1.57017	0.906538	123.2828	131.0839
Huti green	3	126.6300	1.07252	0.619220	123.9657	129.2943
Akondro M.	3	102.5200	0.83217	0.480451	100.4528	104.5872
Njuru	3	96.9767	0.73501	0.424356	95.1508	98.8025
Muraru M.	3	105.9633	0.93511	0.539887	103.6404	108.2863
Majimaji	3	90.2200	0.44508	0.256970	89.1143	91.3257
Muraru	3	116.7100	1.03436	0.597188	114.1405	119.2795
Muraru Wh.	3	112.9967	0.47648	0.275096	111.8130	114.1803
Muraru red	3	102.6167	0.97797	0.564634	100.1872	105.0461

Appendix 15: ANOVA Table for Potassium Content

Univariate Tests of Significance for Potassium (Spreadsheet 8). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	7390845	1	7390845	40166.09	0.000000
Cultivar	113089	14	8078	43.90	0.000000
Error	5520	30	184		

Appendix 16: Descriptive Statistics for Potassium Content

Variety	N	K Content Mean	K Content Std. Dev.	K Content Std. Err.	K Content -95.00%	K Content +95.00%
Total	45	405.2666	51.91975	7.73974	389.6682	420.8650
Mlelembo M.	3	410.0000	14.83903	8.56732	373.1378	446.8622
Huti hite	3	371.6000	3.02203	1.74477	364.0929	379.1071
Kahuti	3	353.9000	7.60738	4.39212	335.0022	372.7978
Ijihu inkundu	3	405.8000	14.51096	8.37790	369.7528	441.8472
Makyughu 1	3	468.9000	8.16008	4.71123	448.6292	489.1708
Makyughu 2	3	433.2000	15.27849	8.82104	395.2461	471.1539
Mchare laini	3	306.2000	12.15961	7.02035	275.9939	336.4061
Huti green	3	348.9000	6.97373	4.02628	331.5763	366.2237
Akondro M.	3	452.2000	22.97932	13.26712	395.1162	509.2838
Njuru	3	455.1000	23.75864	13.71706	396.0803	514.1197
Muraru M.	3	349.4987	10.12240	5.84417	324.3532	374.6441
Majimaji	3	467.3000	16.09224	9.29086	427.3247	507.2753
Muraru	3	368.3000	9.81070	5.66421	343.9289	392.6711
Muraru Wh.	3	438.5000	6.60654	3.81429	422.0884	454.9116
Muraru red	3	449.6000	13.11439	7.57160	417.0220	482.1780

Appendix 17: ANOVA Table for Calcium Content

Univariate Tests of Significance for Potassium (Spreadsheet 8). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	579.3185	1	579.3185	18705.23	0.00
Cultivar	34.9933	14	2.4995	80.71	0.00
Error	0.9291	30	0.0310		

Appendix 18: Descriptive Statistics for Calcium Content

Variety	N	Ca Content Mean	Ca Content Std. Dev.	Ca Content Std. Err.	Ca Content -95.00%	Ca Content +95.00%
Total	45	3.588000	0.903559	0.134695	3.316541	3.859459
Mlelembo M.	3	2.590000	0.051962	0.030000	2.460920	2.719080
Huti white	3	4.280000	0.055678	0.032146	4.141689	4.418311
Kahuti	3	2.810000	0.151327	0.087369	2.434082	3.185918
Ijihu inkundu	3	3.910000	0.257099	0.148436	3.271330	4.548670
Makyughu 1	3	3.650000	0.170587	0.098489	3.226238	4.073762
Makyughu 2	3	4.550000	0.062450	0.036056	4.394866	4.705134
Mchare laini	3	3.770000	0.034641	0.020000	3.683947	3.856053
Huti green	3	2.890000	0.251595	0.145258	2.265004	3.514996
Akondro M.	3	6.070000	0.033061	0.019088	5.987873	6.152127
Njuru	3	3.500000	0.096286	0.055591	3.260812	3.739188
Muraru M.	3	3.200000	0.079373	0.045826	3.002828	3.397172
Majimaji	3	2.620000	0.465725	0.268887	1.463074	3.776926
Muraru	3	3.760000	0.186815	0.107858	3.295925	4.224075
Muraru Wh.	3	2.730000	0.050000	0.028868	2.605793	2.854207
Muraru red	3	3.490000	0.036056	0.020817	3.400433	3.579567

Appendix 19: ANOVA Table for Iron Content

Univariate Tests of Significance for Iron (Spreadsheet 9). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	15.73656	1	15.73656	22820.34	0.00
Cultivar	0.79056	14	0.05647	81.89	0.00
Error	0.02069	30	0.00069		

Appendix 20: Descriptive Statistics for Iron Content

Variety	N	Fe Content Mean	Fe Content Std. Dev.	Fe Content Std. Err.	Fe Content -95.00%	Fe Content +95.00%
Total	45	0.591356	0.135784	0.020242	0.550561	0.632150
Mlelembo M.	3	0.570000	0.024637	0.014224	0.508797	0.631203
Huti white	3	0.660000	0.014933	0.008622	0.622904	0.697096
Kahuti	3	0.460000	0.012823	0.007404	0.428145	0.491855
Ijihu inkundu	3	0.410000	0.020298	0.011719	0.359578	0.460422
Makyughu 1	3	0.510000	0.036346	0.020984	0.419713	0.600287
Makyughu 2	3	0.510333	0.009452	0.005457	0.486854	0.533812
Mchare laini	3	0.360000	0.021932	0.012662	0.305519	0.414481
Huti green	3	0.630000	0.036056	0.020817	0.540433	0.719567
Akondro M.	3	0.800000	0.060828	0.035119	0.648896	0.951104
Njuru	3	0.750000	0.026458	0.015275	0.684276	0.815724
Muraru M.	3	0.660000	0.020518	0.011846	0.609030	0.710970
Majimaji	3	0.440000	0.020000	0.011547	0.390317	0.489683
Muraru	3	0.730000	0.018028	0.010408	0.685217	0.774783
Muraru Wh.	3	0.640000	0.010000	0.005774	0.615159	0.664841
Muraru red	3	0.740000	0.010000	0.005774	0.715159	0.764841

Appendix 21: ANOVA Table for Zinc Content

Univariate Tests of Significance for Zinc (Spreadsheet 10). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	0.510721	1	0.510721	1593.678	0.000000
Cultivar	0.051131	14	0.003652	11.397	0.000000
Error	0.009614	30	0.000320		

Appendix 22: Descriptive Statistics for Zinc Content

Variety	N	Zn Content Mean	Zn Content Std. Dev.	Zn Content Std. Err.	Zn Content -95.00%	Zn Content +95.00%
Total	45	0.106533	0.037156	0.005539	0.095370	0.117696
Mlelembo M.	3	0.090000	0.010000	0.005774	0.065159	0.114841
Huti white	3	0.070000	0.010000	0.005774	0.045159	0.094841
Kahuti	3	0.060000	0.010000	0.005774	0.035159	0.084841
Ijihu inkundu	3	0.180000	0.010000	0.005774	0.155159	0.204841
Makyughu 1	3	0.130000	0.017321	0.010000	0.086973	0.173027
Makyughu 2	3	0.070000	0.017321	0.010000	0.026973	0.113027
Mchare laini	3	0.090000	0.034641	0.020000	0.003947	0.176053
Huti green	3	0.120000	0.017321	0.010000	0.076973	0.163027
Akondro M.	3	0.160000	0.026458	0.015275	0.094276	0.225724
Njuru	3	0.078000	0.002646	0.001528	0.071428	0.084572
Muraru M.	3	0.090000	0.000000	0.000000	0.090000	0.090000
Majimaji	3	0.090000	0.026458	0.015275	0.024276	0.155724
Muraru	3	0.120000	0.026458	0.015275	0.054276	0.185724
Muraru Wh.	3	0.140000	0.010000	0.005774	0.115159	0.164841
Muraru red	3	0.110000	0.010000	0.005774	0.085159	0.134841

Appendix 23: ANOVA Table for Total Soluble Solids (TSS)

Univariate Tests of Significance for TSS (Spreadsheet 11). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	126.6722	1	126.6722	5588.480	0.000000
Cultivar	1.1778	14	0.0841	3.711	0.001257
Error	0.6800	30	0.0227		

Appendix 24: Descriptive Statistics for Total Soluble Solids (TSS)

Variety	N	TSS Content Mean	TSS Content Std. Dev.	TSS Content Std. Err.	TSS Content -95.00%	TSS Content +95.00%
Total	45	1.677778	0.205480	0.030631	1.616045	1.739511
Mlelembo M.	3	1.866667	0.057735	0.033333	1.723245	2.010088
Huti white	3	1.433333	0.057735	0.033333	1.289912	1.576755
Kahuti	3	1.766667	0.152753	0.088192	1.387208	2.146125
Ijihu inkundu	3	1.800000	0.200000	0.115470	1.303172	2.296828
Makyughu 1	3	1.766667	0.057735	0.033333	1.623245	1.910088
Makyughu 2	3	1.700000	0.173205	0.100000	1.269735	2.130265
Mchare laini	3	1.766667	0.208167	0.120185	1.249552	2.283781
Huti green	3	1.466667	0.115470	0.066667	1.179823	1.753510
Akondro M.	3	1.800000	0.264575	0.152753	1.142759	2.457241
Njuru	3	1.766667	0.152753	0.088192	1.387208	2.146125
Muraru M.	3	1.766667	0.152753	0.088192	1.387208	2.146125
Majimaji	3	1.833333	0.115470	0.066667	1.546490	2.120177
Muraru	3	1.366667	0.057735	0.033333	1.223245	1.510088
Muraru wh.	3	1.633333	0.208167	0.120185	1.116219	2.150448
Muraru red	3	1.433333	0.057735	0.033333	1.289912	1.576755

Appendix 25: ANOVA Table for Total Titratable Acidity (TTA)

Univariate Tests of Significance for TA (Spreadsheet 12). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	142.6492	1	142.6492	14575.87	0.000000
Cultivar	3.2156	14	0.2297	23.47	0.000000
Error	0.2936	30	0.0098		

Appendix 26: Descriptive Statistics for Total Titratable Acidity (TTA)

Variety	N	TA Level Mean	TA Level Std. Dev.	TA Level Std. Err.	TA Level -95.00%	TA Level +95.00%
Total	45	1.780444	0.282408	0.042099	1.695600	1.865289
Mlelembo M.	3	1.600000	0.100000	0.057735	1.351586	1.848414
Huti white	3	1.933333	0.057735	0.033333	1.789912	2.076755
Kahuti	3	2.000000	0.100000	0.057735	1.751586	2.248414
Ijihu inkundu	3	2.200000	0.264575	0.152753	1.542759	2.857241
Makyughu 1	3	1.700000	0.100000	0.057735	1.451586	1.948414
Makyughu 2	3	1.566667	0.057735	0.033333	1.423245	1.710088
Mchare laini	3	1.633333	0.115470	0.066667	1.346490	1.920177
Huti green	3	1.700000	0.000000	0.000000	1.700000	1.700000
Akondro M.	3	2.300000	0.100000	0.057735	2.051586	2.548414
Njuru	3	1.633333	0.057735	0.033333	1.489912	1.776755
Muraru M.	3	2.206667	0.011547	0.006667	2.177982	2.235351
Majimaji	3	1.500000	0.050000	0.028868	1.375793	1.624207
Muraru	3	1.500000	0.086603	0.050000	1.284867	1.715133
Muraru Wh.	3	1.500000	0.000000	0.000000	1.500000	1.500000
Muraru red	3	1.733333	0.057735	0.033333	1.589912	1.876755

Appendix 27: ANOVA Table for pH

Univariate Tests of Significance for pH (Spreadsheet 13). Sigma-restricted Parameterization Effective Hypothesis Decomposition.

Effect	SS	DF	MS	F	p
Intercept	1406.724	1	1406.724	204201.8	0.000000
Cultivar	0.510	14	0.036	5.3	0.000066
Error	0.207	30	0.007		

Appendix 28: Descriptive Statistics for pH

Variety	N	pH Level Mean	pH Level Std. Dev.	pH Level Std. Err.	pH Level -95.00%	pH Level +95.00%
Total	45	5.591111	0.127604	0.019022	5.552775	5.629448
Mlelembo M.	3	5.666667	0.115470	0.066667	5.379823	5.953510
Huti white	3	5.566667	0.057735	0.033333	5.423245	5.710088
Kahuti	3	5.466667	0.057735	0.033333	5.323245	5.610088
Ijihu inkundu	3	5.566667	0.152753	0.088192	5.187208	5.946125
Makyughu 1	3	5.666667	0.057735	0.033333	5.523245	5.810088
Makyughu 2	3	5.700000	0.100000	0.057735	5.451586	5.948414
Mchare laini	3	5.766667	0.057735	0.033333	5.623245	5.910088
Huti green	3	5.733333	0.057735	0.033333	5.589912	5.876755
Akondro M.	3	5.466667	0.057735	0.033333	5.323245	5.610088
Njuru	3	5.633333	0.057735	0.033333	5.489912	5.776755
Muraru M.	3	5.466667	0.115470	0.066667	5.179823	5.753510
Majimaji	3	5.466667	0.057735	0.033333	5.323245	5.610088
Muraru	3	5.600000	0.100000	0.057735	5.351586	5.848414
Muraru Wh.	3	5.433333	0.057735	0.033333	5.289912	5.576755
Muraru red	3	5.666667	0.057735	0.033333	5.523245	5.810088