# RELATIONSHIP BETWEEN PHYSICOCHEMICAL AND SENSORY PROPERTIES OF SELECTED LOCAL AND HYBRID COOKING BANANAS IN UGANDA

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**A DISSERTATION SUBMITTED TO GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FOOD TECHNOLOGY OF KYAMBOGO UNIVERSITY**

**JANUARY, 2021**

## DECLARATION

I declare that the dissertation which I hereby submit for a Master of Science Degree in Food Technology of Kyambogo University is my original concept and has never been presented by anybody for any award at any institution of higher learning.

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## DEDICATION

This work is dedicated to my uncle, Mr. Musisi Emmanuel for his selfless contribution towards my education. I am forever grateful and may you see the graceful hand of God more and more in your life.

## ACKNOWLEDGEMENT

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| CIAT | International Center for Tropical Agriculture |
| NARO | National Agricultural Research Organization |
| FHIA | Fundacion Hondurena de Investigacion Agricola |
| IITA | International Institute of Tropical Agriculture |
| NARL | National Agricultural Research Laboratories |
| NARO | National Agricultural Research Organization |
| UBOS | Uganda Bureau of Statistics |
| FAO | Food and Agriculture Organization |
| RTB | Roots, Tubers and Bananas |
| ABC | Alliance of Bioversity International and CIAT |
| TA | Titratable Acidity |
| TSS | Total Soluble Solids |

## DEFINITION OF KEY TERMINOLOGIES

| | |
|---|---|
| NARITA | Name given to banana hybrids jointly developed by NARO and IITA. The name specifies the contribution of the two organizations |
| NAROBans | Banana hybrids bred by NARO in Uganda. 'NAROBan' denotes the institution NARO, which developed these hybrids. NAROBan is the name currently used at official release |
| KABANA | Acronym for Kawanda Banana depicting hybrids and introduced cultivars where 'Kawanda' is the institution which introduced evaluated and released the variety under the National Banana Research Programme in Uganda. Cultivars given the KABANA name include hybrids (e.g. FHIA 1 was released as KABANA 1 or non-hybrids introduced in the country (e.g. Yangambi Km5 from DRC was released as KABANA 5) |
| NABIOs | Banana hybrids developed by NARO in collaboration with Bioversity International |

## ABSTRACT

The East African Highland Cooking bananas are a staple food in Uganda. In this work, the relationship between sensory characteristics and the physicochemical properties of 23 local and hybrid cooking bananas was studied. The selected cultivars included officially released hybrids (n=2), hybrids still under evaluation (n=12), female parents used in breeding (n=3), and popular local East African Highland (EA-AAA) cooking bananas (n=6).

Peel thickness, finger length, TSS, TA, dry matter, starch content including amylose & amylopectin composition, crude fat, ash, protein, texture, phenolic compounds, tannins and total flavonoids were determined using standard methods. Results of proximate composition and starch composition indicated that local cultivars *Mpologoma, Mbwazirume,* and *Muvubo* had significantly ($p < 0.05$) higher values of moisture, crude fat, ash, protein and amylose than hybrids. Hybrids NARITA 6 and NARITA 2 had significantly ($p < 0.0001$) the highest dry matter content of 27.94 % and 28.09 %, respectively. Hybrids NARITA 2, NARITA 11, 17914S-24 and NARITA 24 had relatively higher phenolic compounds than most of the local cultivars.

To examine the eating quality characteristics, the traditional steam and mash method was used. Thirteen trained panellists were used to assess sensory characteristics of the cooked bananas. The main sensory characteristics of cooked bananas according to panellists were; a homogeneous yellow colour, moist smooth and soft texture, an aroma of bananas in leaves, a mild sweet taste and low astringency. Sourness, high astringency, pale yellow, blackish & mottled colours, extreme firmness and too soft texture were described as undesirable characteristics. Some hybrid cultivars (N21, N15, N11, N8, 17914S-24, N2 and N6) had significantly ($p < 0.05$) lower scores for sensory characteristics than the local bananas. However, the sensory scores of other hybrids such as M32, NARITA 17, M9, M33 and NARITA 24 were not significantly different from those of local cultivars.

According to the PCA, flavonoids and ash content are correlated with astringency ($r = 0.014$, $r = -0.006$), stickiness ($r = 0.310$, $r = 0.402$), mouldability ($r = 0.121$, $r = 0.226$) & smoothness ($r = 0.130$, $r = 0.295$) of hybrids N8, N21, & 17914S-24. Total tannins and amylopectin content determine the moistness ($r = 0.454$, $r = 0.193$) of cooked bananas as observed in Nakitembe, M32, and Enzirabahima. Sourness is correlated with total phenols ($r = 0.453$) content in hybrids N11, NI5. The large finger circumference is explained by the high dry matter and high amylose

content (r = -0.064, r = 0.090) in N11 & N15. Firmness and hardness are explained by high starch (r =0.244, r = 0.282) content mainly in hybrids N2, N6, M9 & M33 and a local cultivar *Nfuuka*. High starch content was associated (r = 0.453) with a firm and hard texture while Matooke taste is correlated with high titratable acidity (r = 0.404) while sweetness & a yellow colour and homogeneous colour are associated with TSS (r = 0.405, r = 0.581, r = 0.578) in *Kibuzi, Nakitembe, Nakawere, Muvubo, Enzirabahima, Kabucuragye,* M32, N14, N24 and N17. Therefore, these quality properties could be used by breeders as parameters for screening clones for food quality to meet consumer expectations.

Key words: Correlation, local, hybrid, cooking banana, sensory, physicochemical

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Banana and plantain (*Musa* spp.), is an important food and cash crop in more than 135 countries in tropical and subtropical regions of the world (Brown, Tumuhimbise, Amah, Delphine, Uwimana, Nyine, Mduma, Talengera, Karamura, Kuriba, & Swennen, 2017). The estimated global production of bananas stands at 166.79 million metric tons, fetching a gross production value of about US$ 39 billion (FAOSTAT, 2018). In the East African region, bananas form an important food crop, providing about a fifth of total calorie consumption per capita (Tumuhimbise, Buregyeya, Barekye, Ssali1, Talengera, Kubiriba, Muhangi, Namagembe, Namanya, Arinaitwe, Tushemereirwe, Karamura and Karamura, 2016). In Uganda, there are five different types of bananas grown such as cooking bananas (e.g. *Nakitembe, Kibuzi, Mbwazirume*) locally known as *Matooke,* brewing bananas (e.g. *Mbidde* and *Musa*) mainly grown for juice or local brew (*Ntoto*), dessert bananas (e.g. *Bogoya* & *Sukali Ndizi* (Apple banana)) mainly eaten as dessert, roasting bananas (e.g. *Gonja*) mainly eaten when cooked or roasted and lastly, the exotic red banana (Edmeades, Smale & Karamura, 2005; Nyombi, 2013; Albertson, 2016).

Bananas are the main staple food in rural and urban centres across the country but mainly in Central and Western Uganda. The annual production of cooking bananas (locally known as *Matooke*)[1] is estimated at 4.34 million metric tons (FAOSTAT, 2018). The average per capita consumption of cooking bananas in Uganda is estimated to range between 250 kg to 480 kg (Kiiza, Abele & Kalyebara, 2004; Kabahenda & Kapiriri, 2010). *Matooke* is steamed in banana

[1] *Matooke* is used to synonymously refer to either the steamed bananas or the EAHB cooking bananas. In this dissertation the terms were used interchangeably depending on the context

leaves and mashed to make a thick paste which is served with sauce. Sometimes, whole fingers are boiled with beans, ground nuts or meat to make a local dish known as *Katogo*. Despite its contribution to food security and household income, production of cooking bananas in Uganda is declining, standing at ~9.2 t/ha compared to its potential of 50 t/ha to 80 t/ha (FAO, 2012; Sabiiti, Ininda, Ogallo, Opijah, Nimusiima, Otieno, Ddumba, Nanteza & Basalirwa, 2016). The low productivity is attributed to various factors including abiotic stresses (climate change and reduced soil fertility) as well as biotic factors such as pests (nematodes and weevils) and diseases such as black Sigatoka, *Fusarium* wilt, bacterial wilt and banana top bunch virus (Ploetz & Evans, 2006; van Asten, Fermont & Taulya, 2011; Tumuhimbise, Buregyeya, Barekye, Ssali, Talengera, Kubiriba, Muhangi, Namagembe, Namanya, Arinaitwe, Tushemereirwe, Karamura & Karamura, 2016). These challenges have significantly contributed to yield losses in banana production in Uganda. For instance, black Sigatoka is estimated to cause yield loss of 30 % to 50 % of bananas if a plantation is attacked (Ssali, Nowankunda, Barekye, Erima, Batte, & Tushemereirwe, 2010; Barekye, 2011). Therefore, if sustainable food security is to be achieved for millions of small-scale farmers relying on bananas in Uganda, the constraints to banana production must be addressed. Different interventions exist including fertiliser application to boost yields, and use of chemicals against pests and diseases, but these are not feasible and/or unsustainable given the poor economic status of the country's small-scale farmers. One of the most effective alternatives is breeding high yielding banana cultivars with host resistance to diseases and pests that are able to thrive even in poor soils and have preferred quality attributes.

Therefore, the National Agricultural Research Organization (NARO) and its partners, including Bioversity International and International Institute of Tropical Agriculture (IITA), have bred bananas with improved yields amidst poor soil fertility and tolerant to drought, pests, and

diseases (Njuguna, Nguthi, Wepukhulu, Wambugu, Gitau, Karuoya & Karamura, 2008; Uazire, Ribeiro, Ruth Bila Mussane, Pillay, Karamura, Blomme, Staver & Fraser, 2011; Tumuhimbise, Barekye, Kubiriba, Akankwasa, Arinaitwe & Karamura, 2018). NARO has also introduced banana cultivars from other countries to boost food security. The introduced and developed hybrids include FHIAs (such as FHIA 17, FHIA 23), NARITAs (such as NARITA 14 (N14), NARITA 21 (N21), NARITA 7 (N7) (also known as M9, KABANA 6H or *Kiwangaazi*), NABIOs (such as M30 (also known as NABIO 808/or M30), M32 and M33, NABIO 808, NABIO 1011), and NAROBans (for instance NAROBan 1, and NAROBan 2) (Njuguna et al., 2008; Uazire et al., 2011; Nowakunda, Barekye, Ssali, Namaganda, Tushemereirwe, Nabulya, Gertrude, Akankwasa, Batte & Karamura, 2015; Tumuhimbise et al., 2018). These hybrids have been subjected to screening for yield characteristics, disease & pest resistance and overall food acceptability. Several studies have reported improved agronomical performance in terms of bunch yield, pest and disease resistance and overall food acceptability for some of the cooking banana hybrids (Ssali et al., 2010; Akankwasa, Ortmann, Wale & Tushemereirwe, 2013; Tushemereirwe, Batte, Nyine, Tumuhimbise, Barekye, Tendo, Talengera, Kubiriba, Lorenzen, Swennen & Uwimana, 2015; Nowakunda et al., 2015; Batte, Akankwasa, Tushemereirwe, Karamura, Karamura, Kubiriba, Ssali & Barekye, 2016; Tumuhimbise et al., 2016, 2018), for example M30, NABIO 1011, NAROBan 1, NAROBan 2, KABANA 7H (M2), and KABANA 6H (M9). Other studies however, have reported consumer rejection of some hybrid cultivars such as FHIAs as cooking bananas (Ssemwanga, Thompson, and Aked, 2000; Nowakunda & Tushemereirwe, 2004). Factors for this rejection need to be investigated.

## 1.2 Problem Statement

Hybrid bananas are mainly rejected as cooking bananas (Ssemwanga, Thompson, and Aked, 2000; Nowakunda & Tushemereirwe, 2004). This may be due to differences in their physicochemical properties compared to local cultivars. Sensory perception for instance, is determined by a combination of different metabolites in a fruit (Nowakunda, Rubaihayo, Ameny & Tushemereirwe, 2000; Nowakunda & Tushemereirwe, 2004; Dufour & Gibert, 2009). Banana pulp colour is associated with presence of carotenoids and tannins while taste is associated with sugars and tannins (Nowakunda et al., 2000, Ssemwanga, Thompson & Aked, 2000; Nowakunda, 2001). Texture is correlated with dry matter (Nowakunda et al., 2000; Ssemwanga et al., 2000). However, there is limited information on the relationship between the sensory characteristics and contribution of the individual chemical components of the bananas to the overall sensory quality of the cooked bananas. For instance, Kikulwe, (2010), Mugisha, Akankwasa, Tushemereirwe, & Ragama, (2010), Akankwasa, (2014) tried to document reasons for cultivar acceptability or rejection and whether this is due to the morphological, sensory and/or physicochemical properties of the cultivar. These studies have mainly focused on the agronomical performance and overall food acceptability of the hybrids, leaving a knowledge gap about the determinants of quality desirability in the crop. There is therefore limited information on the relationship between the sensory characteristics and the chemical composition of cooking bananas.

Correlation between physicochemical and desired sensory characteristics of cooked bananas using trained panellists hasn't been deeply studied yet it could explain the rejection criterion for some of the hybrid bananas (Ssemwanga, 1995; Ssemwanga et al., 2000).

Knowing the relationship between physicochemical properties & sensory characteristics of cooking bananas will inform breeders to develop hybrids that meet consumer expectations for enhanced adoption & consumption of hybrid bananas in Uganda.

### 1.3 Justification

In spite of emerging constraints of reduced soil fertility, pests and diseases, cooking bananas still contributes to household incomes, food and nutrition security to millions of small scale farmers in Uganda (Njuguna et al., 2008; Thiele, Khan, Heider, Kroschel, Harahagazwe, Andrade, Bonierbale, Friedmann, Gemenet, Cherinet, Quiroz, Faye, Dangles, 2017). Newly developed hybrids at NARO-Kawanda could be the ultimate solution to ensure sustainable food security in Uganda and East Africa at large. However, there is still rejection of hybrids such as FHIA 3 and FHIA 23 due to poor eating qualities by consumers (Ssemwanga, Thompson, & Aked, 2000; Nowakunda & Tushemereirwe, 2004). Reasons for rejection and acceptance of hybrid bananas could be better understood by clearly examining the relationship between sensory quality characteristics and the physicochemical properties of the bananas. Few studies (Ssemwanga, Thompson, & Aked, 2000; Gafuma, Byarugaba-Bazirake, & Mugampoza, 2018a, b) have documented this. And still, among the above studies, Gafuma et al. (2018a, b) focused only at local cultivars while Ssemwanga et al. (2000) studied only one hybrid cultivar (FHIA 3) in comparison with local cultivars leaving a knowledge gap on how other hybrids compare with each other and with popular local cultivars. Moreover, the drivers of quality desirability that influence sensory characteristics of cooking bananas are not clearly established and known by breeders. This has led to development of hybrids with inferior sensory qualities regardless of their superior agronomical characteristics compared to local cultivars. Knowing the drivers of quality desirability will avail a selection tool for breeders to evaluate the sensory characteristics

early enough in the breeding program so as to produce hybrids with desirable characteristics similar or close to local cultivars. This will potentially increase the adoption and consumption of hybrid bananas in Uganda and beyond. The results of the study will also avail breeders the determinants of sensory quality for cooking bananas so as to improve the sensory qualities of existing hybrids and for breeding bananas with better sensorial characteristics.

### 1.4 Significance of the study

The study will add to the limited literature on the physicochemical properties and sensory characteristics of local and hybrid cooking bananas. Results will inform current and future banana breeding programs about the relationship between physicochemical properties & sensory characteristics of cooking bananas to enable breeders develop hybrids that meet consumer expectations for enhanced adoption & consumption of hybrid cooking bananas in Uganda.

### 1.5 OBJECTIVES

#### 1.5.1 General Objective

To investigate the relationship between physicochemical properties and sensory characteristics of selected local and hybrid cooking banana cultivars in Uganda.

#### 1.5.2 Specific objectives

1. To determine the physical properties (finger length, finger circumference, peel thickness, and pulp\peel ratio) of selected local and hybrid cooking banana cultivars.
2. To analyse the chemical composition (TSS, pH, TA, pulp colour, starch, amylose, amylopectin, proximate, mineral and polyphenol composition) of the selected banana cultivars.

3. To establish the major sensory characteristics of selected local and hybrid banana cultivars.
4. To determine the relationship between sensory characteristics and the physicochemical properties of cooking bananas in Uganda.

## 1.6 Hypotheses

1. There is no difference in the physical properties of local and hybrid cooking banana cultivars grown in Uganda.
2. There is no difference in the chemical composition of local and hybrid cooking banana cultivars.
3. There is no difference in the major sensory characteristics of local and hybrid cooking bananas.
4. There is no relationship between sensory quality characteristics and the physicochemical properties of cooking bananas in Uganda.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

Bananas are edible fruits produced by large monocotyledonous flowering plants belonging to the genus *Musa*. The individual banana fruits are known as fingers and they occur in clusters known as hands (Dufour & Gibert, 2009). Edible bananas originated from two wild and seedy species, *Musa acuminate* Colla (2n=22) and *Musa balbisiana* Colla (2n=22) (Karamura et al., 1998). Simmonds & Shepherd (1955) suggested that these species are native to South-East Asia and came to East Africa as a result of the Arabian trade at the East African Coast. The two banana species later mutated into a series of diploid, triploids and tetraploids classified as AA, AB, AAA, AAB, ABB, AABB, AAAB, ABBB with the letters A and B representing the contributions of *M. acuminate* Colla and *M. balbisiana*, respectively (Karamura et al., 1998).

The cultivars grown in Uganda have been classified into four groups depending on utilization and these include the dessert, beer, roasting and cooking bananas (Karamura et al., 1998). Dessert bananas are eaten raw at ripeness when they have developed the characteristic sweet flavour. Cultivars in this group include Cavendish locally known as *Bogoya* in Uganda (*Musa* AAA triploids) and apple bananas (*Sukali Ndizi*) (*Musa* AB). Beer bananas are ripened after harvest and used for juice extraction. The juice can be fermented for production of local brew called *Tonto* in the central region of the country. *Kisubi* (AB) is an example of a beer banana. Roasting bananas (plantain AAB locally known as *Gonja*) are ripened and roasted for consumption (Simmonds & Shepherd, 1952).

East African Highland cooking bananas (AAA- EAHB) are a staple food in Uganda mainly in Central and Western regions of the country. These are majorly cooking types locally known as *Matooke* although some brewing bananas (*Mbidde* types) have also been classified in this group

due to their close similarity in shape and form (Karamura et al., 1998). However, the main differentiating feature is that the *Mbidde* pulp is bitter and astringent even at full green maturity which is uncommon with the pulp of cooking bananas.

Cooking bananas are further divided into four clone sets (Table 2.1) to ease the study of their agronomical performances such as disease resistance, plant yield as well as identifying strategies for their improvement. The clone sets include *Musakala, Nakabululu, Nakitembe* and *Nfuuka* (Karamura et al., 1998).

Table 2.1 Differentiation of the EAHB cooking banana clone sets

| **Clone sets** | **Differentiating feature** |
|---|---|
| *Musakala* | Long fingers above 20 cm with bottlenecked apices on pendulous lax bunches. They also have a pendulous nude male inflorescence rachis. Cultivars belonging here include *Kisansa, Mpologoma, Mayovu.* |
| *Nakabululu* | Short fingers below 15 cm with blunt apices attached to very compact oriented bunches. They also consist of a sub-horizontal to oblique nude male inflorescence rachis. Cultivars in this group are *Kibuzi, Nakabululu, Nakyetengu, Mukubakonde* |
| *Nakitembe* | The fingers are medium in size (15-20 cm long) with intermediate apices between bottle-necked and blunt apices. They are attached on perpendicular compact bunches and there are no brown sticky excretions across the pulp. *Nandigobe, Mbwazirume, Nakitembe, Namulondo* belong to this clone set. |

| | |
|---|---|
| *Nfuuka* | Medium fingers 1-20 cm long with intermediate apices between bottle-necked and blunt apices attached to oblique compact bunches. They have sigmoid curved nude male inflorescence rachis and no brown sticky excretions across the pulp. *Bitambi, Bukumo, Nalugolima,* and *Nakibule* belong here. |

Source: Karamura et al. (1998).

**2.2 Utilization and processing of bananas**

Bananas in Uganda have been categorised as dessert, cooking, roasting and beer banana based on products made out of them (Karamura et al., 1998). They are mainly consumed in fresh or cooked form without undergoing secondary processing with exception from beer bananas which go through both primary and secondary processing. Some efforts (Table 2.2) have been applied to processing of bananas for extended shelf life as well as availing alternative raw materials for secondary products. However, most of the value addition techniques are still rudimentary to date ranging from hands, foot and small-scale machines which are not economical and hygienic (Omulo, Banadda & Kiggundu, 2015). For instance, traditionally, cooking bananas are peeled, wrapped in banana leaves, and then steamed until soft and yellowish in colour. The cooked bananas are either mashed manually to make cooked banana paste which is served with a sauce or left whole but mixed with groundnuts, beans or meat to make *Katogo* (Marocco, Mukiibi, Nsenga, Sardo, Marocco, Mukiibi, Wanyu, & Whitney, 2018). For juice production, physiologically mature beer bananas are ripened and the juice is extracted by peeling the fingers into a saucepan into which chopped spear grass is mixed as a pressing aid and vigorously squeezed by hand or trumped with the feet to extract the juice (Aked, J., & Kyamuhangire, 1996). Local beer known as *Tonto* is produced by diluting the extracted juice, adding coarsely ground roasted sorghum and left to ferment at room temperature in a pot for about four days.

*Tonto* maybe distilled in drums to produce a neutral spirit locally known as *Waragi* (Gensi & Kyamuhangire, 1994). Plantain (*Gonja*) is ripened, peeled and roasted for consumption mainly along highway bus stops and in restaurants. Dessert bananas are eaten ripe.

Apart from steaming the fruits into cooked bananas, there are various value addition technologies for cooking bananas that remain underutilized. These include production of flour, banana chips, banana juice, jam and spirits distilled from wine or beer with large volumes of peels which are mainly used as animal feeds (Adeniji, Tenkouano, Ezurike, Ariyo & Vroh-Bi, 1996; Emaga, Herinavalona Andrianaivo, Wathelet, Tchango Tchango, & Paquot, 2007). Bread has also been made through the optimisation of raw *tooke* flour, vital gluten and water absorption (Muranga, Mutambuka, Nabugoomu & Lindhauer, 2010). Banana flour is obtained from any cultivar of the processor's choice and has been commercially utilised for the production of banana based products such as cookies and bread (Table 2.2). The unripe bananas are peeled, sliced, dried and milled into flour. Banana chips are preferably made from sliced and deep-fried ripe *Gonja* due to its sweet taste. On an industrial scale, juices in Uganda are extracted by mechanically pulping and pressing the ripe bananas generating a thick puree which is diluted with portable water to a low viscosity clear juice that is pasteurised and packaged in either plastic bottles or tetra packs ready for sale (Kibazohi, Kyamuhangire, Kaunga, & Rokoni, 2017). Wine is also produced mainly from juice bananas by fermentation of the banana juice using wine yeast (Byarugaba-bazirake, 2008).

Banana juice producing companies in Uganda include Jakana Foods Ltd, Uhuru Fruit Drinks Ltd and the department of Food Science and Technology at Makerere University among others. Afribanana Ltd, Bushenyi Banana and Plantain Farmers Association and Tigebwa Development Farmers Association are examples of banana wine producing companies in Uganda (Kabahenda

et al., 2010). Apart from food uses, there are various non-food applications of the plant. These include animal feeds in form of banana peelings, wrapping of bananas for steaming before mashing, production of handcrafts such as bags & mats from banana pseudo stems and mulching gardens to prevent moisture loss/soil erosion (Kumar, Bhowmik, Duraivel, & Umadevi, 2012).

Table 2.2 Banana flour based food products

| Variety | Products | Comment | Reference |
|---|---|---|---|
| *Nandigobe* (EAHB) | Bread (from raw banana-wheat composite flour) | Optimal substitution of raw banana flour into wheat produced no significant effect on baking quality of the composite flour | *(Muranga et al., 2010)* |
| *Musa sapientum* | Biscuits (from raw banana-wheat composite flour) | Banana flour increased the levels of ash, fibre, carbohydrate, calcium, phosphorus, iron and zinc in the biscuits made of banana-wheat composite flour while the fat and protein contents reduced.<br>Eating qualities of<br>5% freeze dried biscuits had the highest scores for colour, texture and overall acceptability while biscuits from 10% hot air dried composite flour had the highest score in flavor. | *(Islam, Hoque, & Monalisa, 2014)* |
| FHIA (Hybrid *Matooke*) | Soup and porridge made from raw, instant and extruded hybrid *Matooke* flour fortified with soy | Maximum hybrid banana flour amounts in the composite were 19.3, 28.8 and 8.2% for raw, instant and extruded banana flour soy-fortified porridges, respectively and 7.6% for instant banana flour soy-fortified soup.<br>The porridges were more acceptable compared to the soups | *(Muranga, Nabugoomu, & Katebarirwe, 2011)* |
| AAA-EA | Banana based weaning formula | Extrusion and pre-gelatinization increased the energy content of cooking bananas hence reducing its bulkiness.<br>Addition of simsim<br>will improve the protein content and quality of the banana-based weaning formulas | *(Bukusuba, Muranga, & Nampala, 2008)* |
| *Bogoya*, *Mbidde* and *Kayinja* (AAA, -EA and<br>ctively) | Banana juice and wine | The TTS of the juices ranged 15°-27°Brix<br>Juices had overall acceptability above 6 points on a 9 point hedonic scale<br>Generally at least 66.7% of the juice were acceptable<br>Overall acceptability of the wine from the three cultivars was 5.5 on a 9 point hedonic scale | *(Byarugaba-bazirake, 2008)* |

## 2.3 Banana breeding

Bananas and plantains are difficult crops to breed for consumer acceptability because of limited knowledge about consumer preferred quality attributes, limited knowledge about *Musa* genetics & cytogenetic and most of the important and popular varieties are highly sterile and therefore do not produce seeds (Jenny, Tomekpé, Bakry & Escalant, 2002).

Despite these constraints, important progress has been made in the genetic improvement of *Musa* in recent years and new varieties are now becoming available from breeding programmes. Major

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## 2.3 Banana breeding

Bananas and plantains are difficult crops to breed for consumer acceptability because of limited knowledge about consumer preferred quality attributes, limited knowledge about *Musa* genetics & cytogenetic and most of the important and popular varieties are highly sterile and therefore do not produce seeds (Jenny, Tomekpé, Bakry & Escalant, 2002).

Despite these constraints, important progress has been made in the genetic improvement of *Musa* in recent years and new varieties are now becoming available from breeding programmes. Major

breeding programmes that use conventional breeding methodologies are located at the Fundación Hondureña de Investigación Agrícola (FHIA) in Honduras, the Centre de Coopération Internationale en Recherche Agronomique pour leDéveloppement (CIRAD-FLHOR) in France and Guadeloupe, the International Institute of Tropical Agriculture (IITA) in Nigeria and Uganda, the Centre Africainde Recherches sur Bananiers et Plantains (CARBAP) in Cameroon and the Empresa Brasiliera de Pesquisa Agropecuaria (EMBRAPA) in Brazil (Jenny et al., 2002).

Banana breeding is built on targets such as yield characteristics, abiotic stress resistance, biotic stress resistance, post-harvest characters and market attributes (Heslop-Harrison, 2011). Biotic and abiotic stresses cause major yield losses and unstable production to farmers and traders.

Bananas, like any other crop, are affected by pests and diseases and, therefore, use their natural defensive mechanisms to overcome these challenges. People have however, devised ways of supplementing the natural protection of bananas by employing cultural strategies, chemical control measures as well as breeding resistant cultivars resistant to pests and disease control. Cultural control strategies such as use of barriers, barrowing land, and high planting densities are expensive to the smallholder farmers (Hilje, Costa, & Stansly, 2001). Chemical control measures by use of pesticides are also expensive and toxic compounds may end up poisoning non-intended organisms for instance earthworms, and causing chronic toxicity in mammals as well as inducing resistance genes within pests (Waard, Georgopoulos, Hollomon, Ishii, Leroux, Ragsdale & Schwinn, 2003).

The Global Musa Genomics Consortium through research is making progress in breeding better bananas by use of genetic maps and DNA markers to identify useful genes, combine desirable

traits or resistance genes and accelerate selection, although these approaches still face limitations due to the sterility of the triploid bananas (Heslop-Harrison, 2011).

Now, knowledge of genomics and understanding of crop design allows super domestication, involving interactions of breeders and genomic scientists to design the characteristics required from a banana cultivar and consider how to produce this ideal cultivar – how to find and evaluate the genes responsible for particular traits, and how to bring them together in a new cultivar (Heslop-Harrison, 2011).

One of the most promising strategies for improving on the quality and quantity of banana breeds is breeding cultivars with better eating qualities, agronomic performance as well as resistance to pests and diseases (Simmonds, 2007). In the case of bananas, different breeding programs have come up to respond to this cause. Such programs include Fundacion Hondurena de Investigacion Agricola (FHIA) in Honduras, and NARO in collaboration with Bioversity International and IITA in Uganda. The resultant hybrids include FHIAs (e.g. FHIA 03, FHIA 017 and FHIA 23), NABIOs (e.g. M9, M2 and M6) and NARITAs (such as NARITA 17, NARITA 14 and NARITA 24) as indicated in table 2.3 (Njuguna et al., 2008; Uazire et al., 2011; Nowakunda et al., 2015; Tumuhimbise et al., 2018).

The process of banana breeding for disease resistance involves cross pollination of the susceptible female fertile banana clones with improved disease resistant diploid male parents (Janick, 1996). The resulting hybrid has better resistance to a specific disease such as black Sigatoka. However, despite an improvement in the disease resistance and agronomical yields in some of the banana hybrids, some cultivars such as FHIA 03 still face rejection due to an astringency taste and poor colour (Ssemwanga et al., 2000). Such rejection is attributed to the failure to allow farmers and consumers to determine the possible food preparations that can be

made out of new varieties. The new varieties that may be rejected by an ethnic group may receive acceptance from others. It is therefore relevant to allow various ethnic groups to evaluate new hybrids according to their food habits and if possible release these varieties as ecotypes (Dzomeku, Darkey, Bam & Ankomah, 2007).

However, other hybrids, for example NARITA 7 (M9/KABANA 6H/ *Kiwangaazi*), have good acceptability ratings and are preferred by consumers for use in the preparation of cooked bananas (Nowakunda et al., 2015). Knowing consumer quality characteristics in cooking bananas that influence their preferences will inform current and future breeding programmes to improve the consumption qualities of hybrids for better adoption and consumption. Thus, the success of the introduction of any new *Musa* hybrid hinges on the sensory quality characteristics of common dishes prepared from these hybrids by the local people (Dzomeku et al., 2007).

Table 2.3 Banana cultivars bred/introduced in Uganda

| Cultivar | Breeder | Purpose | Advantages | Limitations | Reference |
|---|---|---|---|---|---|
| **NARITA *Matooke* hybrids** (N23, N7, N18, N4, N22, N14, N12, N11, N26, N15, N1, N24, N25, N20, N2, N17, N19 & N5) | NARO-IITA, Uganda | Host resistance to weevils, nematodes and diseases | High bunch weight (8.7-0.4 kg)<br>Many hands per bunch (5.9-11.6 hands)<br>Many fruit fingers per hand (89.4-218.7 fingers) | Longer days to bunch maturity (119.2-182 days) compared to locals such as *Mbwazirume* (115.0 days)<br>Longer plant height at flowering (263.1-372.5 cm) vulnerable to wind breaks<br>Generally lower plant height at flowering (36.5-59.5 cm) compared to local check *Mbwazirume* (273.9 cm) | *(Tushemereirwe et al., 2015)* |
| **NAROBan *Matooke* hybrids** (NAROBan1, NAROBan2, NAROBan3 & NAROBan4) | NARO, Uganda | Multiple resistance to pests and diseases | Good taste, aroma, mouth feel, colour and overall acceptability ranging 4.03-5.03 on a hedonic scale of 1-6<br>Medium to tall cultivars (281.1-341.8 cm) with wide pseudo stem girth<br>Many function leaves (11.0-12.8 leaves) compared to *Enjagata* and *Kisansa* (7-9 leaves)<br>High average bunch yield per year (54.9-68.8 t/ha/year) compared to local checks (23.4-34.4 t/ha/year)<br>Resistant to weevils and Nematodes | Tall bananas >300 cm are susceptible to wind breaks | *(Tumuhimbise et al., 2018)* |
| **NABIO *Matooke* hybrids** (NABIO-1009, NABIO-1011, NABIO-1117, NABIO216, NABIO306, NABIO318, NABIO614, NABIO617, NABIO808, NABIO15, NABIO17 & Kabana 6H) | NARO-Bioversity, Uganda | Multiple resistance to weevils, nematodes and black sigatoka | Resistant to weevils, nematodes and black Sigatoka<br>M 30 tastes as good as traditional cultivars such as *Mbwazirume*<br>Stable for heavy bunch yielding<br>Soft and yellow pulp on cooking (NABIO306, NABIO1011, NABIO808 & NABIO1009 ) | Some cultivars (NABIO1009, NABIO216, NABIO318 & NABIO614) have low resistance to black Sigatoka | *(Tumuhimbise et al., 2016)* |
| **FHIA *Matooke* hybrids** (FHIA-01, FHIA-02, FHIA-03, FHIA-17, FHIA-18, FHIA-21, FHIA-23 & FHIA-25) | FHIA, Honduras | Multiple resistance to black sigatoka, weevils and *Fusarium* wilt | Good bunch weight (25.8-45.6 kg)<br>High yield per acre (24.3-55.7 t/ha/year)<br>Resistance to *Fuzarium* wilt and black Sigatoka<br>Higher fruit weight (113.0-130.0 gr) compared to local checks *Kisansa* and *Mbwazirume* (122.5-114.0 gr) | Longer maturity dates (122.7-133.0 days) compared to local checks *Kisansa* and *Mbwazirume* (120.0 & 122.0 days, respectively)<br>Higher tannins content (0.207-0.598 g/kg) unlike local counter parts (0.10-0.008) hence a puckering sensation in the mouth<br>Poor sensory attributes (taste, flavor, colour, texture) and low acceptability compared to *Mbwazirume* and *Kisansa*<br>High proportion of peels (32.0-44.5 %) compared to local cultivars (30.0-37.8 %)<br>Higher dry matter content (28.6-31.1 %) compared to local checks (17.8-18.3 %) associated with hard cooked *Matooke* products | *(Nowakunda & Tushemereirwe, 2004; Njuguna et al., 2008; Gaidashova, et al., 2008)* |

## 2.4 Composition of cooking bananas

The biggest proportion of unripe cooking bananas is carbohydrates accounting for about 91% dry weight followed by ash, proteins and fat (Table 2.4). Starch is the dominant carbohydrate and levels increase with maturity giving a higher bunch weight which translates to greater economic value to traders. Total starch consists of the resistant starch, which is indigestible in the human gut and the digestible/non-resistant starch which is hydrolysed to glucose for energy production (Menezes, Tadini, & Tribess, 2015). The resistant starch in bananas has been reported to reduce constipation, cholesterol levels in the body as well as risks of colon cancer (Le Leu et al., 2007). Other carbohydrates in bananas include pectin, cellulose, hemicellulose and sugars such as glucose and fructose which contribute significantly to the perceived taste of ripe bananas (Muchui, Njoroge, Kahangi & Onyango, 2010). The yellow colour of cooked banana pulp is due to carotenoids such as beta carotene and flavonoids whereas aroma is attributed to alcohols, aldehydes and benzenoid (benzene like aromatic compounds) derivatives (Stewart et al., 2007). Bananas are also good sources of vitamins such as thiamine, carotenoids, pro-vitamin A and vitamin C; all these are potential antioxidants in the body against cancers and therefore should be recommended in deficiency areas (Ohizua, Adeola, Idowu, Sobukola, Afolabi, Ishola, Ayansina, Oyekale & Falomo, 2017). There are substantial amounts of minerals in bananas particularly K, Na, Fe, Cu, Mn, Zn, Mg and Ca (Ohizua et al., 2017). Minerals are needed for enhancing enzyme activity, protection of cells against free radical attack and in osmoregulation in the body (Anhwange, 2008).

However, minerals such as calcium and sodium influence the texture of bananas (Qi, Moore, and Orchard, 2000). For instance, calcium has been reported to influence the firmness of cooked bananas by inducing the formation of ionic $Ca^{2+}$ gels that cementing pectin chains and reducing

their hydration and solubilisation abilities hence delayed cell wall softening and separation (Morris, Powell, Gidley and Rees, 1982; van Buren, 1986). However, Qi, Moore, and Orchard (2000) reported that the calcium-linked pectin may only represent a small proportion of the total pectin content, which could be attributed to the low levels of calcium in the pulp hence this effect could have a relatively low impact on the texture of cooked plant tissues. On the other hand sodium ions have been associated with a soft texture due to displacement of calcium ions in plant cells hence enhanced solubilisation of pectin causing softening (van Buren and Pitifer, 1992). Mineral nutrients have been classified as macro elements which are required in the body in amounts higher than 50 mg/day (such as sodium, potassium, chloride, calcium, magnesium and phosphorus) and the trace elements which are needed in amounts less than 50 mg/day (such as iron, copper, zinc, manganese, selenium, iodine, chromium, cobalt, molybdenum, fluoride, arsenic, nickel, silicon and boron) (Belitz et al., 2004; Cashman, 2006). However, excessive consumption of mineral elements can be harmful to the human body for instance, high levels of essential nutrients such as such as copper, chromium, selenium and zinc can cause toxic effects to the body (Ministry of Agriculture, Fisheries and Food, 1998ab; Martino et al., 2000). Therefore Recommended Dietary Allowances (RDA) are put in place to regulate the amounts of each nutrient consumed by an individual. RDA stands for a set of nutrient standards established by Committee on Dietary Allowances or Adequate Intakes (AIs) or Tolerable Upper Intake Levels (ULs). The RDA is the average daily intake of energy and nutrients considered adequate to meet the needs of almost all (97-98 %) healthy infants, children and people (Vahčić et al, 2010). RDAs and AIs may both be used as goals for individual intake. Much as the adequate intake (AI) for healthy breastfed infant is the mean intake, the AI for other life stage and gender groups is believed to cover the needs of all individuals in the group, but lack of data prevents

ability to specify with confidence the percentage of individuals covered by this intake (Vahčić et al, 2010). The Tolerable Upper Intake Levels (ULs) is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects for almost all individuals (Anonymous 2, 2010). Table 3.4 below shows the different RDA for children and adults.

Table 3.4 RDA for mineral nutrients for persons aged 8-9 years and 15-18 years

| | RDA (mg/day) | |
|---|---|---|
| Minerals (mg) | 8-9 years | 15-18 years |
| Calcium | 1300 | 1300 |
| Phosphorus | 1250 | 1250 |
| Magnesium | 240 | 410 |
| Iron | 8 | 11/15 |
| Copper | 0.7 | 0.89 |
| Zinc | 8 | 11/9 |
| Manganese | 1.9/1.6 | 2.2/1.6 |
| Nickel | 0.6 | 1.0 |
| Potassium | 4500 | 4700 |
| Sodium | 1500 | 1500 |

Source: (Vahčić et al, 2010).

Consumption of bananas provides health benefits to the body such as protection against cancers, cardiovascular diseases and skin damage because they are rich sources of phytochemicals, in addition to vitamins and provitamins (Singhal & Ratra, 2013). Bananas are viable sources of therapeutic compounds such as polyphenols which are biologically active metabolites essential in human diets and overall health (Amri & Hossain, 2018). Polyphenols have also been documented to have antimicrobial effect and to slow lipid oxidation in food products (Tomekpe et al., 2014). There are also substantial amounts of flavonoids such as flavones, flavanones and flavanols with therapeutic benefits against cardiovascular diseases, cancers and reversing the

adverse effects of cyclosporine and cardiovascular diseases (Pothavorn, Kitdamrongsont, Swangpol, Wongniam, Atawongsa, Svasti & Somana, 2010). Green bananas contain high amounts of tannins which are responsible for the astringent taste in banana juice and steamed *Matooke* (Kyamuhangire, Krekling, Reed, & Pehrson, 2006). Knowing the levels of phytochemicals in different bananas avails information that can be used by researchers to develop medicines that can be used for the treatment of different diseases.

Table 2.4 Proximate composition of bananas

| Sample source | Variety | Protein (%) | $CH_2$ (%) | Fat (%) | Moisture (%) | Ash (%) | Fibre (%) | Reference |
|---|---|---|---|---|---|---|---|---|
| East Africa | EAHB | 0.6-1.3 | 13.48-18.64 | 0.05-1.59 | 75.87-79.22 | 3.1-3.8 | 0.65-2.92 | *(Walugembe, Buah, Runo, Ateka, Kubiriba & Tushemereirwe, 2020)* |
| Tanzania | EAHB | 0.61-1.75 | 21.59-29.96 | 0.09-0.53 | 65.53- 74.44 | 0.66-1.45 | 0.92-2.79 | *(Dotto, Athanasia, Matemu, Patrick & Ndakidemi, 2019)* |
| Ethiopia | EAHB | 0.91-1.40 | 84.16-85.48 | 1.04-1.24 | 7.89-9.61 | 1.32-2.00 | 2.13-2.93 | *(Zerihun & Minuye, 2019)* |
| East Africa | EAHB | 1.1-4.7 | 16.1-80.0 | 0.4-4.2 | 1.0-27.7 | 2.4-11.7 | 6.0-7.5 | *(Dotto, Matemu, & Ndakidemi, 2018)* |
| Ghana | Cooking banana hybrids | 2.5-3.4 | | 0.0-0.3 | 53.1-75.0 | 2.0-2.9 | 4.0-6.7 | *(Annor, Asamoah-Bonti, & Sakyi-Dawson, 2016)* |
| Uganda | EAHB flour | 4.05 | | 0.72 | 8.06 | 3.36 | 2.88 | *(Bukusuba, Muranga, & Nampala , 2008)* |
| Bangladesh | *Musa sapientum* | 3.19±0.08 | 80.80±0.05 | 0.5±0.05 | 14.31±0.6 | 1.2±0.09 | 4.2±0.1 | *(Islam et al., 2014)* |
| Nigeria | *Cajanus cajan* | 2.4±0.30 | 79.86±1.37 | 0.34±0.00 | 6.0±0.01 | 4.40±0.10 | 6.00±0.40 | (Anuonye, Ndaliman, Elizabeh, & Yakubu, 2012) |
| Malaysia | *Musa acuminata × balbisiana Colla cv. Awak* | 6.77±0.06 | 79.89±0.24 | 0.94±0.04 | 9.94±0.20 | 2.46±0.05 | 7.53±0.08 | (Haslinda, Cheng, Chong, & Aziah, 2009) |
| East Africa | Plantain and cooking bananas | 0.8-1.3 | 21.8-24.3 | 0.1-0.37 | 63-65 | | 2.0-5.4 | (Aurore, Parfait, Fahrasmane, Aurore, & Parfait, 2009) |
| India | *Jawari', 'Shrimanti', 'Grand Naine' (G-9) and 'Basrai'* | - | - | - | - | 4.20-15.36 | - | (Deshmukh, Pai, Nimbalkar, & Patil, 2009) |
| Ghana | FHIA 03, FHIA 19, FHIA 20 and Apantu pa | 2.5-3.1 | - | 0.0-0.2 | 53.1-75.0 | 2.0-3.1 | 3.9-6.7 | *(Annor, Asamoah-Bonti & Sakyi-Dawson, 2016)* |

## 2.5 Physical and chemical properties of banana starch and pectin

### 2.5.1 The structure of starch

Starch is a polymer of α-D-glucopyranosyl residues existing as starch granules in the storage parenchyma cells of starch rich foods (BeMiller & Dekker, 2008). It consists of two monomer units i.e. amylose which is mainly linear with a few branches and amylopectin which is extensively branched resulting into a complex structure (Brown & Poon, 2005). Both amylose and amylopectin chains consist of α (1→4) linked D-glucose residues with branch points being formed by α (1→6) glycosidic linkages for both amylose and amylopectin (Bertoft, 2017).

#### 2.5.1.1 Amylose

Amylose is a helical polymer made of α-D-glucose units bonded to each other through α (1→4) glycosidic bonds (Fig. 2.1). Because of its tightly packed structure, amylose is more resistant to digestion than other starch molecules and is therefore an important form of resistant starch which is an effective prebiotic (Espírito Santo, Cartolano, Silva, Soares, Gioielli, Perego & Oliveira, 2012). Amylose is also an important thickener, water binder, emulsion stabilizer and gelling agent.

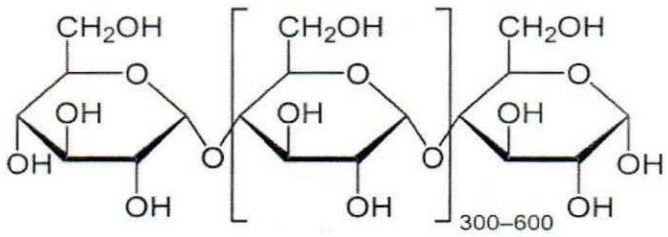



Fig. 2.1. Structure of amylose

### 2.5.2.2 Amylopectin

Amylopectin is a water-soluble polysaccharide and highly branched polymer of glucose found in plants (Fig. 2.2). Glucose units are linked via α (1→4) glycosidic bonds. Branching takes place with α (1→6) bonds occurring every 24 to 30 glucose units. Amylopectin is highly branched, with 2,000 to 200,000 glucose units. Its inner chains are formed of 20-24 glucose subunits. Dissolved amylopectin has a lower tendency of retrogradation during storage and cooling. For this main reason, the waxy starches rich in amylopectin are normally used in different applications mainly as a thickening agents or stabilizers.

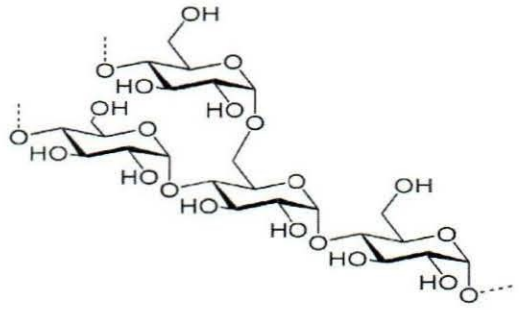


Fig. 2.2. Structure of amylopectin

Short chains of amylopectin form double helices which crystallize and contribute to the semi-crystalline nature of starch granules. The starch crystalline regions are mainly made up of amylopectin polymers hydrogen bonded to the branches forming crystallites that disentangle during gelatinization. The amorphous regions of starch granules are predominantly composed of amylose and amylopectin branch points (Ratnayake & Jackson, 2006).

### 2.5.2 Relationship between banana starch and texture

Texture is attributed to the structural cell wall components of plant materials such as pectic polysaccharides, hemicelluloses, cellulose and starch (Qi, Moore & Orchard, 2000). Any

physiological changes during ripening or heat treatments result into a soft texture due to cell wall disruption. For instance, when *Matooke* is cooked, a soft texture, which is a preferred quality attribute, is obtained (Ssemwanga et al., 2000). Softness is characteristic of *Matooke* while still hot; upon cooling, *Matooke* hardens (Gafumaet al., 2018), a textural change undesirable to consumers. Hardness in cooled *Matooke* is attributed to starch gelatinization and retrogradation as well as pectin hydrolysis (Fennema et al., 2008; Morris, Kirby, Quesada, Paniagua, Posé, Morris, Kirby, Quesada & Mercado, 2014).

During gelatinization, insoluble starch granules dissolve in hot water, swell and burst leaching out amylose producing a swollen starch mass (Ratnayake & Jackson, 2006). With continued heating, the crystallites melt leading to enhanced molecular freedom of movement eventually leading to complete separation of amylose and amylopectin. Gelatinization occurs in conjunction with β-elimination in the lamellae to cause softening of plant tissues (Fennema et al., 2008).

On the other hand, during starch retrogradation, which occurs during cooling, the amylose and amylopectin chains originally disrupted during gelatinization, gradually re-associate by hydrogen bonding. The initial rapid recrystallization of amylose followed by slow recrystallization of amylopectin molecules results into gel formation of β-type polymorphs (Wang, Li, Copeland, Niu & Wang, 2015). Thus, cooked starchy foods with low amylose content such as rice and banana produce softer and sticky cooked food, while those with higher amylose are firm (Perdon, Siebenmorgen, Buescher & Gbur, 1999). Therefore, determination of the total starch content in cooking bananas could explain the consumer textural perspectives in the cooked banana meal.

## 2.6 Pectin degradation and solubilisation

Pectin is a polysaccharide found in the middle lamella of primary cell walls in plants where it acts as a cementing agent (Van Buggenhout, Sila, Duvetter, Van Loey & Hendrickx, 2009). In the middle lamella, pectic substances (e.g. xyloglucan) are covalently bonded to cellulose fibres contributing to tissue firmness. The free carboxyl groups along the pectin chains are also engaged in calcium binding between pectin polymers reinforcing the firm texture in plant tissues (Thakur, Singh & Handa, 1997).

During thermal processing and enzyme treatment, high molecular mass pectin is hydrolysed and depolymerised into intermediate and short chain pectin (Morris et al., 2014). Degradation and solubilisation occur with initial loss of tissue firmness which is associated with loss of turgidity due to membrane disruption. Subsequent tissue softening mainly occurs due to successive enzymatic demethoxylation and depolymerization by pectinmethylesterase and polygalacturonase enzymes, respectively (Van Buggenhout et al., 2009). Thermal degradation also leads to the solubilisation of pectin by either β-elimination or acid hydrolysis depending on the degree of methoxylation (DM) and pH whereby, a higher DM results into higher levels of β-elimination. Loss of the cementing agent within cell walls and middle lamellae leads to cell separation thus loss of firmness in fruits such as bananas (Ni, Lin & Barrett, 2005).

## 2.7 Sensory quality characteristics and physicochemical properties of bananas

Consumers prefer cooked bananas that are soft, having a good aroma, slightly sweet and not highly astringent (Ssemwanga et al., 2000). Taste is mainly the balance between sugar and acid content in a fruit. The main acids in bananas are malic and acetic acid with levels ranging from 1.5% to 2.5% respectively which is indicative of green maturity (Dadzie, 1998). On the other hand, total soluble solids (sugars) must balance with the acidity of the fruit to conform to the

desired maturity of bananas used for the production of juice, wine and cooked banana meals depending on the cultivar (Muchui, Njoroge, Kahangi & Onyango, 2010). The level of sweetness in a banana decreases with cooking due to water absorption during cooking which dilutes the total soluble solids within the plant tissues and interferences with phytochemical compounds on the sugar/acid ratio (Ssemwanga et al., 2000). Astringency due to tannins and phenolic compounds also modifies the level of sweetness leading to poor score of flavour within the hybrid bananas such as FHIA 3 which has been reported to contain high levels of astringency (Joslyn & Goldstein, 1964; Nowakunda et al., 2000; Ssemwanga et al., 2000; Nowakunda & Tushemereirwe, 2004).

The polyphenol compounds found in bananas include tannins which are responsible for astringency of the pulp (Khawas, Das, Sit, Badwaik & Deka, 2014). However, the level of tannins decreases with fruit maturity due to insolubilization and polymerization of polyphenols with other constituents of pulp improving the palatability of bananas (Khawas et al., 2014).

The shiny appearance of the skin of banana is one of the characteristics that consumers lookout for to judge the freshness of the raw bananas. This glossy appearance is associated with the rate of moisture loss by the fingers after harvest since cells with full turgidity stretch and appear shiny (Ferris, 1991).

The specific gravity of the bananas is directly related to the processing efficiency, texture and yield of the banana products (Belayneh, Workneh, & Belew, 2014).

Pulp firmness is determined by cell size and structure as well as the chemical composition (such as starch, cellulose, pectin) of the uncooked banana cultivars. Loss of pulp firmness is attributed to loss in cell turgidity during cooking along with starch solubilisation and pectin hydrolysis

(Dadzie, 1998). Therefore, a banana with a good pulp firmness and high specific gravity has a good perceived texture although some hybrids including FHIA 3 have been reported to be less soft and lumpy compared to local cultivars, which can be traced back to their high specific gravities (Ssemwanga et al., 2000). It is therefore important to determine the specific gravity of bananas to predict and account for their textural characteristics in relation to consumer preferences.

Texture of the cooked banana products is also dependant on the cooking time besides the banana cultivar (Belayneh et al., 2014). As the banana fingers cook, hot water is absorbed in the tissues by starch, cellulose and pectin, which causes tissue softening (Qi et al., 2000). The starch granules swell and burst undergoing gelatinization thus producing a soft-jelly texture in the cooked bananas. Pectin is hydrolysed to a more soluble form making the final product soft and easy to chew and digest ( Dadzie, 1998; Qi et al., 2000). The low water absorption characteristic is related to low dry matter content of the bananas which depends on the cultivar used. For example, dessert hybrids and the East African Highland cooking bananas with low dry matter content have been reported to become partially or completely disintegrated in boiling water (Dufour & Gibert, 2009). On the other hand, hybrid cultivars such as FHIA 20 with high dry matter content exhibit low water absorption potential making them more suitable for cooking (Belayneh et al., 2014; Dufour & Gibert, 2009).

Dry matter content of bananas is an indirect measurement of their cooking qualities (Muchui et al., 2010). A high dry matter content indicates the banana has good cooking qualities, a longer shelf life and the fruit has a bigger proportion that can be utilised for food preparation (Ferris, Adeniji, Chukwu & Akalumhe, 1996; Muchui et al., 2010). Therefore, analysis of banana dry matter can give an explanation of its acceptability for *Matooke* preparation.

Amylose and amylopectin ratios also influence the cooking qualities of bananas (Ssonko & Muranga, 2017). For example, in Columbia, hybrid cooking bananas for instance *Blanco*, *Harton* and *Dominico* clones with hard textures and amylose content in the range 23% to 24.9% were reported as the hardest to cook in water (Dufour & Gibert, 2009). This is attributed to their tendency to harden after cooking and during the cooling phase due to starch retrogradation (Dufour & Gibert, 2009). Hence, it is important to determine the amylose content of the cooking bananas since such findings would help breeders improve the texture of existing hybrids especially those that harden quickly on cooling.

The poor colour uniformities of the hybrids for instance, the yellow and/or cream colour with patches of red-brown in FHIA 3 when cooked, dark brown or greyish appearance contributes to their low or no acceptance (Ssemwanga et al., 2000; Nowakunda & Tushemereirwe, 2004) (Ssemwanga et al., 2000). This is because the preferred colour of a cooked *Matooke* is yellow and any deviation from is perceived undesirable. Colour assessment by sensory evaluation enables food scientists to account for consumer acceptance or rejection beyond the results obtained from physicochemical analysis.

A thick peel is associated with difficulty in peeling (Dadzie & Ochard, 1997). Therefore, the thickness of the peel may partly explain consumer's choices of preferences when deciding whether to use hybrid or local bananas for preparation. A higher pulp/peel ratio offers good cooking banana qualities and greater yields since less material is thrown away as waste. Therefore, measurement of this quality attribute is crucial in understanding the quality characteristics of the bananas that matter to the consumers.

Cooking bananas have been reported to exhibit relatively low pasting temperatures of less than 75°C, a high peak viscosity in the ranges of 488.42-558.71 RVU and a high level of viscosity

breakdown in the ranges of 235.00-311.92 RVU (Ssonko & Muranga, 2017). The banana starches have relatively higher swelling power (SP) (12.43-14.27 g water/g starch) at temperatures between 70°C and 80°C which is indicative of the stability of starch granules in this temperature range, and is attributed to the SP temperatures of the starches being lower than the gelatinization temperatures (Ssonko & Muranga, 2017).

Discussion of the above factors highlights the importance of documenting the physicochemical properties and consumer quality characteristics of popular local and hybrid cooking banana cultivars grown in Uganda. Limited work has been done to correlate these parameters in the Ugandan setting. This study was undertaken to bridge these gaps. Studying the relationship between consumer quality characteristics and physicochemical properties of cooking bananas will lay a foundation for improving the quality characteristics of existing hybrids for better adoption rates by consumers and other banana value chain actors.

# CHAPTER THREE: METHODOLOGY

## 3.1 Source of samples

Three mature green-bunches (per cultivar) of cooking bananas were harvested from Kawanda and Sendusu trial stations in Uganda. A total of 23 cultivars were evaluated and these included two officially released hybrids which were selected due to their higher acceptability as cooking bananas(Nowakunda et al., 2015; Tumuhimbise et al., 2016; Tumuhimbise et al., 2018): (M30/NAROBan5 and N7/KABANA 6H/M9); twelve hybrids under evaluation: NARITAs (N17, N24, N2, N6, N8, N11, N14, N15, N21), NABIOs (M32 and M33) and 17914S-24; three female parents used in breeding: (*Nakawere, Kabucuragye* and *Enzirabahima*) and six local cooking banana cultivars as controls: (*Nakitembe, Kibuzi, Muvubo, Nfuuka, Mbwazirume*, and *Mpologoma*). Bunches were labelled and transported to National Agricultural Research laboratories-Kawanda (NARL) between 8:00 and 10:00 am for analysis.

## 3.2 Preparation of banana flour

### 3.2.1 Preparation of banana flour

Banana flours for individual cultivars were prepared according to the procedure of Belayneh et al. (2014). The second hand of each cultivar was used to prepare a composite sample of fifteen fingers for physicochemical analysis since fingers from the second hand have the least variations (Stover & Simmonds, 1987). Five fingers per cultivar were peeled and their pulp sliced with a stainless-steel knife, placed on sterile plastic petri plates and kept in a drier (JW-1350ED, KOREA) for 48 h at 40°C. The dry slices were ground in a mortar and pestle, sieved using a plastic sieve mesh of 0.2 mm pore size (Kenpoly, Kenya). The fine powder was then kept in a clean sterile 15 mL plastic tube with HDPE screw caps (cat 188271, Greiner Bio-One, Germany) at room temperature for further analysis for proximate and chemical composition.

### 3.3 Morphometric measurements

A total of nine fingers from each experimental block was sampled for morphometric measurements according to the protocol of Dadzie & Orchard (1997). Finger circumference and length were measured using a tape measure. Pulp and peel weight were determined by hand peeling the fingers, and then separately measuring their weights using a digital analytical balance (New classic B338807259, Switzerland). The weights of the pulp and peel were expressed as a ratio. Peel thickness was measured using a micro-caliper across the transversely cut banana fruit.

### 3.4 Physicochemical composition

#### 3.4.1 Total soluble solids (TSS)

TSS were measured in °Brix using a method adopted from Ssemwanga et al. (2000). The pulp sample (50 g) was thoroughly crushed using a blender (Snijders Scientific 8011E W1102-295, Holland) in 50 ml of deionized water for 2 min. The blend was filtered through a Whatman No. 1 filter paper. A single drop of the filtrate at room temperature (~24°C) was placed on a prism of a calibrated handheld refractometer (Leica Buffalo, NY 14215 0-50 °Brix, USA) and the reading was recorded.

#### 3.4.2 The pH and titratable acidity

The pH of the filtrate from section 3.4.1 was determined using the protocol of Reed et al. (1982). The pH meter (Oakton 35423-10, Malaysia) was first calibrated using standard buffers at pH 4 and 7. Sample pH was measured at 24°C by submerging the tip of the probe into the sample for about 2 min until a stable reading was registered on the pH meter scale.

Titratable acidity (TA) was determined by titrating 6 ml of the filtrate against 0.1 N sodium hydroxide solution to the phenolphthalein end point. Percent TA was calculated using the following formula (Kotecha & Desai, 1995):

TA = (titre volume x Normality of NaOH x 0.067 x 100)/Volume of sample

Where 0.067 is the factor of malic acid, the dominant acid in bananas

### 3.5 Proximate composition

#### 3.5.1 Dry matter

Dry matter content was determined using the air oven method according to AOAC (2000) method no. 44-15A. An aluminum Petri dish was washed with portable water and rinsed with distilled water. The dish was dried in an oven (Gallenkamp C010055, UK), cooled to room temperature in a desiccator for 30 min and its weight taken. A 3 g sample was weighed on the aluminium dish using a digital analytical balance (New classic). The dish containing the sample was transferred into the preheated oven (Gallenkamp) at 105 ± 1°C for 4 h until a constant weight was obtained. The sample was removed from the oven using a pair of tongs and cooled in a desiccator for 30 min. The weight of the dish and the dry sample was recorded. Dry matter content was reported as the weight difference of the dish & sample after drying and weight of empty dish. Dry matter was then expressed as a percentage of the original sample weight.

#### 3.5.2 Crude fat

Crude fat was determined by Soxhlet method according to AOAC (2000), method no. 920.39. An aluminum cup was washed, rinsed with distilled water and oven dried at 105°C for 30 min. The cup was cooled to room temperature in a desiccator and its weight recorded. A 3 g dried sample from section 3.2 was weighed into a clean muslin thimble laid with fat free cotton wool. The thimble was then covered with the same cotton wool, inserted into the extraction column and the condenser switched on. Using a measuring cylinder, 50 ml of petroleum ether was transferred into the clean and pre-weighed aluminium cup and inserted to the extraction unit. The Soxhlet apparatus (J.P.Selecta 637427, Spain) was operated at 120°C for 3 h to boil the sample while

condensation taps were opened 2 h for rinsing, and 2 h for petroleum ether recovery while taps were closed. The aluminum cup containing the fat extract and residual petroleum ether was oven dried at 105°C for 1 h and cooled in a desiccator before weighing. The difference in weight of the aluminum cup after and before extraction was calculated as the fat content of the sample and expressed as a percentage of the original sample weight using the following formula:

Percent crude fat = ((weight of aluminium cup and fat – weight of empty aluminium cup) x 100) / weight of sample

### 3.5.3 Total carbohydrates

Total carbohydrate content of the samples was determined by the anthrone method as described by (Bartkienė, 2012). A 50 mg dried sample (section 3.2) was weighed into a falcon tube and hydrolyzed by addition of 2.5 ml of 2.5 N HCl for 3 h in a boiling water bath (Wangtech OLS 200 8Q0319001, England). The mixture was cooled and neutralized by addition of solid anhydrous sodium carbonate (Analar 102404H, England) until effervescence ceased. The volume was made to 50 ml and allowed to stand at room temperature overnight. An aliquot of 500 µl was pipetted from the supernatant and diluted to 1 ml using 50% $H_2SO_4$ (v/v). Then, 2 ml of anthrone reagent (Acros 104960250, India) was added to the tube and heated for 8 min in a boiling water bath. The sample was rapidly cooled and the absorbance of the green to dark green colour was read at 630 nm using a spectrophotometer (Jenway 3047, UK). The concentration of glucose in the sample was extrapolated from the standard curve prepared using glucose standards (Appendix VIII). The glucose stock solution was prepared by dissolving 10 mg glucose monohydrate in 10 ml deionized water. The working standard was prepared by diluting 10 ml of stock with deionized water to 100 ml. Further standards were prepared by pipetting 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard and topped up to 1 ml using distilled water. Total carbohydrates were estimated using the following formula:

Total carbohydrate in 100 mg of the sample = (mg of glucose x 100)/ volume of test sample

### 3.5.4 Crude protein

Crude protein (mico-Kjeldahl, ×6.25) was determined by AOAC (2004) . A 2 g sample from section 3.2 was weighed into a digestion flask and another flask without the sample (blank) prepared. A Kjeldahl catalyst (6.25% $CuSO_4.5H_2O$ tablet) (Panreac 0000531841, Spain) was added to each flask. Concentrated $H_2SO_4$ (10 ml) was added and the flask was placed into the digestion block (J.P. Selecta 639394, Spain). The sample was first digested for 45 min at 150°C,

temperature was adjusted to 280°C for the next 30 min to reduce production of fumes, and finally digested for 60 min at 400°C until clear green liquid was observed. The tubes were cooled to room temperature and 25 ml of deionised water was slowly added. A 250ml Erlenmeyer flask containing 50ml of 2% boric acid and three drops of the mixed indicator (bromocresol green and methyl red) was connected to the condenser. Then, 15 ml of 40% sodium hydroxide solution was introduced into the decomposition chamber of the distillation apparatus and 10 ml of the digested sample into a Kjedahl flask. Ammonia was distilled into boric acid until it changed to bluish green. The distillate was titrated with standardized 0.1N sulphuric acid to a reddish colour. Protein content was calculated as percent total nitrogen and a factor of 6.25 using the following formula:

Percent nitrogen (% N) = ((titre volume of sample-titre volume of blank) × N × 1.4007)/ weight of sample

Crude protein = % N × 6.25

**3.5.5 Total ash**

Ash content was determined according to the method described by AOAC (2000), method no. 923.03. A porcelain crucible was washed and dried at 120°C in an oven (Gallenkamp C010055, UK), for 15 min, cooled to room temperature in a desiccator and its weight taken. A 3 g dried sample (section 3.2) was weighed into the dried pre-weighed crucible and incinerated at 550°C for 8 h in a Muffle furnace (Gallenkamp, FSL 340-0100, UK). The sample was cooled for 45 min in a desiccator and weighed. Ash content was calculated as the difference between the weight of the crucible and ash and weight of the crucible before ashing according to the following formula:

% Ash = ((weight of crucible and ash - weight of empty crucible) x 100)/ weight of the sample

### 3.6 Chemical composition

#### 3.6.1 Starch content

Total starch was determined by the α-amylase method described by AOAC (2000), method no. 996.11. A 50 mg sample was weighed in duplicate into separate glass test tubes. Using a micro pipette, 0.2 ml of 80% (v/v) aqueous ethanol was added and stirred on a vortex mixer (Gallenkamp SGP-200, England) to wet and disperse the sample. Cold 1.7 M sodium hydroxide solution (1 ml) was added to the tube and the contents stirred on a vortex mixer for 15 s making sure there were no lumps in the mixture. Then, 4 ml of 600 mM sodium acetate buffer (pH 3.8) was added and the tube stirred with a vortex mixer. Undiluted thermo-stable α-amylase (0.05 ml) was added followed by 0.05 ml of amyloglucosidase enzyme (AMG) (3,300 U/ml). To the blank, 0.1 ml of 100 mM sodium acetate buffer (pH 5.0) was added and both tubes capped and vortexed for 3 s. The tubes were incubated for 30 min at 50°C in a water bath. The tubes were then cooled to room temperature and 1 ml of each solution (sample and blank) were transferred to a micro centrifuge tube and centrifuged at 13,000 rpm for 5 min at 24°C. Using a micropipette, 0.5 ml aliquot of each of the supernatants was transferred into separate tubes containing 2 ml of 100 mM acetate buffer (pH 5.0) and the contents mixed. Duplicates of 0.05 ml aliquots of each sample and a single 0.05 ml aliquot of the blank were transferred to the bottom of glass test tubes. Using a micropipette, 15 ml of GOPOD reagent was added to each tube and incubated at 50°C for 20 min. Absorbance against the reagent blank was measured at 510 nm using a using a spectrophotometer (Jenway 3047, UK). Starch content was calculated using the following formula:

Starch, % (w/w) = ΔA X F X EV X D X 0.9 / W

Starch % (dry wt. basis): = Starch, % (w/w) X 100 / (100 - moisture content (% w/w))

*Where:*

$\Delta A$ = absorbance of sample solution read against reagent blank, less the absorbance of the sample blank against the reagent blank

F = factor to convert absorbance values of µg glucose (100 µg glucose divided by the GOPOD absorbance value obtained for 100 µg of glucose)

EV = sample extraction volume (5.1 ml)

D = dilution factor of sample solution

W = sample weight in mg

### 3.6.2 Amylose content

Amylose content was determined according to the method described by Bartkienė (2012). Fifty milligrams of the banana powder was weighed into a falcon tube. Then, 500 µl of 96% ethanol was added followed by 5 ml of 1 N NaOH and left to stand overnight. The mixture was made up to 50 ml using 1 N NaOH. An aliquot of 1.25 ml of the sample was pipetted into a test tube and diluted with 10 ml of deionised water followed by three drops of 0.1% phenolphthalein indicator. The sample was titrated drop by drop using 0.1 N HCl until the pink colouration just disappeared. Then, 500 µl of iodine reagent was added and made up the volume to 25 ml using deionised water. The colour was read at 590 nmusing a spectrophotometer (Jenway 3047, UK). Amylose reference material (Commission of the European Communities Bureau of Reference N°135) was used to prepare the standard amylose solutions. The pipetted amounts of 0.2, 0.4, 0.6, 0.8, and 1 ml of the amylose stock solution were developed for colour as in the case of the sample. Amylose content of the sample was determined from the standard graph (Appendix VIII).

Amylose content was calculated using the following formula:

Absorbance corresponding to 1.25 ml of the test solution = y mg of amylose

Thus, 100 ml contains = y X 100 mg amylose / 1.25

= % amylose

### 3.6.3 Crude fibre

Fibre content was determined using a fibre extraction apparatus (J.P.Selecta624798, Spain) according to AOAC (2000), method no. 962.09. A clean dry crucible was weighed. A 0.4 g defatted sample from section 3.5.2 was weighed into the crucible and fixed onto the digestion column. Then, 120 ml of 0.128 M $H_2SO_4$ was added to the digestion column and the heater was set to 100°C for 30 min to hydrolyse the sample by boiling. The sample was cooled by holding at 30°C for 30 min, filtered and rinsed with hot deionised water. Then, 120 ml of KOH was added and heating continued until the second boiling. The sample was cooled, and rinsed with warm deionised water. The crucible containing the digested sample was dried for 45 min at 140°C and then cooled to room temperature in a desiccator for 30 min. The pre-weighed crucible was ashed at 550°C for 3 h, cooled in a desiccator and the final weight was recorded. Crude fibre content was reported as the difference between weight of the crucible and ash and weight of the crucible and sample after drying the digested sample.

% Crude fibre = ((weight of crucible and sample – weight of crucibles and ash) x 100)/ weight of the sample.

### 3.7 Colour measurement

Colour was measured using a Minolta color meter (Minolta CR-10 72311054, Japan) using the L*a*b* notation as described by Ssemwanga et al. (2000). To perform colour measurement, the banana fruit was cut into cross section and placed the cut end placed directly onto the optical glass of a 6.4 mm diaphragm. The parameters determined were black, white, greenness, redness, blueness and yellowness. The L*a*b* notation was used where L* measures the lightness of the sample, the higher the value the lighter the sample; a* measures the colour of the sample on a

red-green axis, where +a* is red and –a* is green and their respective magnitudes show the extent to which the sample is red or green; and b* measures the colour of the sample on the yellow-blue axis, where +b* is yellow and –b* is blue and their respective magnitudes indicate the extent to which a sample is blue or yellow.

### 3.8 Determination of polyphenol compounds

#### 3.8.1 Extraction of polyphenols from banana flour

Phenolic compounds were extracted using the method of Nazarudin, Roseli, Fui, Tsan, Ying, Othman, Ding, Osman & Othman. (2011) with minor modifications. The dried sample (200 mg, section 3.2) was weighed into a 15 ml falcon tube and 1.8 ml of 80% methanol added. The tube was gently placed in a sonicator (Bandelin 3255.00079781.003, Germany) operating at a frequency of 35 kHz for 1 h to extract polyphenols. After extraction, the tube was allowed to stand overnight and the supernatant pipetted and kept in dark in a refrigerator at 4°C until further analysis.

#### 3.8.2 Determination of total tannins

Total tannins were determined by Folin-Denis' method (Schanderi, 1970). To the supernatant in section 3.8.1, 100 µl of Folin-Denis' reagent (Sigma-Aldaich BCBR 878IV, USA) was added followed by addition of 200 µl of 7.5% sodium carbonate solution and mixed well. The solution was made up to a volume of 2 ml with deionized water, mixed well, left to stand at room temperature for 30 min and then optical density was taken at 760 nm. Standard solutions were prepared from the stock solution of tannic acid (Acros Organics A0268670, Belgium) (0.5 mg/ml) by pipetting 0, 10, 20, 30, 40, and 50 µl in test tubes and each of the volumes made up to 1 ml with deionized water. Then, 500 µl of Folin-Denis' reagent and 2.5 ml 20% sodium carbonate were added and the contents mixed. After 30 min at room temperature, absorbance

was read at 760 nm using a spectrophotometer (Jenway 3047, UK). Results were used to draw a standard curve (Appendix VIII) from which the total tannins content was extrapolated.

### 3.8.3 Determination of total phenols

Total phenolic content was determined using the Folin-Ciocalteu (FC) protocol as described by Alothman, Bhat, & Karim (2009). A 20 µl banana extract solution from section 3.8.1 was mixed with 900 µl of FC reagent (Loba chemie LM00471601, India). The reagent was pre-diluted 10 times with deionized water. After standing for 5 min at room temperature, 600 µl of 7.5% (w/v) sodium carbonate solution was added; the solution was mixed and left to stand for 1 h at room temperature. Optical density was measured at 765 nm using a UV-Visible spectrophotometer (Jenway 3047, UK) and used for extrapolation of tannins concentration from the standard curve (Appendix VIII). The standard curve was developed using standard solutions of Gallic acid (20, 40, 60, 80, and 100 mg/l). Standard stock solution was prepared by dissolving 10 mg of Gallic acid (Fluka 14506247, Germany) in 1 ml of deionized water. Results were expressed on dry weight basis as mg Gallic acid equivalents/100 g of sample.

### 3.8.4 Determination of total flavonoids

Total flavonoids content was determined calorimetrically according to Zhishen, Mengcheng & Jianming (1999). An aliquot of 250 µl banana extract (section 3.8.1) was pipetted into a test tube and mixed with 1 ml of deionized water. Then, 75 µl of 5% (w/v) $NaNO_2$ was added and after 5 min, 75 µl of 10% (w/v) $AlCl_3$ was added. After a further 1 min, 500 µl of 1 M solution of NaOH was added and the volume made up to 2.5 ml using deionized water. The mixture was agitated for thorough mixing and absorbance read at 510 nm using a UV-Visible spectrophotometer (Jenway 3047, UK) to estimate the flavonoid content of the sample as in sections 3.8.2-3.8.3. A calibration curve (Appendix VIII) was prepared using standard solutions of catechin (Sigma

C1251-10G, Japan) (20, 40, 60, 80, and 100 mg/l). The results were expressed on dry weight basis as mg catechin equivalents/100 g of sample.

### 3.9 Mineral analysis

Mineral content was determined using the closed tube digestion method for microwave plasma atomic emission spectrometry (MP-AES) as described by Wheal & Palmer, (2011) and Vysetti, Vummiti, Roy, Taylor, Kamala & Satyanarayanan (2014). A 250 mg dried sample was weighed into clean sterile 15 mL plastic tubes with HDPE screw caps (cat # 188271, Greiner Bio-One, Germany). Then, 2 ml of 69% (v/v) $HNO_3$ and 500 µl of 30% (v/v) $H_2O_2$ were added. The cap was tightened and the tube vortexed to thoroughly wet the entire sample. The sample was allowed to pre-digest overnight at room temperature. The sample was again vortexed before placing it into the digestion block and heated at 80°C for 30 min, and then at 125°C for 2 h in a fume hood. It was cooled to room temperature and the volume made to 25 ml using deionized water. The tube was re-sealed and agitated by vortexing for 5 min. The sample was allowed to settle for 1 h and decanted into a 4.5 ml polystyrene tube. The tube was placed into the auto-sampler rack and analyzed using MP-AES (Agilent Technologies G8003A MY16460002, Australia). The required hollow cathode lamp corresponding to the tested mineral and holder in the lamp compartment was installed to determine the concentration of each mineral. The MP-AES instrumental conditions included power reference incident power of 1 Kw, plasma argon flow rate of 20 L $min^{-1}$, auxillary argon flow rate of 1.5 L $min^{-1}$, nebulizer argon flow rate of 0.55-1 L $min^{-1}$, nebulizer of one $Neb^R$, sample flow rate of 0.9 mL $min^{-1}$, an axial optics viewing position, integration time of 3 s and number of reading as 3 (Wheal et al., 2011).

### 3.10 Determination of the major sensory quality characteristics

#### 3.10.1 Preparation of cooked *Matooke*

Cooked bananas were prepared using the traditional steam-and-mash method described by Gafuma et al. (2018). Clusters from the same bunch used for physicochemical analysis were sampled for sensory evaluation. For each cultivar, 6 kg of green banana fingers was washed in portable water, peeled to obtain about 3 kg of peeled bananas which was wrapped in a layer of fresh banana leaves. An aluminum saucepan was filled with 10 L of portable water and the wrapped bananas were placed on a porous metallic tray inside the saucepan. The saucepan and its contents were warmed on a gas stove turned to maximum for 15 min to ensure uniform distribution of heat in the saucepan. Bananas were then cooked by steaming over the heated water in a saucepan for 1 h. Steamed banana fingers were mashed manually for 2 min and then simmered for one extra hour before texture and sensory analysis.

#### 3.10.2 Texture analysis

Hardness, cohesiveness (mouldability) and adhesiveness (stickiness) of the cooked bananas were determined using the texture profile analysis (TPA) method adopted from Trinh, Tuoc, & Glasgow (2012). At the end of the simmering (section 3.10.1), the mashed steamed bananas were scooped from the banana leaves with a stainless-steel spoon and put into a metallic dish of 7 cm diameter and 1.5 cm height. The dish was leveled using a meter ruler. A hollow tube of diameter 4.5 cm and height 7.7 cm was used to cut out a cylindrically shaped sample which was placed on a measuring table under a 6 cm cylindrical probe of the texture analyzer (Mecmesin RH13OSZ 18-1020-08, UK). The probe was operated in the downward movement at a rate of 60 mm/ min and allowed to deform the sample 3 mm deep. The maximum force needed to cause the deformation was recorded as the hardness of the sample. The sample was rested for 10 s by

upward movement of the probe to enable sample recovery from deformation. The sample was then subjected to the second compression and the maximum negative and/or opposite force exerted on the probe was recorded as its adhesiveness.

### 3.10.3 Sensory evaluation

Sensory profiling was done using the Quantitative Descriptive Analysis (American Society for Testing and Materials, 1968). A pre-selection survey of sensory panelist was done to collect panelist bio data, identify their days of availability during the week, eating habits, health status in regard to foods they are allergic to and to get their consent to participate in the sensory training and evaluation exercise. Eighteen panelists were recruited and subjected to a 35 hours' training on basic tastes (sweet, salty, sourness, astringency and bitterness) including identification of basic tastes, basic taste thresholds, identification of aromas, ranking tests and triangle test before they evaluated the banana samples. Panelists were trained and assessed on the basis of functional taste buds using dilute solutions of basic tastes: sourness (tartaric acid at 6 g/l), bitterness (quinine at 0.06 g/l), salty (sodium chloride anhydrous at 7.5 g/l), sweetness (sucrose at 6 g/l) and astringency (aluminium potassium sulfate dodecahydrate (KAI $(SO_4)2.12H_2O$) at 5 g/l). Panelist were evaluated for repeatability using XLSTAT- Student version (2019.3.2.62913) sensory analysis tool bar and only thirteen consistent panelist were chosen to proceed with the sensory evaluation exercise. The selected panelists were taken through a series of tests involving non-experimental bananas to allow them to identify and learn the various descriptors of banana quality characteristics and to generate a sensory vocabulary from which sensory descriptors adopted on the scale were obtained. Experimental samples were coded with four digits to eliminate name bias and presented to the panelists in a random order. The samples were served to individual panelists along with an evaluation form, a pencil and water for rinsing in-between

sample tasting. Panelists were tasked to assess the different cooked banana samples on the basis of eating qualities on an 11-point category scale with verbal anchors as category labels (Lawless, Popper, & Kroll, 2010). The scale was ranging 0 to 10 where 0 represented complete absence of the quality characteristic while 10 represented its extreme intensity. Panelists assessed one sample at a time and on a daily basis a total of four cooked banana samples which included a control sample in each testing shift were served in a random sequence to reduce bias. The sensory characteristics evaluated as generated by the panel included aroma, colour, colour uniformity, taste (sweetness & astringency), mouth feel (softness & smoothness), impression (mouth feel), texture by hand (stickiness & lumpiness), and texture in the mouth (softness).

### 3.11 Statistical analysis

Results were presented as mean ± SE (standard error of mean) for three independent determinations. A one-way analysis of variance (ANOVA) was performed using XLSTAT-Student version (2019.3.2.62913) to identify significant differences in physicochemical properties of the bananas. A one-way ANOVA was also applied to identify significant differences in sensory characteristics of the cooked bananas assessed by the trained panelists. Principal component analysis for the sensory characteristics and physicochemical properties of the different cultivars were analyzed using XLSTAT. Eigenvalue was used to establish clusters and to explain the variability within each cluster while XLSTAT's Pearson (n) correlation matrix was applied to identify sensory characteristics that are associated or not with the physicochemical properties of the bananas. The differences between the cultivars were evaluated with a Turkey's test at $p < 0.05$.

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1 Physical characteristics of the selected *Matooke*

### 4.1.1 Fruit characteristics

#### 4.1.1.1Finger length

Finger length ranged from 13.25 cm to 27.25 cm (Table 4.1). The morphological variations that were observed were mostly due to size differences in cultivars. Hybrids N14, N17, N11, M9 and N8 produced significantly ($p < 0.05$) longer fingers than the local cultivars apart from *Mpologoma, Nakitembe* and *Kibuzi* (Table 4.1). From literature, *Mpologoma* and *Nakitembe* belong to *Musakala* and *Nakitembe* clone sets which are characterised by long fingers above 20 cm and 15cm to 20 cm, respectively (Karamura, 1998). On the basis of finger length, this study suggested that the above hybrid cultivars might have a competitive advantage in the market over the local cultivars in the study. This is so because banana consumers normally indicate preference for cultivars with long fingers (Dadzie & Orchard, 1997; Ssemwanga, 1994).

#### 4.1.1.2 Finger circumference

Finger circumference was in the range of 11.10 cm to 14.65 cm (Table 4.1). However, the finger circumferences of local cultivars such as *Nakitembe, Mpologoma, Nfuuka, Muvubo* and *Kibuzi* were not significantly ($p < 0.05$) larger than some of some of the hybrid banana cultivars such as M9, N21 and N17 (Table 4.1). Hybrids N6, N11 and the local cultivar *Nakawere* had the smallest finger circumference. Cultivars with greater finger circumference and length are mostly desired by consumers due to higher dry matter content hence higher yields of the edible portion and this may also depend on the growth conditions such as soil fertility, climate and fruit maturity (Dadzie & Orchard, 1997; Ssemwanga, 1994).

#### 4.1.1.3 Peel thickness

Peel thickness varied between 1.83 mm to 3.89 mm (Table 4.1). Local cultivars *Mpologoma, Kibuzi, Muvubo* and *Nakitembe* were not significantly ($p < 0.05$) thicker than hybrids such as N11, N14, M32 and M33. Hybrids 17914S-24, N8, N24, M30 and M9 had thin feels which were not significantly different ($p > 0.05$) from the local AAA-EA cooking banana cultivars *Enzirabahima* and *Mbwazirume*. Banana fingers with thinner peels are easy to peel and therefore could be easily preferred by food preparers (Dadzie & Ochard, 1997; Karamura, 1998; Belayneh et al., 2014).

#### 4.1.1.4 Pulp to peel ratio

Pulp to peel ratio was in the range of 1.36 to 1.87 (Table 4.1). However, individually, hybrids N17, N 24, N2, N8 & 17914S-24 and local cultivars *Enzirabahima* & *Kibuzi* had significantly ($p < 0.05$) higher pulp/peel ratios which were significantly ($p < 0.05$) different from local cooking bananas *Nakawere, Kabucuragye*, *Muvubo,* & *Nfuuka* and hybrids N6 & M33 (Table 4.1). The results of this study generally agreed with findings in literature (Belayneh et al., 2014; Dadzie, 1998; Kachru, 1995). These authors reported that banana fruit pulp to peel ratio ranges from 1.1 - 1.7 for cooking bananas at green physiological maturity. A higher pulp to peel ratio is indicative of higher pulp yield for food preparation per unit fresh weight since less material will be discarded as peels (Dadzie & Orchard, 1997; Muchui et al., 2010).Hybrids N17 & N24 and the local cultivar *Kibuzi* which had the highest pulp-to-peel ratio which is advantageous for food preparation since consumers prefer bananas with more pulp relative to the peels (Forster, Rodríguez Rodríguez, Darias Martín, & Romero, 2003; Belayneh et al., 2014).

**Table 4.1 Physical characteristics of selected local and hybrid banana cultivars**

| Cultivar | Finger length (cm) | Finger circumference (cm) | Peel thickness (mm) | Pulp/peel |
|---|---|---|---|---|
| N2 | 18.15±0.61 $^{fghi}$ | 12.60±0.12 $^{fgh}$ | 2.96±0.06 $^{ef}$ | 1.54±1.04 $^{cdef}$ |
| N6 | 13.40±0.09 $^{k}$ | 11.10±0.60 $^{l}$ | 3.30±0.33 $^{de}$ | 1.37±0.03 $^{ef}$ |
| N8 | 20.80±0.33 $^{bcde}$ | 12.15±0.15 $^{hij}$ | 2.25±0.09 $^{g}$ | 1.78±0.12 $^{abcd}$ |
| N11 | 20.85±0.0.42 $^{bcde}$ | 11.35±0.35 $^{kl}$ | 3.61±0.12 $^{bcd}$ | 1.79±0.09 $^{abcd}$ |
| N14 | 22.50±0.41 $^{b}$ | 12.00±0.24 $^{hijk}$ | 3.53±0.17 $^{bcd}$ | 1.69±0.04 $^{abcde}$ |
| N15 | 18.90±0.10 $^{defghi}$ | 12.25±0.12 $^{ghij}$ | 2.93±0.15 $^{f}$ | 1.56±1.03 $^{cdef}$ |
| N17 | 21.00±0.33 $^{bcd}$ | 13.60±0.20 $^{de}$ | 2.83. ±0.18 $^{f}$ | 2.03±0.22 $^{a}$ |
| N21 | 17.70±1.80 $^{ghij}$ | 13.65±0.21 $^{de}$ | 3.33±0.27 $^{d}$ | 1.84±0.00 $^{abcd}$ |
| N24 | 18.40±0.62 $^{fghi}$ | 11.75±0.12 $^{ijkl}$ | 1.83±0.09 $^{h}$ | 2.01±0.34 $^{ab}$ |
| M9 | 20.17±0.89 $^{bcdef}$ | 14.00±0.38 $^{cd}$ | 2.13±0.01 $^{gh}$ | 1.54±0.09 $^{cdef}$ |
| M30 | 19.10±0.68 $^{cdefgh}$ | 12.50±0.30 $^{fghi}$ | 2.13±0.00 $^{gh}$ | 1.57±0.03 $^{cde}$ |
| M32 | 16.55±0.87 $^{ij}$ | 12.95±0.12 $^{efg}$ | 3.77±0.50 $^{bc}$ | 1.54±0.19 $^{cdef}$ |
| M33 | 15.55±0.52 $^{jk}$ | 12.60±0.12 $^{fgh}$ | 3.61±0.21 $^{bcd}$ | 1.50±0.03 $^{cdef}$ |
| 17914S-24 | 17.00±0.47 $^{hij}$ | 12.05±0.15 $^{hijk}$ | 1.83±2.041 $^{h}$ | 1.74±0.24 $^{abcde}$ |
| Muvubo | 19.50±2.25 $^{cdefg}$ | 13.50±0.22 $^{de}$ | 4.42±0.15 $^{a}$ | 1.38±0.13 $^{ef}$ |
| Kibuzi | 20.80±042 $^{bcde}$ | 14.65±0.15 $^{bc}$ | 3.73±0.06 $^{bc}$ | 1.87±1.04 $^{abc}$ |
| Nakitembe | 21.30±0.88 $^{bc}$ | 14.90±0.25 $^{b}$ | 3.72±0.14 $^{bc}$ | 1.69±0.05 $^{abcde}$ |
| Mpologoma | 27.25±0.46 $^{a}$ | 13.65±0.25 $^{de}$ | 3.89±0.18 $^{b}$ | 1.64±0.03 $^{bcde}$ |
| Nfuuka | 19.20±0.76 $^{cdefgh}$ | 14.15±0.05 $^{bcd}$ | 3.65±0.04 $^{bcd}$ | 1.46±0.04 $^{def}$ |
| Mbwazirume | 13.25±0.05 $^{k}$ | 13.05±0.15 $^{ef}$ | 2.14±0.01 $^{gh}$ | 1.54±2.29 $^{cdef}$ |
| Kabucuragye | 18.55±0.25 $^{efghi}$ | 12.10±0.10 $^{hijk}$ | 3.51±0.06 $^{cd}$ | 1.36±0.14 $^{ef}$ |
| Enzirabahima | 17.15±0.45 $^{ghij}$ | 13.05±0.25 $^{ef}$ | 2.12±0.01 $^{gh}$ | 1.83±0.05 $^{abcd}$ |
| Nakawere | 16.95±0.69 $^{hij}$ | 11.60±0.08 $^{jkl}$ | 3.35±0.36 $^{d}$ | 1.18±0.07 $^{f}$ |

Values are means of three replicates ± standard errors of the means. Two means without any letter in common are significantly different ($p < 0.05$).

## 4.2 Chemical composition

### 4.2.1 Total soluble solids (TSS)

The TSS of the raw banana pulp varied from 0.00 °Brix to 1.30 °Brix (Table 4.2). Individually hybrids N8 and N2 had higher TSS in the range 1.30-1.00 °Brix which were significantly higher than M30, 17914S-24 and local cultivars *Nfuuka* and *Enzirabahima*. TSS (sugars) are associated with the degree of sweetness in fruits and together with organic acids influence the sensory perception of taste (Nowakunda et al., 2000, Ssemwanga, Thompson & Aked, 2000; Nowakunda, 2001). These results were in agreement with the findings of Belayneh et al., (2014) and (Aquino Salomão, Ribeiro, Rocha, Siqueira & Cecon, (2016) and Zerihun & Minuye, (2019). Aquino et al. (2016) reported TSS of physiologically mature bananas in Brazil to be less than 1 °Brix while reported TSS for three cooking bananas in Ethiopian in the range of 1.5 °Brix to 1.7 °Brix. The differences could be attributed to mainly cultivar differences physiological green maturity prior to analysis. Results of this study were also close to the findings of Belayneh et al., (2014) and Zerihun & Minuye, (2019) who reported TSS in the range of 1.5 °Brix to 1.7°Brix for cooking banana cultivars (*Cardaba*, *Nijiru*, *Matoke* and *Kitawira*) in Ethiopia. The low TSS values of cooking bananas are due to the fact that the banana samples were analysed at green maturity stage when only little starch is hydrolysed to sugars. It could therefore, be concluded that the bananas examined in this study for physicochemical and sensory attributes were at optimum physiological green maturity based on results of their TSS.

### 4.2.2 pH and total titratable acidity

There was no significant difference ($p = 0.496$) between sample means on the basis of pH (Table 4.2). In general, pH of the raw banana pulp ranged from 5.50 to 6.75. These results were in conformity with the findings of Belayneh et al. (2014) Arvanitoyannis & Mavromatis, (2009)

and Pain et al. (2009) who reported pH of green mature cooking bananas in the range of 4.7 to 6.5. For titratable acidity (TA), cultivars N14, N11, and *Kibuzi* had the highest values which were significantly higher ($p < 0.05$) than M30, *Enzirabahima* and 17914S-24 which had the lowest titratable acidity. pH and titratable acidity indicate levels of malic acid and contribute to the taste of cooked bananas (Dadzie & Orchard, 1997; Stewart et al., 2007).

### 4.2.3 Pulp Colour

The lightness (L* values) of the banana pulp ranged from 23.45 to 48.00 for all cultivars in the study (Table 4.2). Hybrid N15, M33 and N6 had significantly ($p < 0.05$) higher values of lightness than M30 and local cultivars *Enzirabahima* & *Mbwazirume* which had the lowest. The a* scale indicated that hybrids were significantly ($p < 0.0001$) more green than local cultivars which were tending to red. M30 and local cultivars *Enzirabahima* and *Mbwazirume* were also significantly ($p < 0.05$) different in greenness from the rest of the samples tending towards red. Hybrids N15, N24 and 17914S-24 had the highest intensity of greenness (Table 4.2). The results indicated that all samples under study had positive b* values highlighting a strong dominance of the yellow colour over blue. Data also indicated that generally, there was no significant ($p > 0.05$) difference between local and hybrids cooking bananas on the basis of yellow pulp colour. By cultivar, *Nakitembe, Kabucuragye*, and *Mpologoma* had the highest degree of yellowness which were significantly ($p < 0.05$) higher than *Enzirabahima*, *Mbwazirume* and M30. The yellowness of the pulp for the rest of the hybrids and local *Matooke* were not significantly ($p > 0.05$) different from each other. The intensity of the yellowness of the pulp could contribute to the desired yellow colour of the cooked *Matooke* meal as mentioned by panellists (Table 4.5). Although hybrids N21, N6 and N11 were dominated by a reddish-brown colour, it was surprising that their intensity of yellowness was not significantly ($p > 0.05$) different from that of

*Nakitembe, Kabucuragye* and *Mpologoma* which were completely yellow (Table 4.2). This could be due to higher levels of carotenoids and flavonoids in these hybrids leading to mottled colours of yellow with red and brown (Abbas et al., 2009; Stewart et al., 2007). Pulp colour of cooking bananas is a key quality characteristic in determining the acceptability of *Matooke* bananas Ssemwanga et al. (2000). In Uganda, if the pulp colour of *Matooke* is white, it will be rejected by consumers as an immature banana, however, if pulp colour is yellow/or deep yellow, the fruit is often accepted as a mature cooking banana (Dadzie & Orjeda, 1998; Ssemwanga et al., 2000; Nowakunda & Tushemereirwe, 2004).

### 4.2.4 Dry matter

Dry matter content of the bananas varied from 19.02 % to 28.09 % for all cultivars studied (Table 4.2). Local cultivars *Nakawere, Muvubo* and *Mbwazirume* had a relatively higher dry matter content which was not significantly different from hybrids N2, N6 and M33 (Table 4.2). Hybrids N8, N24, M9 and N17 did not significantly ($p > 0.05$) differ from local cultivars *Nakitembe, Nfuuka, Kabucuragye* and *Enzirabahima* on the basis of dry matter content. The values of dry matter content of banana cultivars recorded in this study were in agreement with values reported by (Agunbiade, Olanlokun, & Olaofe, 2006) and Belayneh et al. (2014) which were in the range of 22.9% to 29.0% for cooking bananas. *Mpologoma* and hybrids N11 & N21 had the lowest dry matter content. A high dry matter content indicates that the banana has good cooking qualities, a longer shelf life and a bigger proportion that can be utilized for food preparation ( Ferris et al., 1996; Dadzie & Orchard, 1997; Muchui et al., 2010). High dry matter content also leads to high bunch weight and yield as well as high starch content since starch is the principle component in bananas (Zhang, Whistler, BeMiller & Hamkaer, 2005). Based on this aspect, hybrids (N8, N24 and N17) whose dry matter content did not vary significantly ($p <$

0.05) different from the locally consumed cultivars would make a good choice for cooked *Matooke* food. Dry matter analysis could also be used in future studies as a driver of consumer acceptability of *Matooke*.

**Table 4.2 Chemical properties of selected banana cultivars grown in Uganda**

| Cultivars | pH | TSS °Brix | Titratable acidity (%) | L | a | b+ | Dry Matter (%) |
|---|---|---|---|---|---|---|---|
| N2 | 5.80±0.00 $^{a}$ | 1.00±0.00 $^{b}$ | 0.13±0.01 $^{de}$ | 46.60±0.40 $^{abcde}$ | -14.60±0.80 $^{cdef}$ | 31.00±0.90 $^{ab}$ | 28.09±0.31 $^{a}$ |
| N6 | 5.70±0.00 $^{a}$ | 0.85±0.05 $^{c}$ | 0.12±0.01 $^{def}$ | 47.30±0.25 $^{abc}$ | -15.95±0.65 $^{efg}$ | 29.75±1.95 $^{ab}$ | 27.94±0.02 $^{a}$ |
| N8 | 5.60±0.00 $^{a}$ | 1.30±0.10 $^{a}$ | 0.11±0.02 $^{fghi}$ | 45.05±1.05 $^{bcde}$ | -14.80±0.20 $^{def}$ | 28.90±0.10 $^{ab}$ | 22.33±0.13 $^{gh}$ |
| N11 | 5.70±0.00 $^{a}$ | 0.60±0.00 $^{ef}$ | 0.16±0.01 $^{ab}$ | 46.50±0.80 $^{abcde}$ | -15.65±0.15 $^{efg}$ | 29.80±1.15 $^{ab}$ | 20.86±0.34 $^{i}$ |
| N14 | 5.60±0.00 $^{a}$ | 0.60±0.00 $^{ef}$ | 0.17±0.01 $^{a}$ | 46.35±1.65 $^{abcde}$ | -15.55±0.75 $^{efg}$ | 31.60±0.00 $^{ab}$ | 26.86±0.02 $^{bc}$ |
| N15 | 5.95±0.05 $^{a}$ | 0.80±0.00 $^{c}$ | 0.11±0.01 $^{fghi}$ | 48.00±0.20 $^{a}$ | -16.90±0.1 $^{g}$ | 28.45±0.70 $^{ab}$ | 24.07±0.09 $^{f}$ |
| N17 | 5.80±0.00 $^{a}$ | 0.40±0.00 $^{h}$ | 0.12±0.01 $^{efg}$ | 45.80±0.50 $^{abcde}$ | -15.25±0.15 $^{efg}$ | 29.80±1.20 $^{ab}$ | 23.21±0.34 $^{fg}$ |
| N21 | 5.70±0.00 $^{a}$ | 0.55±0.05 $^{efg}$ | 0.13±0.01 $^{de}$ | 44.55±0.1.45 $^{cde}$ | -14.85±1.15 $^{defg}$ | 30.55±2.95 $^{ab}$ | 21.91±0.28 $^{h}$ |
| N24 | 5.70±0.00 $^{a}$ | 0.60±0 $^{ef}$ | 0.11±0.01 $^{efgh}$ | 45.80±0.40 $^{abcde}$ | -16.25±0.25 $^{fg}$ | 30.70±3.650 $^{ab}$ | 22.09±0.34 $^{h}$ |
| M9 | 5.57±0.05 $^{a}$ | 0.00±0.00 $^{k}$ | 0.12±0.00 $^{def}$ | 44.23±0.85 $^{de}$ | -12.73±0.25 $^{bc}$ | 32.00±0.65 $^{ab}$ | 24.10±0.33 $^{f}$ |
| M30 | 5.90±0.00 $^{a}$ | 0.20±0.00 $^{ij}$ | 0.09±0.01 $^{j}$ | 23.45±1.20 $^{f}$ | -9.60±0.60 $^{a}$ | 18.35±0.25 $^{c}$ | 25.19±0.24 $^{e}$ |
| M32 | 5.80±0.00 $^{a}$ | 0.75±0.05 $^{cd}$ | 0.15±0.01 $^{bc}$ | 46.15±1.25 $^{abcde}$ | -15.10±0.20 $^{efg}$ | 31.25±0.90 $^{ab}$ | 26.24±0.49 $^{cd}$ |
| M33 | 5.80±0.00 $^{a}$ | 0.80±0.00 $^{c}$ | 0.12±0.01 $^{efg}$ | 47.60±0.50 $^{ab}$ | -16.10±0.25 $^{efg}$ | 30.45±0.75 $^{ab}$ | 27.49±0.19 $^{ab}$ |
| 17914S-24 | 5.75±0.05 $^{a}$ | 0.10±0.00 $^{jk}$ | 0.09±0.00 $^{hij}$ | 47.05±0.04 $^{abcd}$ | -16.25±0.25 $^{fg}$ | 27.25±0.21 $^{b}$ | 25.54±0.13 $^{de}$ |
| Muvubo | 5.80±0.00 $^{a}$ | 0.60±0.00 $^{ef}$ | 0.14±0.01 $^{cd}$ | 45.45±0.25 $^{abcde}$ | -12.90±0.40 $^{bcd}$ | 31.80±1.15 $^{ab}$ | 26.81±1.02 $^{bc}$ |
| Kibuzi | 5.55±0.05 $^{a}$ | 0.50±0.0 $^{fgh}$ | 0.16±0.00 $^{abc}$ | 46.50±0.70 $^{abcde}$ | -14.95±0.05 $^{defg}$ | 31.20±0.60 $^{ab}$ | 22.82±0.05 $^{gh}$ |
| Nakitembe | 6.50±0.00 $^{a}$ | 0.80±0.00 $^{c}$ | 0.13±0.01 $^{de}$ | 44.00±0.70 $^{e}$ | -12.05±1.15 $^{b}$ | 33.15±1.55 $^{a}$ | 22.06±0.08 $^{h}$ |
| Mpologoma | 6.75±0.05 $^{a}$ | 1.10±0.10 $^{b}$ | 0.11±0.00 $^{efgh}$ | 45.15±0.75 $^{abcde}$ | -14.10±0.20 $^{bcde}$ | 32.15±2.75 $^{ab}$ | 19.05±0.36 $^{j}$ |
| Nfuuka | 5.60±0.00 $^{a}$ | 0.25±0.05 $^{i}$ | 0.11±0.01 $^{fghi}$ | 47.20±0.10 $^{abc}$ | -16.15±0.60 $^{efg}$ | 30.00±0.05 $^{ab}$ | 23.24±0.13 $^{fg}$ |
| Mbwazirume | 6.05±0.05 $^{a}$ | 0.60±0.00 $^{ef}$ | 0.10±0.00 $^{fghij}$ | 24.15±1.15 $^{f}$ | -9.65±0.25 $^{a}$ | 19.55±1.40 $^{c}$ | 26.38±0.21 $^{cd}$ |
| Kabucuragye | 5.50±0.00 $^{a}$ | 0.65±0.05 $^{de}$ | 0.10±0.00 $^{ghij}$ | 43.80±0.80 $^{e}$ | -12.20±1.50 $^{b}$ | 33.10±1.90 $^{a}$ | 23.91±0.39 $^{f}$ |
| Enzirabahima | 5.85±0.05 $^{a}$ | 0.40±0.00 $^{h}$ | 0.09±0.00 $^{ij}$ | 23.70±0.80 $^{f}$ | -9.15±0.50 $^{a}$ | 20.25±0.90 $^{c}$ | 23.85±0.37 $^{f}$ |
| Nakawere | 5.52±0.05 $^{a}$ | 0.45±0.05 $^{gh}$ | 0.10±0.00 $^{ghij}$ | 47.10±1.30 $^{abcd}$ | -15.70±0.40 $^{efg}$ | 29.55±2.20 $^{ab}$ | 27.66±0.24 $^{ab}$ |

Values are means of three replicates ±standard errors of the means (mg/100 g dry weight basis). Values are means of three independent determinations ± standard errors of the means. Two means without any letter in common are significantly different ($p < 0.05$). L* for the lightness from black (0) to white (100), a* from green (−) to red (+), and b* from blue (−) to yellow (+)

### 4.3 Proximate composition

#### 4.3.1 Ash content

Results of ash content ranged from 2.61 % to 4.93 % (Table 4.3). Local bananas *Mpologoma* and *Mbwazirume* had significantly ($p < 0.05$) the highest ash content while hybrids N6, N2 and M33 had the lowest. When compared with data from mineral analysis (section 4.4), there was conformity in such a way that the former two local cultivars generally had higher levels of trace and macro elements compared to the rest of the samples under study (Table 4.4). Results of this study were in agreement with ash content in bananas reported in other studies ranging from 2.46 % to 4.30 % dry weight basis (Bukusuba et al., 2008; Haslinda et al., 2009; Pain et al., 2009; Annor et al., 2016; Walugembe et., 2020). Further studies on bioavailability of minerals in these bananas that registered the highest level of ash content such as *Mpologoma* and *Mbwazirume* should be done so that they could be recommended to individuals with mineral dietary deficiencies. Trace and macro mineral analysis was further conducted to quantify selected mineral elements in the banana cultivars studied (Table 4.4).

#### 4.3.2 Crude fat

Crude fat content varied from 0.45 % to 0.72 % with *Nfuuka, Mpologoma and Kibuzi* having the highest levels while hybrids N24 and N11 had the lowest (Table 43). Results of crude fat content in this study were close to the findings reported in other studies with ranges from 0.58 g/100 g to 0.94 g/100 g (Bukusuba et al., 2008; Haslinda et al., 2009; Khawas et al., 2014; Batista, et al., 2017; Walugembe et al., 2020). However, current results were higher than those reported by Annor et al. (2016) for FHIA hybrids in the range of 0.0 g/100g to 0.3 g/100g dry basis which could be attributed to cultivar variations.

### 4.3.3 Crude protein composition

The crude protein content varied in the range 2.08 % to 4.94 % dry weight basis (Table 4.3). Generally, local cultivars had significantly ($p < 0.05$) higher protein content than hybrids bananas with *Muvubo* and *Mpologoma* having the highest crude protein which was not significantly different from N2 (Table 4.3). Cultivars N17, M9 and *Nakitembe* had the lowest crude protein while hybrids N6, N21 and N14 were not significantly ($p < 0.05$) different from local bananas *Nakawere, Enzirabahima* and *Kabucuragye*. The observed results were congruent with the literature values in the range of 0.6 % to 4.8 % (Cano, Ancos, Matallana, & Cámara, 1997; Bukusuba, Muranga & Nampala, 2008; Taylor, Arvanitoyannis, & Mavromatis, 2008; Pain et al., 2009; Annor et al., 2016; Walugembe et al., 2020).

### 4.3.4 Crude fibre

Crude fibre content was in the range of 0.99 % to 2.29 % (Table 4.3). However, local cultivars *Mbazirume, Muvubo* and *Kibuzi* were not significantly different from hybrids such as M30, N17, and N21 on the basis of crude fibre (Table 4.3). Cultivars N2, N24 and 17914S-24 had the lowest crude fibre values. These results were similar to those reported by (Bukusuba, Muranga & Nampala, (2008) and Walugembe et al. (2020) in the range of 0.65% to 2.92%.

### 4.3.5 Total carbohydrates

Total carbohydrate content of banana flour ranged between 65.38 mg/ 100g to 82.96 mg/ 100g dry weight basis (Table 4.3). In particular, *Mbwazirume, Nfuuka* and *Nakawere* had the highest total carbohydrates (82.96, 80.91 and 79.46 mg/ 100g dry weight basis, respectively) while N8, 17914S-24, N11 and *Nakitembe* had the lowest (Table 4.3). In comparison, *Nfuuka*, a local cultivar had the highest total carbohydrate content (82.96 mg/100 g), whereas N8, a hybrid

cultivar had the lowest (65.38 mg/100 g). The results were in agreement with the findings of Aurore, Parfait, & Fahrasmane, (2009), Haslinda et al. (2009), Anuonye et al. (2012) and Walugembe et al. (2020) which ranged 13.48 mg/100 g to 80.0 mg/100 g. The results also showed that carbohydrates were the major nutrients found in cooking bananas as reported by Aquino et al. (2016).

### 4.3.6 Moisture content

Moisture content ranged from 71.91 % to 80.95 % with *Mpologoma* having the highest moisture content significantly different ($p < 0.05$) from N2 which had the lowest. A high moisture content indicates that the banana has poor eating qualities since it can easily be mashed during cooking, a shorter shelf life and a smaller proportion that can be utilized for food preparation ( Ferris et al., 1996; Dadzie & Orchard, 1997; Muchui et al., 2010).

**Table 4.3 Proximate composition of selected banana cultivars**

| Cultivars | Moisture (%) | Ash (%) | Crude fat (%) | Protein (%) | Dietary Fibre (%) | Carbohydrates (mg/100g) |
|---|---|---|---|---|---|---|
| N2 | 71.91±0.31 $^{h}$ | 2.80±0.00 $^{k}$ | 0.52±0.02 $^{defghi}$ | 4.78±0.14 $^{ab}$ | 1.11±0.12 $^{de}$ | 73.41±1.30 $^{cde}$ |
| N6 | 72.07±0.19 $^{gh}$ | 2.61±0.07 $^{l}$ | 0.48±0.02 $^{ghi}$ | 2.97±2.25 $^{ghi}$ | 1.87±0.37 $^{abc}$ | 71.60±1.46 $^{cde}$ |
| N8 | 77.67±0.13 $^{bcd}$ | 3.58±0.09 $^{d}$ | 0.47±0.00 $^{hi}$ | 3.73±2.25 $^{d}$ | 1.60±0.13 $^{bcd}$ | 65.38±1.05 $^{fgh}$ |
| N11 | 79.17±0.34 $^{b}$ | 3.48±0.05 $^{e}$ | 0.46±0.00 $^{hi}$ | 3.73±2.25 $^{d}$ | 1.49±0.01 $^{bcde}$ | 69.15±1.13 $^{fghi}$ |
| N14 | 73.14±0.39 $^{fgh}$ | 3.29±0.03 $^{f}$ | 0.51±0.01 $^{defghi}$ | 2.84±1.22 $^{hij}$ | 1.37±0.13 $^{cde}$ | 70.21±2.72 $^{i}$ |
| N15 | 75.93±0.09 $^{de}$ | 2.85±0.09 $^{jk}$ | 0.48±0.02 $^{ghi}$ | 4.00±0.90 $^{c}$ | 1.60±0.38 $^{bcd}$ | 74.34±2.13 $^{bcd}$ |
| N17 | 76.80±0.02 $^{cd}$ | 2.83±0.01 $^{jk}$ | 0.49±0.03 $^{fghi}$ | 2.11±0.07 $^{l}$ | 1.99±0.25 $^{ab}$ | 72.92±3.05 $^{cde}$ |
| N21 | 78.09±0.28 $^{bc}$ | 3.29±0.00 $^{f}$ | 0.51±0.01 $^{efghi}$ | 3.02±0.05 $^{fghi}$ | 1.96±0.02 $^{ab}$ | 71.86±1.38 $^{cde}$ |
| N24 | 77.90±0.31 $^{bc}$ | 3.29±0.03 $^{f}$ | 0.45±0.05 $^{i}$ | 4.00±0.02 $^{c}$ | 0.99±0.02 $^{e}$ | 69.76±0.11 $^{def}$ |
| M9 | 75.94±0.15 $^{de}$ | 3.54±0.15 $^{d}$ | 0.58±0.01 $^{bcdef}$ | 2.13±0.07 $^{l}$ | 1.71±0.02 $^{bc}$ | 73.96±0.66 $^{cde}$ |
| M30 | 74.82±0.33 $^{ef}$ | 3.73±0.23 $^{c}$ | 0.57±0.04 $^{cdefg}$ | 2.63±0.04 $^{jk}$ | 2.29±0.11 $^{a}$ | 72.84±3.86 $^{cde}$ |
| M32 | 73.76±0.49 $^{fg}$ | 3.27±0.01 $^{f}$ | 0.59±0.03 $^{bcde}$ | 4.11±0.14 $^{c}$ | 1.62±0.12 $^{bcd}$ | 74.61±2.57 $^{bcd}$ |
| M33 | 72.50±0.24 $^{gh}$ | 2.81±0.13 $^{k}$ | 0.55±0.03 $^{defgh}$ | 2.56±4.51 $^{k}$ | 1.37±0.12 $^{cde}$ | 73.49±2.70 $^{bcd}$ |
| 17914S-24 | 74.46±0.02 $^{ef}$ | 3.45±0.18 $^{e}$ | 0.58±0.01 $^{bcdef}$ | 3.43±0.02 $^{e}$ | 0.99±0.01 $^{e}$ | 66.94±3.45 $^{fgh}$ |
| Muvubo | 73.19±0.10 $^{fgh}$ | 3.44±0.62 $^{e}$ | 0.58±0.02 $^{bcdef}$ | 4.94±4.51 $^{a}$ | 1.74±0.24 $^{abc}$ | 73.12±0.71 $^{cde}$ |
| Kibuzi | 77.19±0.05 $^{cd}$ | 3.16±0.30 $^{g}$ | 0.67±0.03 $^{ab}$ | 2.53±0.04 $^{k}$ | 1.85±0.13 $^{abc}$ | 75.81±0.50 $^{bcd}$ |
| Nakitembe | 77.94±0.08 $^{bc}$ | 2.88±0.02 $^{j}$ | 0.59±0.03 $^{bcd}$ | 2.08±4.51 $^{l}$ | 1.87±0.13 $^{abc}$ | 69.33±0.94 $^{fghi}$ |
| Mpologoma | 80.95±0.36 $^{a}$ | 4.93±0.04 $^{a}$ | 0.69±0.03 $^{a}$ | 4.63±1.35 $^{b}$ | 1.86±0.13 $^{abc}$ | 70.84±1.37 $^{cde}$ |
| Nfuuka | 76.76±0.37 $^{cd}$ | 2.95±0.53 $^{i}$ | 0.72±0.02 $^{a}$ | 3.75±1.28 $^{d}$ | 1.73±0.02 $^{bc}$ | 80.91±1.64 $^{ab}$ |
| Mbwazirume | 73.62±0.21 $^{fgh}$ | 4.02±0.07 $^{b}$ | 0.56±0.07 $^{cdefg}$ | 2.81±0.05 $^{ij}$ | 1.96±0.27 $^{ab}$ | 82.96±0.15 $^{a}$ |
| Kabucuragye | 76.09±0.24 $^{de}$ | 3.09±0.08 $^{h}$ | 0.65±0.02 $^{abc}$ | 3.05±0.02 $^{fgh}$ | 1.37±0.13 $^{cde}$ | 72.86±4.71 $^{cde}$ |
| Enzirabahima | 76.16±0.56 $^{de}$ | 3.32±0.07 $^{f}$ | 0.53±0.00 $^{defghi}$ | 3.19±2.26 $^{fg}$ | 1.95±0.00 $^{ab}$ | 71.26±1.22 $^{cde}$ |
| Nakawere | 72.34±0.13 $^{gh}$ | 2.85±0.48 $^{jk}$ | 0.58±0.02 $^{bcdef}$ | 3.23±1.35 $^{ef}$ | 1.61±0.10 $^{bcd}$ | 79.46±2.74 $^{abc}$ |

Values are means of three replicates ± standard errors of the means (mg/100 g dry weight basis). Two means without any letter in common are significantly different ($p < 0.05$).

### 4.3.7 Starch and its composition

#### 4.3.7.1 Starch content

The starch content of the banana flour was in the range 63.89 % to 73.25 % dry basis (Table 4.3). Local *Matooke Nfuuka*, *Mbwazirume* and *Kibuzi* had relatively high starch content which was not significantly different from hybrids N15, N17, M9 and M33 while N8, 17914S-24 and N6 had the lowest. Results of the current study were higher than those reported by Aquino et al. (2016) which were in the range 11 % to 39.3% dry weight basis for fifteen banana cultivars which could be due to varietal differences. Aquito and colleagues studied bananas belonging to AA, AAA, AAB, ABB and AAAB genomes grown in Brazil. However, the results of this study were also relatively lower than those reported in previous studies which were in the range of 70 % to 85 % and this could be due to differences in cultivars (Qi et al., 2000; Pain et al., 2009; Annor et al., 2016). High starch content in bananas is associated with hardness especially after cooking due to starch retrogradation, which is an undesirable characteristic (Nowakunda & Tushemereirwe, 2004; Gafuma et al., 2018b).

#### 4.3.7.2 Amylose and amylopectin content of starch

The amylose content of the bananas under study varied 11.73 % to 33.68 % (Table 4.3). *Mbwazirume, Nfuuka* and *Muvubo* had the highest amylose content which were significantly lower than N8, M9 and N14 (11.727, 18.471 and 18.986 %, respectively) In UK, Qi et al. (2000) also reported amylose content in Green *Cavendish* dessert banana and Big *Ebanga* plantain pulp (27.35 % and 33.37 %, respectively) with values in agreement with levels observed in this work. The lower amylose content of the hybrids contributes to their high cooking abilities due to their low pasting and gelatinization temperatures (Dufour & Gibert, 2009).

The amylopectin content varied in the ranges of 34.53 % to 52.31 % (Table 4.3). Hybrids M9, N8 and N15 had the highest amylopectin content while 17914S-24, N2 and *Mbwazirume* had the lowest. Local cooking bananas such as *Mbwazirume, Nfuuka, Mpologoma* and *Nakawere* were not significantly ($p > 0.05$) different from some of the hybrid cultivars such as M30, N17, 17914S-24, N6, N2, N21 on the basis of amylopectin content (Table 4.3). High levels of starch, amylose and dry matter in food crops has been associated with a harder texture (McComber, Homer, Chamberlin, & Cox, 1994; Sharma, Isleib, & Dexter, 1959; Homayouni, Amini, Keshtiban, Mortazavian, Esazadeh & Pourmoradian, 2014; Gafuma, et al., 2018). Firmness in raw and cooked food products with high amylose content has been attributed to the transfer of calcium ions to galacturonan and to formation of hydrogen bonds within the plant tissue (Linehan & Hughes, 1969; Keijbets, Pilnik, & Vaal, 1976; Qi et al., 2000). In this study, *Nfuuka* and N2 which had high amylose contents were found to be among the hardest in cooked form (section 4.6.1). Thus, amylose and amylopectin content can be used as indices for predicting firmness in cooking bananas. However, more studies are needed to investigate the effect of different amylose/ amylopectin ratios on the cooling rate and hardening of cooked *Matooke* products.

Table 4.3.1 Starch composition of selected banana cultivars

| Cultivars | Starch (%) | Amylose (mg/100 g) | Amylopectin (mg/100 g) |
|---|---|---|---|
| Hybrids | 68.24±2.99 $^{b}$ | 23.73±6.06 $^{b}$ | 44.50±5.95 $^{a}$ |
| Locals | 69.84±2.14 $^{a}$ | 27.12±4.18 a | 42.71±3.16 $^{b}$ |
| N2 | 67.99±1.97 $^{def}$ | 33.46±0.21 $^{a}$ | 34.53±1.75 $^{f}$ |
| N6 | 65.26±0.06 $^{fg}$ | 25.77±1.63 $^{abcde}$ | 39.49±1.69 $^{def}$ |
| N8 | 63.89±0.41 $^{g}$ | 11.73±0.13 $^{f}$ | 52.17±0.54 $^{ab}$ |
| N11 | 66.39±2.24 $^{efg}$ | 19.46±1.42 $^{ef}$ | 46.93±0.82 $^{abcd}$ |
| N14 | 65.83±0.04 $^{fg}$ | 18.99±4.73 $^{ef}$ | 46.84±4.70 $^{abcd}$ |
| N15 | 72.67±0.84 $^{ab}$ | 23.19±0.09 $^{cde}$ | 49.47±0.49 $^{abc}$ |
| N17 | 72.00±0.64 $^{abc}$ | 29.59±2.45 $^{abcd}$ | 42.41±1.81 $^{cdef}$ |
| N21 | 68.71±0.08 $^{cdef}$ | 25.77±6.19 $^{abcde}$ | 42.94±6.26 $^{cdef}$ |
| N24 | 67.48±1.54 $^{defg}$ | 19.97±2.79 $^{e}$ | 47.51±4.33 $^{abcd}$ |
| M9 | 70.78±1.64 $^{abcd}$ | 18.47±0.77 $^{ef}$ | 52.31±0.86 $^{a}$ |
| M30 | 69.94±1.73 $^{abcde}$ | 30.11±3.05 $^{abcd}$ | 39.83±1.32 $^{def}$ |
| M32 | 69.88±0.70 $^{abcde}$ | 23.24±4.08 $^{cde}$ | 46.64±3.38 $^{abcd}$ |
| M33 | 70.56±0.33 $^{abcd}$ | 24.14±2.15 $^{bcde}$ | 46.42±1.81 $^{abcd}$ |
| 17914S-24 | 63.93±1.35 $^{g}$ | 28.35±1.46 $^{abcd}$ | 35.58±2.81 $^{ef}$ |
| Muvubo | 70.37±0.06 $^{abcd}$ | 30.76±0.43 $^{abc}$ | 39.61±0.49 $^{def}$ |
| Kibuzi | 70.35±0.51 $^{abcd}$ | 23.67±1.76 $^{bcde}$ | 46.68±1.25 $^{abcd}$ |
| Nakitembe | 68.26±0.41 $^{cdef}$ | 24.49±1.37 $^{bcde}$ | 43.78±0.96 $^{bcde}$ |
| Mpologoma | 67.35±0.38 $^{defg}$ | 24.87±3.05 $^{bcde}$ | 42.47±3.44 $^{cdef}$ |
| Nfuuka | 73.25±0.88 $^{a}$ | 31.44±1.29 $^{ab}$ | 41.81±2.17 $^{cdef}$ |
| Mbwazirume | 72.80±0.43 $^{ab}$ | 33.68±2.06 $^{a}$ | 39.13±1.63 $^{def}$ |
| Kabucuragye | 69.04±1.62 $^{bcdef}$ | 24.23±1.80 $^{bcde}$ | 44.81±3.40 $^{abcd}$ |
| Enzirabahima | 68.42±1.93 $^{cdef}$ | 22.25±1.46 $^{de}$ | 46.17±0.47 $^{abcd}$ |
| Nakawere | 68.71±1.09 $^{cdef}$ | 28.74±0.99 $^{abcd}$ | 39.97±0.10 $^{def}$ |

## 4.4 Essential mineral composition

Mineral composition in the banana flour samples ranged from 1.29 mg/100g to 25.27 mg/100g, 104.41 mg/100g to 385.91 mg/100g, 4.63 mg/100g to 12.52 mg/100g, 3082.94 mg/100g to 8770.48 mg/100g, 329.04 mg/100g 1100.94 mg/100g and 18.28 mg/100g to 109.19 mg/100g for zinc, calcium, iron, potassium, magnesium and sodium, respectively (Table 4.4). These results were similar to earlier studies on mineral content of cooking banana; potassium in the ranges 259.0 mg/100g to 733.9 mg/100g, magnesium ranging 21.2 mg/100g to 106.0 mg/100g, calcium between 10.1 mg/100g and 132.4, sodium ranging 0.1 mg/100g to 23.9 mg/100g, iron in the range 0.3 mg/100g to 12.2 mg/100g and 0.7 mg/100g to 2.8 mg/100g (Hardisson, Rubio, Baez, Martin, & Alvarez, 2001; Taylor et al., 2008; Aurore et al., 2009; Deshmukh et al., 2009; Haslinda et al., 2009). Hybrid cooking bananas had significantly ($p < 0.0001$) higher levels of

zinc than local cultivars in the study (Table 4.4). Hybrids N11, N21 and N15 had significantly ($p < 0.05$) higher levels of zinc than local cultivars *Enzirabahima, Muvubo* and *Mbwazirume* which had the lowest. Generally, the iron content in hybrids was significantly ($p < 0.0001$) higher than that in local cultivars (Table 4.4). Cultivars N8, *Mpologoma* and N15 had the highest levels of iron while *Muvubo, Enzirabahima* and *Nfuuka* had the lowest. Mineral elements (Zn and Fe) together with polyphenols, vitamin C and carotenoids act as free radical scavengers in the human body preventing loss of cell integrity (Aquino et al., 2016). The calcium content in hybrid cultivars was significantly ($p < 0.0001$) different from that in local *Matooke* (Table 4.4). In particular, N15, N11and N6 had the highest calcium content while locals *Mpologoma* & *Enzirabahima*, and hybrids 17914S-24 & N17 had the lowest. Magnesium content of the banana samples varied 329.04 mg/100g to 1209.55 mg/100g with hybrids having significantly ($p < 0.0001$) higher levels of magnesium than local cultivars (Table 4.4). Hybrids N11, N24 and N21 had the highest levels of magnesium while locals *Nfuuka, Nakitembe* and *Enzirabahima* had the lowest. There was no significant differences between local and hybrid cooking bananas on the basis of potassium and sodium contents (Table 4.4). Local cultivars *Mpologoma*, and hybrids N8 & M9 had the highest levels of potassium while N6, N2 and *Enzirabahima* had the lowest. On the other hand, a local cooking banana *Muvubo*, and hybrids N11 & N15 had the highest levels of sodium which were significantly different from M30, M9 and *Enzirabahima*. The highest mineral element was potassium (3082.94 mg/100g to 8770.48 mg/100g) followed by magnesium (329.04 mg/100g to 1209.55 mg/100g), calcium (101.73 mg/100g to 385.91 mg/100g), sodium (18.28 mg/100g to 109.19 mg/100g), zinc (1.29 mg/100g to 25.27 mg/100g) and lastly iron (4.63 mg/100g to 12.52 mg/100g).

**Table 4.4 Essential mineral nutrients of selected cooking banana cultivars**

| Cultivars | Zn (mg/100g) | Ca (mg/100g) | Fe (mg/100g) | K (mg/100g) | Mg (mg/100g) | Na (mg/100g) |
|---|---|---|---|---|---|---|
| N2 | 12.36±0.09 $^{def}$ | 155.51±3.33 $^{cde}$ | 9.40±0.55 $^{ab}$ | 6155.55±19.08 $^{ab}$ | 989.86±4.62 $^{abcd}$ | 49.96±1.37 $^{b}$ |
| N6 | 12.04±0.12 $^{def}$ | 296.29±4.59 $^{abc}$ | 10.51±0.31 $^{ab}$ | 6343.10±9.06 $^{ab}$ | 930.93±11.21 $^{abcd}$ | 50.79±0.44 $^{b}$ |
| N8 | 14.99±0.09 $^{bcd}$ | 160.89±1.47 $^{cde}$ | 12.52±0.49 $^{a}$ | 8061.57±46.79 $^{a}$ | 1032.45±2.94 $^{abcd}$ | 52.07±0.88 $^{b}$ |
| N11 | 25.27±0.38 $^{a}$ | 371.78±8.73 $^{ab}$ | 11.68±0.78 $^{a}$ | 7393.61±8.18 $^{a}$ | 1209.55±17.41 $^{a}$ | 56.66±1.42 $^{b}$ |
| N14 | 11.55±1.33 $^{defg}$ | 136.32±1.59 $^{de}$ | 8.38±0.08 $^{ab}$ | 6851.77±14.22 $^{ab}$ | 933.83±11.04 $^{abcd}$ | 41.67±1.55 $^{bc}$ |
| N15 | 15.93±0.18 $^{bc}$ | 385.91±1.61 $^{a}$ | 12.08±0.08 $^{a}$ | 6484.09±6.54 $^{ab}$ | 1053.80±2.02 $^{abcd}$ | 54.17±0.16 $^{b}$ |
| N17 | 6.32±0.49 $^{hij}$ | 110.64±0.36 $^{e}$ | 8.37±0.33 $^{ab}$ | 6191.11±46.23 $^{ab}$ | 831.71±2.00 $^{abcd}$ | 42.17±0.58 $^{bc}$ |
| N21 | 18.16±0.46 $^{b}$ | 113.86±0.16 $^{e}$ | 8.96±0.56 $^{ab}$ | 7141.14±135.02 $^{a}$ | 1077.34±16.68 $^{abc}$ | 39.36±2.75 $^{bc}$ |
| N24 | 13.87±0.22 $^{cde}$ | 151.95±4.96 $^{de}$ | 11.79±0.44 $^{a}$ | 7349.61±263.07 $^{a}$ | 1100.94±6.41 $^{ab}$ | 47.42±0.59 $^{b}$ |
| M9 | 6.20±0.41 $^{hij}$ | 138.68±1.15 $^{de}$ | 8.27±0.55 $^{ab}$ | 7923.63±7.06 $^{a}$ | 777.39±10.32 $^{bcd}$ | 36.59±0.20 $^{bc}$ |
| M30 | 4.19±0.08 $^{jkl}$ | 237.66±1.47 $^{bcde}$ | 9.24±0.04 $^{ab}$ | 6493.37±12.97 $^{ab}$ | 953.44±3.91 $^{abcd}$ | 37.48±0.14 $^{bc}$ |
| M32 | 10.93±0.27 $^{efg}$ | 151.93±3.95 $^{de}$ | 9.18±0.17 $^{ab}$ | 7054.23±32.93 $^{a}$ | 815.49±6.69 $^{abcd}$ | 47.20±0.86 $^{b}$ |
| M33 | 7.08±0.21 $^{hij}$ | 234.65±0.29 $^{bcde}$ | 9.24±0.23 $^{ab}$ | 6220.28±68.05 $^{ab}$ | 982.91±4.79 $^{abcd}$ | 39.34±0.13 $^{bc}$ |
| 17914S-24 | 5.01±0.36 $^{ijk}$ | 104.41±1.09 $^{e}$ | 9.77±0.04 $^{ab}$ | 7815.72±15.47 $^{a}$ | 652.41±1.15 $^{cde}$ | 53.83±026 $^{b}$ |
| Muvubo | 2.63±0.05 $^{kl}$ | 112.95±0.68 $^{e}$ | 6.36±0.05 $^{ab}$ | 7530.59±6.62 $^{a}$ | 835.95±5.71 $^{abcd}$ | 109.19±1.40 $^{a}$ |
| Kibuzi | 11.71±0.01 $^{defg}$ | 166.65±1.28 $^{cde}$ | 9.89±0.05 $^{ab}$ | 7151.52±39.27 $^{a}$ | 741.24±7.49 $^{bcde}$ | 50.89±0.29 $^{b}$ |
| Nakitembe | 7.38±0.62 $^{hij}$ | 167.21±0.92 $^{cde}$ | 8.77±0.04 $^{ab}$ | 6498.69±10.62 $^{ab}$ | 636.01±4.47 $^{de}$ | 39.63±1.87 $^{bc}$ |
| Mpologoma | 5.76±0.17 $^{hijk}$ | 101.73±1.68 $^{e}$ | 12.22±0.00 $^{a}$ | 8770.48±70.67 $^{a}$ | 1019.26.67 $^{abcd}$ | 49.16±1.11 $^{b}$ |
| Nfuuka | 6.44±1.40 $^{hij}$ | 129.93±0.69 $^{de}$ | 7.79±0.16 $^{ab}$ | 6383.67±62.05 $^{ab}$ | 650.88±4.33 $^{de}$ | 39.15±0.61 $^{bc}$ |
| Mbwazirume | 4.69±1.29 $^{jkl}$ | 259.71±108.43 $^{abcd}$ | 11.01±4.53 $^{a}$ | 7251.94±9.52 $^{a}$ | 815.83±12.75 $^{abcd}$ | 40.91±17.88 $^{bc}$ |
| Kabucuragye | 8.41±0.44 $^{ghi}$ | 159.12±6.89 $^{cde}$ | 9.43±0.47 $^{ab}$ | 6732.01±58.93 $^{ab}$ | 853.52±24.20 $^{abcd}$ | 37.98±2.58 $^{bc}$ |
| Enzirabahima | 1.29±0.0.04 $^{l}$ | 110.74±1.61 $^{e}$ | 4.63±0.09 $^{b}$ | 3082.94±12.97 $^{b}$ | 329.04±6.65 $^{e}$ | 18.28±0.37 $^{c}$ |
| Nakawere | 9.03±0.09 $^{fgh}$ | 214.33±1.71 $^{cde}$ | 8.41±0.43 $^{ab}$ | 6470.99±70.49 $^{ab}$ | 878.48±8.18 $^{abcd}$ | 39.76±0.61 $^{bc}$ |

Values are means of two replicates ±standard errors of the means (mg/100 g dry weight basis). Values in columns with different superscript letters are significantly different ($p < 0.05$).

### 4.5 Phytochemical composition

#### 4.5.1 Total phenolic compounds

The varietal differences observed in total phenols ranged 23.01 mg GAE/100g to 48.39 mg GAE/100g (Table 4.5). Local cultivars *Enzirabahima* & *Mbwazirume* and hybrids N 2, & N 11 had significantly ($p < 0.05$) higher levels of phenolic compounds compared to hybrids M 9, N 15 and N 6 which had the lowest. The content of total phenolic compounds in the bananas studied was in conformity with the findings of Aquino et al. (2016) who reported total phenol content in unripe bananas grown in Brazil in the range of 23.15 mg GAE/100g to 33.28 mg GAE/100g. Results of the study were also close to those reported for *Pisang Mas* banana in the range 51 mg GAE/100 g to 56.1 mg GAE/100 g ( Kang, Xu, Tao, Sun & Wang, 2002; Lim, Lim & Tee, 2007; Alothman et al., 2009). Phenolic compounds act as antioxidants inhibiting the decomposition of hydroperoxides into free radicals (Lim et al., 2007; Stewart et al., 2007; Mascitelli, & Goldstein, 2014). However, phenolic compounds participate in undesired enzymatic browning of bananas after peeling affecting their colour and also negatively influencing the taste of bananas due to a puckering taste as observed by Joslyn & Goldstein (1964) in FHIA 3 hybrid bananas. For instance, in section (4.2.3) the L* value for *Enzirabahima* and *Mbwazirume* indicated that the samples were dark (23.70 and 24.15, respectively) in colour yet the b* value was relatively low (20.25 and 19.55, respectively) which meant the darkness in colour were not due to intensity of pulp yellowness (Table 4.2). The pulp darkness could have been due to phenolic compounds (Table 4.5) causing enzymatic browning in the banana pulp hence the observed instrumental colour measurement.

### 4.5.2 Total flavonoids

The total flavonoid content of cooking bananas ranged from 17.34 mg CEQ/100g to 95.75 mg CEQ/100g dry weight basis. 17914S-24, N21 and N8 hybrids had total flavonoid content which were significantly higher ($p < 0.05$) than local cultivars *Kibuzi*, *Nakawere* and *Enzirabahima*. These values were close to those (23.7 CEQ/100 g to 47.0 CEQ/100 g fresh weight) reported by Alothman et al. (2009) for *Pisang Mas* bananas in Malaysia. Fatemeh et al. (2012) also observed flavonoid content in green and ripe pulp and peel of Cavendish and Dream banana cultivars (39.01 mg CEQ/100 g to 389.33 mg CEQ/100 g of dry weight) in Malaysia, with values in the range of those observed in this work. The differences in total phenols and flavonoid content of bananas could be attributed to differences in cultivars, physiological maturity at harvest, post-harvest storage conditions, chemical composition of the banana fruit, and the soil fertility (Huang et al., 2005). Flavonoids in combination with other metabolites such as carotenoids in a banana fruit contribute to the pulp colour of *Matooke* (Stewart et al., 2007). Therefore, flavonoid content of bananas could have possible implications on consumer acceptability of *Matooke* for food preparation.

### 4.5.3 Total tannins

There were varietal significant differences ($p < 0.05$) in the total tannins content of the selected bananas under study (Table 4.5). Local cooking banana, *Mbwazirume* and hybrids N15, N2 and M30 had significantly ($p < 0.05$) higher total tannins content than N24, *Nakitembe, Nfuuka* and *Kibuzi*. Unlike juice bananas, cooking cultivars are not expected to have high tannins content which causes an astringent impression in the mouth (Stewart et al., 2007). In Uganda, Kyamuhangire et al. (2006) obtained average values of 0.544 $gkg^{-1}$ and 0.521 $gkg^{-1}$for green *Musakala* and *Kibuzi* banana pulp, respectively, close to those observed in this study. The

difference in tannins content can be attributed to differences in extraction and analysis method since we worked on dry powder samples not fresh samples like the case for Kyamuhangire and colleagues. The alteration could also be due to differences in banana cultivars, growth conditions and post-harvest storage conditions (Fatemeh, Saifullah, Abbas & Azhar , 2012). Data therefore suggests that hybrid bananas in the study may not differ much from local cultivars with respect to the low astringent taste when cooked.

**Table 4.5 Phytochemical composition of selected cooking banana cultivars**

| Cultivars | Total phenols (mg GAE/100g) | Total flavonoids (mg CEQ/100g) | Total tannins (mg CEQ/100g) |
|---|---|---|---|
| N2 | 47.36±0.62 $^{a}$ | 25.59±1.65 $^{cde}$ | 52.41±0.79 $^{abc}$ |
| N6 | 24.86±0.12 $^{fgh}$ | 19.26±0.41 $^{de}$ | 51.95±0.35 $^{abc}$ |
| N8 | 27.84±0.29 $^{cdefg}$ | 78.46±3.03 $^{b}$ | 51.25±1.04 $^{abcd}$ |
| N11 | 44.06±0.56 $^{a}$ | 21.65±1.11 $^{de}$ | 49.63±0.12 $^{abcd}$ |
| N14 | 31.88±0.00 $^{bc}$ | 20.37±0.96 $^{de}$ | 51.14±0.93 $^{abcd}$ |
| N15 | 23.42±0.71 $^{gh}$ | 21.81±0.04 $^{de}$ | 53.68±0.46 $^{ab}$ |
| N17 | 28.58±1.24 $^{cdef}$ | 20.53±0.02 $^{de}$ | 49.17±1.50 $^{bcd}$ |
| N21 | 28.62±0.41 $^{cdef}$ | 87.87±0.32 $^{ab}$ | 50.67±0.93 $^{abcd}$ |
| N24 | 30.44±0.21 $^{bcd}$ | 25.48±0.16 $^{cde}$ | 46.86±0.35 $^{d}$ |
| M9 | 23.00±0.62 $^{h}$ | 22.45±0.96 $^{de}$ | 48.94±0.58 $^{bcd}$ |
| M30 | 25.80±0.73 $^{efgh}$ | 17.34±0.00 $^{e}$ | 52.52±0.46 $^{abc}$ |
| M32 | 27.55±0.21 $^{cdefg}$ | 20.37±0.48 $^{de}$ | 49.98±0.23 $^{abcd}$ |
| M33 | 25.69±2.48 $^{efgh}$ | 20.05±0.16 $^{de}$ | 48.94±0.58 $^{bcd}$ |
| 17914S-24 | 34.67±0.15 $^{b}$ | 95.75±7.66 $^{a}$ | 51.37±0.69 $^{abcd}$ |
| Muvubo | 27.34±0.41 $^{defgh}$ | 36.49±1.28 $^{c}$ | 51.71±0.35 $^{abcd}$ |
| Kibuzi | 28.99±0.00 $^{cdef}$ | 20.85±0.64 $^{de}$ | 48.71±0.81 $^{cd}$ |
| Nakitembe | 24.66±0.20 $^{fgh}$ | 25.79±0.48 $^{cde}$ | 48.01±0.23 $^{cd}$ |
| Mpologoma | 27.55±0.21 $^{cdefg}$ | 25.48±0.16 $^{cde}$ | 50.33±0.12 $^{abcd}$ |
| Nfuuka | 24.66±0.21 $^{fgh}$ | 28.83±2.87 $^{cde}$ | 48.59±0.23 $^{cd}$ |
| Mbwazirume | 45.29±0.62 $^{a}$ | 30.90±1.44 $^{cd}$ | 54.38±0.69 $^{a}$ |
| Kabucuragye | 29.61±0.21 $^{cde}$ | 28.51±2.87 $^{cde}$ | 49.87±1.28 $^{abcd}$ |
| Enzirabahima | 48.39±0.83 $^{a}$ | 24.36±0.96 $^{cde}$ | 51.48±1.27 $^{abcd}$ |
| Nakawere | 28.58±0.28 $^{cdef}$ | 22.13±0.96 $^{de}$ | 49.28±0.93 $^{bcd}$ |

Values are means of two replicates ± standard errors of the means (mg/100 g dry weight basis). Mean values in the same columns with different superscript letters are significantly different ($p < 0.05$).

### 4.6 Sensory quality characteristics of cooked bananas

#### 4.6.1 Texture of cooked bananas

##### 4.6.1.1 Hardness

Hardness of cooked bananas varied significantly ($p < 0.05$) and ranged from 1.34 N to 8.66 N (Table 4.6). For instance, N6, N15 and N2 were significantly ($p < 0.05$) harder (8.66 N, 6.32 N, and 4.43 N, respectively) than local cultivars *Kibuzi, Mpologoma* and *Kabucuragye* (Table 4.6). Data for hardness also indicated N21, N24 and N11 produced the softest cooked bananas among all cultivars studied while hybrids M30, M32 and N8 were not significantly different ($p < 0.05$) from local cultivars *Kabucuragye, Muvubo*, and *Mpologoma* in terms of hardness of cooked bananas (Table 4.6). Results of this study were in agreement with the findings of Gafuma, et al. (2018b) who reported *Kibuzi* and *Mpologoma* as the softest local cultivars in Uganda after 130 minutes of steaming. However, values of hardness of cooked bananas in this work were slightly higher than those reported by Gafuma, et al. (2018b). The difference in experimental results could be due to differences in method of analysis used since the TPA method involved moulding the sample into a cylindrical shape for uniformity before analysis which could have led to the observed slight hardening. Hardness in bananas is an undesirable sensory quality characteristic by consumers (Table 4.5). Ssemwanga et al. (2000) reported that a banana hybrid FHIA 3 was rejected in Uganda as a cooking cultivar due to its hardness among other factors such as astringency. Hardness in cooked bananas is normally associated with high dry matter content, high levels of starch, high amylose content and low pectin content in the cell walls of bananas leading to increased starch-starch interactions in the structural integrity of the banana matrix (Gafuma et al., 2018a). No wonder, hybrids N21, N24 and N11 which exhibited the softest texture were also among the samples which had the lowest dry matter content ranging from 20-

22% (Table 4.3). High dry matter content is also associated with low water holding capacity of starch which reduces the water activity of cooked bananas leading to hardening of cooked bananas (Homayouni et al., 2014; Gafuma et al., 2018a; Gafuma et al., 2018b). Therefore, hybrids N21, N24, N11, M30, M32 and N8 could be accepted as cooking bananas on the basis of their soft texture similar to or close to that of local AAA-EA cooking bananas as evidenced in the current study (Table 4.6). Texture of cooked bananas was expressed in terms of hardness, cohesiveness and adhesiveness. Hardness is the ability of the sample to resist plastic deformation by penetration whereas cohesiveness is a mechanical textural attribute referring to the ability of a food product to stay together after deformation. Adhesiveness is the force required to remove the sample material that adheres to the mouth or probe (Bugaud et al., 2016).

#### 4.6.1.2 Cohesiveness

There were no significant differences ($p > 0.05$) in cohesiveness of both local and hybrid cultivars in this study (Table 4.6). Cohesiveness of cooked bananas varied from 0.41 to 0.84 N. Results showed that N21, *Nakawere* and M9 had the highest degree of cohesiveness (0.87 N, 0.84 N and 0.82 N, respectively) while N24, N 11 and N15 had the lowest (0.46 N, 0.46 N and 0.41 N, respectively). Cohesiveness is desirable in lower amounts by consumers (Ssemwanga & Thompson, 1994). High degree of cohesiveness in bananas is linked to high pectin content which makes cooked bananas stick together making them less tolerant to stress during processing, packaging and delivery (Gafuma et al., 2018a). Hybrid N24 had the lowest degree of cohesiveness therefore, not easily mouldable into a bolus, a desirable quality characteristic of cooked bananas (Table 4.7). Future studies should focus on quantifying and regulating pectin levels in both local and hybrid cooking bananas to improve the ease of their processing and handling by consumers.

#### 4.6.1.3 Adhesiveness

Adhesiveness of cooked bananas varied from -0.24 N to -1.37 N (Table 4.6). *Nakawere, Kabucuragye* and hybrid M9 had the highest degree of adhesiveness/stickiness to the probe (-2.74 N, -1.72 N and -1.37 N, respectively). Excessive adhesiveness in cooked bananas has been reported as an undesired sensory quality characteristic (Ssemwanga & Thompson, 1994). Adhesiveness is linked to high starch content and higher degree of gelatinization which interferes with the ability of the bananas to adhere to each other upon cooking (Sozer, Dalgıç & Kaya, 2007). On the other hand, N24, N11 and N2 had the lowest degree of adhesiveness (-0.25 N, -0.36 N and -0.37, respectively) which could be attributed to their high starch content and higher degree of gelatinization (Sozer et al., 2007).

**Table 4.6. Textural attributes of selected cooked bananas grown in Uganda**

| Cultivars | Hardness (N) | Cohesiveness | Adhesiveness (N) |
|---|---|---|---|
| N2 | 4.43±2.42 $^{c}$ | 0.55±1.60 $^{abcd}$ | -0.37±0.00 $^{ab}$ |
| N 6 | 8.66±3.06 $^{a}$ | 0.52±1.49 $^{bcd}$ | -0.65±2.10 $^{ab}$ |
| N8 | 3.16±10.00 $^{defg}$ | 0.53±1.04 $^{abcd}$ | -0.69±1.50 $^{abc}$ |
| N11 | 1.72±3.08 $^{h}$ | 0.46±0.01 $^{d}$ | -0.36±0.01 $^{ab}$ |
| N14 | 3.49±5.51 $^{cdef}$ | 0.51±2.05 $^{bcd}$ | -0.91±1.90 $^{abc}$ |
| N15 | 6.32±0.04 $^{b}$ | 0.41±0.16 $^{d}$ | -0.59±2.04 $^{ab}$ |
| N17 | 2.11±2.02 $^{gh}$ | 0.53±0.64 $^{bcd}$ | -0.55±1.70 $^{ab}$ |
| N21 | 1.34±3.43 $^{h}$ | 0.87±0.02 $^{a}$ | -1.26±1.20 $^{abc}$ |
| N24 | 1.56±0.01 $^{h}$ | 0.46±1.57 $^{d}$ | -0.24±1.10 $^{a}$ |
| M9 | 2.41±8.52 $^{fgh}$ | 0.82±0.34 $^{abc}$ | -1.37±2.20 $^{bc}$ |
| M30 | 3.02±2.87 $^{efg}$ | 0.78±0.04 $^{abcd}$ | -1.31±040 $^{bc}$ |
| M32 | 2.91±±0.29 $^{efg}$ | 0.56±1.29 $^{abcd}$ | -0.67±1.00 $^{abc}$ |
| M33 | 4.01±0.05 $^{cde}$ | 0.51±0.12 $^{bcd}$ | -0.72±1.20 $^{abc}$ |
| Muvubo | 3.01±3.08 $^{efg}$ | 0.48±0.01 $^{d}$ | -0.47±1.80 $^{ab}$ |
| Kibuzi | 2.34±2.42 $^{gh}$ | 0.50±0.68 $^{cd}$ | -0.52±2.42 $^{ab}$ |
| Nakitembe | 3.55±0.03 $^{cde}$ | 0.55±0.55 $^{abcd}$ | -0.60±3.00 $^{ab}$ |
| Mpologoma | 2.99±0.57 $^{efg}$ | 0.49±0.08 $^{cd}$ | -0.45±0.57 $^{ab}$ |
| Nfuuka | 2.32±2.15 $^{gh}$ | 0.52±0.19 $^{bcd}$ | -0.54±2.40 $^{ab}$ |
| Mbazirume | 3.50±1.27 $^{cdef}$ | 0.61±1.58 $^{abcd}$ | -0.61±2.13 $^{ab}$ |
| Kabucuragye | 3.01±2.77 $^{efg}$ | 0.73±0.45 $^{abcd}$ | -1.72±1.90 $^{cd}$ |
| Enzirabahima | 2.94±1.60 $^{efg}$ | 0.51±0.23 $^{bcd}$ | -0.65±0.38 $^{ab}$ |
| Nakawere | 4.16±5.82 $^{cd}$ | 0.84±0.58 $^{ab}$ | -2.74±040 $^{d}$ |

Values are means of three replicates ± standard errors of the means. Mean values in the same columns with different superscript letters are significantly different ($p < 0.05$).

### 4.6.2 Sensory quality characteristics of cooked bananas

During sensory analysis, panellists generated 40 descriptors for the quality characteristics of cooking bananas which were grouped into six categories (Table 4.7). The list of descriptors was used as the quality screening tool to measure the differences in consumer eating quality attributes of the cooked bananas samples as described in section 4.6.3.

Results indicated that the main sensory quality characteristics of cooked bananas included a yellow homogeneous colour by appearance, moist smooth soft texture by mouth, a soft cooked banana that sticks between fingers which is easily mouldable by hand, an aroma of cooked

banana leaves, a mild sweet taste tending to flatness and a very low sensation of astringency (Table 4.7). Panellists also mentioned that sourness "sap like taste" was considered as a bad sensory quality characteristic of cooked bananas since it is associated with immaturity of the bananas, while astringency was associated with juice bananas and good for beer brewing but not cooked bananas. An astringent taste due to tannins in cooked bananas was also reported by Nowakunda & Tushemereirwe, (2004) as being in FHIA 03, IITA hybrids and *Yangambi* KM5. Nowakunda (2000) and Nowakunda (2001) reported that an astringent taste due to tannins in cooked bananas is an undesirable eating quality identified mostly in hybrid bananas.

The other inferior sensory quality characteristics of cooked bananas mentioned by panellists in this study were a pale yellow colour, blackish and mottled colour homogeneity gave a visual impression of immaturity which is undesirable to consumers (Table 4.7). Firm and hard texture were undesired. Panellists desired moderate softness, excessive softness was regarded as an inferior quality attribute. Similar textural desirability was reported about Ugandan cooking bananas by Ssemwanga et al. (2000); Nowakunda & Tushemereirwe, (2004); Gafuma et al. (2018).

Sweet taste and banana juice aroma were classified as undesirable characteristics of the cooked *Matooke* since they gave an impression of ripeness. Cooked bananas are superior in sensory characteristics when prepared from physiologically green mature bananas with a relatively blunt taste. When asked about the taste of bananas, panellists indicated that some samples were mildly sweet. The findings of this study were in agreement with those reported by Ssemwanga et al. (1996). In the latter study, authors identified a total of 80 quality characteristics of cooking bananas falling under three categories i.e. physical, sensory and socio-economic descriptors. Majority of their sensory descriptors were identical with the ones obtained from this work.

**Table 4.7 Descriptors for sensory characteristics of cooked bananas as generated by the trained panel in Kawanda-Uganda**

| Characteristics | Descriptors |
|---|---|
| **Appearance** | |
| Yellow colour | Pale yellow like white yam with black spots* |
| Homogeneity in colour | Bright yellow√ |
| | Sunny yellow like colour of egg yolk√ |
| | Deep yellow colour tending to orange√ |
| | Golden yellow√ |
| | Creamy orange√ |
| | Brown and yellow√ |
| | Dirty yellow* |
| | Normal yellow of cooked *Matooke* with black spots* |
| | Bright yellow like the colour of sun flower√ |
| | Blackish* |
| | Homogeneous colour√ |
| | Mostly homogeneous with black spots* |
| | Homogeneous colour when hot but on cooling it becomes creamy with black spots* |
| | Non-homogeneous colour* |
| **Texture** | |
| **In the mouth** | Smooth and soft√ |
| Firmness | Firm* |
| Smoothness | Sticky√ |
| Moisture | Watery* |
| | Leaves particles in the mouth* |
| | Moist√ |
| | Mealy with cramps* |
| **By touch** | Hard and not mouldable* |
| Hardness | Very firm* |
| Mouldability | Mouldable√ |
| Stickiness | Soft and sticks between fingers± |
| | Moist√ |
| **Aroma** | |
| *Matooke* | Strong aroma of local mature *Matooke* √ |
| Pumpkin | Aroma of cooked banana leaves √ |
| Grassy | Aroma of burnt *Matooke** |
| | Pumpkin aroma* |
| | No aroma* |
| | Grassy aroma* |
| | Banana juice* |
| | Immature *Matooke** |
| **Taste** | |
| Sweetness | Mild sugary taste± |
| | Non-sweet *Matooke* taste√ |
| | Bland taste* |
| **Impression** | |
| Astringency | Sour taste* |
| Sourness | Astringent after taste± |

√=Desirable, ±=Desirable in very low quantities, *=Undesirable

### 4.6.3 Sensory characteristics of cooked bananas

This section presents the results from scoring cooked banana samples by trained panellists on the basis of the main descriptors of colour, texture, taste, impression and aroma (Table 4.7). Results of sensory evaluation of cooked bananas indicated that generally hybrid bananas had significantly ($p < 0.0001$) lower scores for the desired eating attributes than the local cultivars (Table 4.8).

All hybrid cultivars were scored significantly lower ($p < 0.05$) in regard to sweetness compared to local cultivars except for *Nfuuka* and *Kabucuragye* which were not significantly different from hybrid cultivars such as N2, N11, N17 and N24. Surprisingly, there was a negative association ($r = -0.053$) between °Brix of raw bananas and perceived sweetness of cooked products (Figure 4.1). This could have been due to interference of the sugar: acid balance by phenols and tannins in the fruit pulp reducing the perception of sweetness in the cooked bananas (Joslyn & Goldstein, 1964). The negative correlation could also be attributed to the differential rates of water absorption of bananas during the cooking process diluting the sugars in the plant tissues hence reducing the perceived sweetness of cooked bananas as reported by Ssemwanga (1996). For instance, M9 which had the highest sugars (2.22 °Brix) was associated with a negative ($r = -0.062$) correlation with perceived sweetness of cooked bananas while *Nfuuka*, N2, and N6 which registered a hard lumpy texture were positively associated with the perceived sweetness after cooking ($r = 0.019$; 0.0197; 0.143, respectively) (Figure 4.1). Results also indicated that *Matooke* taste and yellow colour of hybrid cultivars were significantly ($p < 0.05$) inferior than the local cultivars. However, M32 and N17 were not significantly ($p > 0.05$) different in colour from local cultivars *Nakitembe, Enzirabahima* and *Kabucuragye.*

There was a negative correlation (r = -0.167) between the °Brix of raw bananas and the perceived astringency of cooked products. This could be due to interferences by phytochemicals destabilising the sugar/acid balance in the plant tissues. N11 scored significantly ($p < 0.05$) higher on perceived astringency than the rest of the samples. Local bananas were scored similar to each other in respect to astringency with exception *Muvubo*. In regards to *Matooke* taste, hybrids were perceived significantly inferior to local cultivars. Hybrid cultivars M9 and N17 were not significantly ($p > 0.05$) different from local cultivars *Kabucuragye* and *Nakawere* (Table 4.5).

M32, N17, N8, were not significantly ($p > 0.05$) different from local cooking cultivars of *Nakitembe, Muvubo* and *Musakala* suggesting that these hybrids are advantageous.

These results also indicated that cultivars N8, N21, N15, N11, N2 and N6 as undesirable in respect to yellow colour intensity and uniformity.

#### 4.6.3.1 Texture

Textural characteristics of the cooked bananas were analysed in terms of 'hardness', 'firmness' or 'softness' according to Ssemwanga et al. (1996). Panellists mentioned an uneven mouth feel due to hybrid cultivars such as N6, N2 and N15 indicating that they were of an inferior eating quality as cooking bananas. The same hybrids were also described as the hardest cultivars (8.22 N, 7.89 N and 7.75 N, respectively) and were significantly ($p < 0.05$) different from local cultivars *Kibuzi, Musakala,* and *Nakitembe* which were scored as the softest cooked bananas (Table 4.8). Hardness is an undesirable sensory quality characteristic of bananas among Ugandan consumers (Table 4.7). The results of this part of the study were congruent with instrumental measurement of hardness which indicated that hybrids were significantly ($p < 0.0001$) harder

than local cultivars with N6, N2 and N15 as the hardest cooked and mashed bananas (section 4.6.1). Hybrids such as M32, N17, N24, N21, N8 were not significantly ($p > 0.05$) different from local cultivars. Stickiness between cultivars was scored in the range 2.56 to 7.22 with cooked products of N21, N8 and *Musakala* scored as the stickiest cooked bananas significantly ($p < 0.05$) higher than hybrids N2, N6 & N15 and local cultivar *Nfuuka* (Table 4.8). Stickiness of bananas is only desired in low amounts, too much of it being referred as a poor quality attribute by consumers (Ssemwanga, 1994). Hybrid cultivars N2, N6, and N15 were lumpier than the rest of the samples studied (Table 4.8). Hybrid cultivars M33, N24 and N17 were not significantly different from local cultivars *Nakiembe, Kibuzi* and *Kabucuragye*, with respect to stickiness (Table 4.8). This therefore showed that these hybrids could be preferred for their sensory stickiness since consumers of cooked bananas prefer moderately sticky cooked banana products (Table 4.7).

#### 4.6.3.2 Yellowness

Colour of cooked bananas ranged from 1.50 - 9.08 with local cultivars *Muvubo, Musakala* and *Kibuzi* having the deepest intensity of yellow colour (9.08, 8.89 and 8.78, respectively) while hybrids 17914S-24, N21 and N8 had the lowest (Table 4.8). This could therefore imply that local cultivars are still being preferred for cooking on the basis of yellow colour of cooked bananas. To some extent, the results of this section were in agreement with the instrumental colour measurements which indicated that hybrids such as N6, and N15 which had significantly ($p < 0.0001$) higher values of lightness in pulp colour were also scored low on the basis of the colour of the cooked bananas (Section 4.2.3). However, much as instrumental measurement of yellowness of the banana pulp indicated no significant ($p > 0.05$) differences between local and hybrid cultivars, panellists scored hybrids N8, N21, 17914S-24 and N15 significantly ($p > 0.05$)

inferior in intensity of the yellow colour compared to their local counterparts such as *Nakitembe, Kabucuragye*, and *Mpologoma* (Table 4.8). These results were in conformity with the findings of Nowakunda & Tushemereirwe (2004) who reported that *Kisansa*, a local AAA-EA cooking bananas was superior in eating quality characteristics than hybrids under their study (Pita-14, Pita-17, FHIA 01, FHIA 03, FHIA 17, FHIA 21, FHIA 23 and KM5). However, hybrids M32, N17, N24, M33 and M9 were not significantly ($p > 0.05$) different from local cultivars *Kibuzi, Nakawere, Kabucuragye, Nakitembe* and *Enzirabahima* on the basis of yellow colour. This indicates that the above hybrids could be easily adopted by banana consumers since they do not vary much from local AAA-EA cooking bananas on the basis of colour of cooked bananas.

#### 4.6.3.3 Sweetness

Local cooking bananas *Musakala, Kibuzi* and *Muvubo* had significantly ($p < 0.05$) the highest mean scores for sweetness while hybrids 17914S-24, N15 and N21 had the lowest. However, the results were in disagreement with instrumental measurements which indicated that N2, *Mpologoma* and N8 raw pulp had the highest levels of sugar significantly lower than *Kibuzi* and *Muvubo* (Table 4.2). The differences could be attributed to the interferences from astringent chemicals disrupting the sugar: acid balance in the pulp hence a reduction in the perception of sweetness (Joslyn & Goldstein, 1964). This probably explains why N2, N6 and *Mpologoma* were not perceived as the sweetest cooked products even though their raw banana pulps had the highest °Brix. No wonder, N2 and N6 had significantly higher levels of phytochemicals (Table 4.5).

#### 4.6.3.4 *Matooke* taste

Local cooking bananas *Kibuzi, Musakala,Muvubo* and *Nakitembe* had the highest mean scores for *Matooke* taste while hybrids N21, N8 and 17914S-24 had the lowest. Earlier studies (Ssemwanga, 1994; Ssemwanga and Thompson, 1996; Ssemwanga and Thompson, 2000) indicated that consumers of cooking bananas prefer cooking bananas that are slightly sweet and not highly astringent. Bugaud, Daribo, & Deverge (2012) also reported that sweetness in bananas is best predicted as a function of pH and TSS while sourness as a function of TA. Results of the current study agree with these predictions since *Kibuzi, Musakala*, *Muvubo* and *Nakitembe* which had the highest scores for taste also had relatively lower levels of these chemical components (5.55 to 6.50; 0.13 to 0.16; 0.50 °Brix to 0.80 °Brix; 24.66 mg GAE/100g to 28.99 mg GAE/100g; 48.01 mg CEQ/100g to 51.71 mg CEQ/100g for pH, TA, °Brix, phenols and tannins, respectively) responsible for the slight sweetness and astringency of cooking bananas desired by consumer as reported by Ssemwanga and colleagues (1994; 1996; 2000).

#### 4.6.3.5 Astringency

Panellist mentioned an astringent taste in the mouth after tasting the cooked samples which was generally significantly ($p < 0.0001$) higher in hybrid cultivars than local cooking bananas (Table 4.8). Hybrids N11, N21 & N24 were significantly ($p < 0.05$) more astringent than local cultivars *Kibuzi, Nakawere* and *Nakitembe* which had the lowest astringency among local cultivars studied (Table 4.8). These results were in conformance with the analytical tests which indicated that hybrid banana generally had higher phytochemicals than local cooking bananas (Table 4.5). The results were also in agreement with the findings of Nowakunda et al. (2000) and Nowakunda (2001) who reported higher astringency in hybrid bananas due to higher levels of tannins in the range of 0.207 g/kg to 0.670 g/kg in hybrid bananas than in local cooking bananas of

*Mbwazirume* and *Kisansa* (0.008, 0.010 g/kg respectively). However, hybrids N24, M9, N17, N14 and N8 were not significantly different from local cooking bananas *Musakala, Enzirabahima, Nakitembe* and *Nfuuka* (Table 4.8). These results therefore suggests that N24, N2, M9, M33, M32, N17, N14 and N8 could be adopted by consumers of cooking bananas for food preparation on the basis of desired astringency.

Table 4.8 Scores of sensory characteristics of selected cooked *Matooke* cultivars

| Cultivars | Yellow | Homogeneity of colour | Firmness | Moistness | Smoothness | hardness | Moldability | Stickiness | Sweetness | Astringency | Sourness | Taste |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N2 | 5.67 cde | 6.00 cd | 7.33 a | 2.889 c | 3.44 ef | 7.88 ab | 2.56 cd | 2.55 e | 2.44 cdef | 1.11 bcde | 1.00 abcde | 4.22 cdefg |
| N4 | 5.83 bcde | 7.78 abc | 4.72 abc | 6.111 abc | 5.61 abcdef | 5.05 abcde | 5.50 abcd | 5.27 abcd | 2.56 cdef | 1.22 bcde | 0.72 abcde | 5.78 abcdef |
| N6 | 5.67 cde | 6.11 bcd | 7.56 a | 3.556 bc | 2.33 f | 8.22 a | 2.44 d | 3.11 de | 2.89 bcd | 0.89 cde | 1.00 abcde | 4.56 bcdefg |
| N8 | 0.89 g | 3.28 de | 2.78 bc | 5.278 abc | 7.17 abcd | 2.44 de | 7.89 abc | 7.18 a | 1.44 efg | 1.83 abcde | 1.33 abcd | 2.28 g |
| N11 | 6.50 abcd | 7.50 abc | 4.72 abc | 6.500 abc | 4.94 cdef | 5.56 abcde | 3.39 bcd | 5.89 abc | 2.28 cdef | 2.89 a | 1.33 abcd | 4.00 defg |
| N14 | 6.33 abcd | 7.72 abc | 4.33 abc | 6.000 abc | 6.22 abcde | 4.11 abcde | 6.94 abcd | 4.67 bcde | 2.78 cde | 1.78 abcde | 0.83 abcde | 5.28 abcdef |
| N15 | 4.09 def | 6.12 bcd | 7.17 a | 4.313 abc | 4.00 def | 7.75 abc | 2.49 d | 4.17 cde | 0.81 g | 0.98 cde | 0.91 abcde | 3.15 fg |
| N17 | 8.18 abc | 8.97 ab | 3.95 abc | 6.438 abc | 6.79 abcde | 3.49 cde | 6.81 abcd | 5.03 abcd | 2.34 cdef | 1.65 abcde | 0.79 abcde | 6.17 abcde |
| N18 | 5.67 cde | 7.89 abc | 4.78 abc | 5.778 abc | 6.22 abcde | 4.00 abcde | 7.78 abcd | 5.13 abcd | 2.89 bcd | 1.44 bcde | 0.56 cde | 5.56 abcdef |
| N21 | 1.49 fg | 2.09 e | 2.29 bc | 6.383 abc | 8.05 abc | 2.66 de | 8.05 ab | 7.22 a | 0.70 g | 2.41 ab | 1.62 ab | 2.05 g |
| N24 | 6.72 abcd | 8.22 abc | 4.44 abc | 6.222 abc | 6.17 abcde | 4.44 abcde | 6.67 abcd | 5.39 abcd | 2.28 cdef | 2.11 abcd | 0.83 abcde | 5.44 abcdef |
| M9 | 7.79 abc | 7.83 abc | 5.48 abc | 5.778 abc | 6.29 abcde | 5.14 abcde | 6.38 abcd | 4.89 abcde | 2.05 cdefg | 1.64 abcde | 0.69 bcde | 5.97 abcdef |
| M32 | 8.22 abc | 8.56 abc | 2.22 bc | 7.889 a | 8.22 abc | 2.33 de | 8.78 a | 5.67 abc | 2.67 cdef | 0.67 e | 0.44 de | 6.56 abcd |
| M33 | 7.00 abcd | 7.22 abc | 4.44 abc | 6.222 abc | 6.11 abcde | 4.44 abcde | 6.67 abcd | 5.00 abcde | 2.11 cdefg | 1.11 bcde | 0.44 de | 5.33 abcdef |
| 24 | 1.50 fg | 1.88 e | 2.88 bc | 5.750 abc | 7.63 abcd | 2.13 de | 8.25 ab | 5.88 abc | 1.25 fg | 1.13 bcde | 1.13 abcde | 2.38 g |
| Musakala | 8.89 ab | 9.67 a | 2.33 bc | 6.778 abc | 9.11 a | 2.11 de | 9.22 a | 7.00 ab | 4.67 a | 1.78 abcde | 0.67 cde | 7.78 a |
| Muvubo | 9.08 a | 9.47 a | 4.15 abc | 6.785 abc | 7.47 abcd | 3.16 de | 8.14 ab | 4.64 bcde | 3.33 abc | 2.24 abc | 0.87 abcde | 7.21 ab |
| Kibuzi | 8.78 abc | 9.33 a | 1.67 c | 7.667 a | 8.78 ab | 1.56 e | 8.89 a | 5.33 abcd | 4.22 ab | 1.44 bcde | 0.56 cde | 7.78 a |
| Nakitembe | 8.11 abc | 8.11 abc | 2.44 bc | 7.556 ab | 8.22 abc | 2.11 de | 7.67 abcd | 6.89 ab | 3.22 bc | 1.56 abcde | 1.44 abc | 7.00 abc |
| Nfuuka | 6.61 abcd | 7.33 abc | 5.33 abc | 4.889 abc | 6.72 abcde | 4.67 abcde | 6.39 abcd | 4.17 cde | 2.44 cdef | 1.78 abcde | 0.72 abcde | 5.28 abcdef |
| Kabucuragye | 8.09 abc | 7.67 abc | 4.42 abc | 6.414 abc | 6.39 abcde | 4.17 abcde | 7.33 abcd | 5.29 abcd | 2.56 cdef | 1.51 abcde | 0.34 e | 6.40 abcde |
| Enzirabahima | 8.67 abc | 8.11 abc | 3.67 abc | 6.333 abc | 6.89 abcde | 3.78 bcde | 7.33 abcd | 5.44 abcd | 3.11 bc | 1.89 abcde | 1.67 a | 7.00 abc |
| Nakawere | 7.48 abc | 7.91 abc | 4.76 abc | 6.000 abc | 7.41 abcd | 4.12 abcde | 7.72 abcd | 4.41 cde | 2.36 cdef | 1.48 bcde | 0.26 e | 6.42 abcde |

Values are means of thirteen independent panellists. Values in columns with different superscript letters are significantly different ($p < 0.05$). Scale: 0= Absence of a characteristic; 10=Extreme perception of a characteristic

## 4.7 Correlation analysis

### 4.7.1 Correlation between sensory characteristics and physicochemical properties of the selected banana cultivars

After measuring the quality characteristics of the selected cooked banana cultivars, principle component analysis (PCA) was performed to determine the relative importance of the major sensory quality characteristics of cooked bananas in relation to their chemical properties (Figure 4.1). A positive correlation would guide breeders on the chemical properties to target that would meet the expectations of end-users.

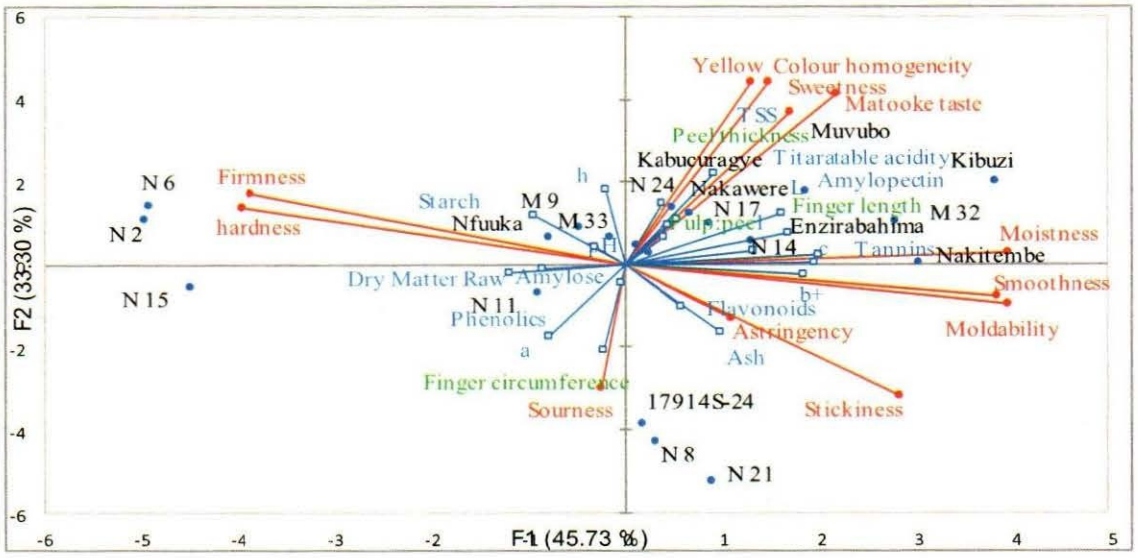



**Fig. 4.1 Principal component analysis of the sensory characteristics and physicochemical properties of selected cooking bananas**

Sensory and physicochemical results were in conformity with the reports that the hybrid bananas were superior to local cultivars on the basis of fruit physical characteristics but of inferior eating quality compared to local cultivars (Anon, 1993; Ssemwanga & Thompson, 1994; Mwenebanda & Banda, 1996; Nowakunda et al., 2000). The correlation between the studied physical characteristics of cultivars and their sensory attributes was described by principal component analysis (Figure 4.1). The first principal component (45.7 % total variability) contrasted bananas with a moist, smooth, and mouldable texture, astringent impression, tannin, and titratable acidity with firm and hard bananas having the highest starch content, amylose, and dry matter. This axis indicated the degree of hardness, mouth feel and impression/after taste perceived by panellists. The second principal component (33.3%) separated sour astringent bananas with total phenols and a cohesive texture from cooking bananas having a yellow homogeneous colour, *Matooke* taste, sweet taste, amylopectin, thick peels, and long fingers.

According to the PCA, flavonoids and ash content (quadrant B) are correlated with astringency (r= 0.014, r = -0.006), stickiness (r =0.310, r = 0.402), mouldability (r = 0.121, r = 0.226) & smoothness (r = 0.130, r = 0.295) of hybrids N8, N21, & 17914S-24. Nowakunda (2000), Nowakunda (2001) and Nowakunda & Tushemereirwe, (2004) reported that an astringent taste due to tannins in cooked bananas as an undesirable eating quality identified mostly in hybrid bananas. The correlation of ash content with a sticky, mouldable smooth texture has been explained by the effect of minerals such as calcium and sodium on the fruit pulp of bananas (Qi, Moore, and Orchard, 2000). For instance, calcium ions induce the formation of ionic $Ca^{2+}$ gels that cement the pectin chains and reduce their hydration and solubilisation abilities hence delayed cell wall softening and separation (Morris, Powell, Gidley and Rees, 1982; van Buren, 1986). On the other hands, sodium ions have been associated with a soft texture due to

displacement of calcium ions in plant cells hence enhanced solubilisation of pectin causing softening (van Buren and Pitifer, 1992). The softening of some bananas such as desert bananas on cooking has also been associated with the relatively smaller sized pectin polymers which produces a relatively lower viscosity of the pectin solution compared bananas with longer pectin polymers and the wide diversity of inter-polymer associations in the cell walls increasing tissue firmness (Greve et al., 1994; Qi, Moore, and Orchard 2000).

Total tannins and amylopectin content (quadrant A) determine the moistness ($r = 0.454$, $r = 0.193$) of cooked bananas as observed in *Nakitembe*, M32, and *Enzirabahima*. Amylopectin is a highly branched water soluble glucose polymer while hydrolysable tannins are generally water soluble phenolic therefore the high water absorption capacity of both amylopectin and tannins could have contributed to the moist texture of the cooked bananas (Ratnayake & Jackson, 2006; Kyamuhangire et al. 2006).

Sourness is correlated with total phenols ($r = 0.453$) content in hybrids N11, NI5 (quadrant C). This could have been due to interference of the sugar: acid balance by organic acids in the fruit pulp leading to increased intensity of sourness in cooked bananas (Joslyn & Goldstein, 1964). The correlation (F 2 33.3%) between polyphenols, sugars & taste suggested that the levels of phenolic compounds significantly ($p < 0.05$) reduces the consumer preferred taste of cooked bananas as reported by Ssemwanga and Thompson (1994) and Nowakunda et al., (2000).

The large finger circumference is explained by the high dry matter and high amylose content ($r = -0.064$, $r = 0.090$) in N11 & N15 (quadrant C). Similar results were reported by Zhang, Whistler, BeMiller & Hamkaer, (2005) which indicated that a high dry matter content leads to high bunch weight and yield as well as high starch content since starch is the principle component in bananas.

Firmness and hardness are explained by high starch (r =0.244, r = 0.282) content mainly in hybrids N2, N6, M9 & M33 and a local cultivar *Nfuuka* (quadrant A). The higher starch content would be expected to cause higher starch swelling and gelatinization producing a soft texture as reported in potatoes by Jarvis et al. (1992). However, from the PCA of the current study, high starch content was associated (r = 0.453) with a firm and hard texture (Fig. 4.1). This is in agreement with the results reported in potatoes (Sharma et al., 1959; Linehan and Hughes, 1969a, b; McComber et al., 1994). Linehan and Hughes (1969c) which suggested that more starch (and amylose) are correlated with a firm tissues due to a cementing effect of amylose via hydrogen bonding with other polysaccharides within the potato tuber cell walls. The results of the current study are also similar to results found in plantain pulp (Qi, Moore, and Orchard, 2000) which reported higher starch, amylose and dry matter content which was associated with firmness compared to desert bananas.

*Matooke* taste is correlated with high titratable acidity (r = 0.404) while sweetness & a yellow colour and homogeneous colour are associated with TSS (r = 0.405, r = 0.581, r = 0.578) in *Kibuzi, Nakitembe, Nakawere, Muvubo, Enzirabahima, Kabucuragye*, M32, N14, N24 and N17 (quadrant A). As fruits (bananas) grow, the sugar content increases, organic acids increase and more carotenoids are formed responsible for a yellow homogeneous colour and desired taste due to well-balanced ratio of acid/sugar balance (Joslyn & Goldstein, 1964; Stewart et al., 2007; Muchui et al., 2010). The PCA clearly indicated that high tannins content have a detrimental effect on the homogeneity of the desired yellow colour of cooked bananas (r = 0.179) since tannins and pale yellow & mottled yellow colours are associated with immature bananas (Nowakunda et al., 2000).

PCA results also indicated a close relationship between tannins and colour since they were all in the same quadrant as reported by (Nowakunda et al., 2000). The PCA clearly indicated that high tannins content negatively affects the homogeneity of the desired yellow colour of cooked bananas. Hybrids N14, N17, N24 and M32 had physicochemical properties (thick peels, long fingers, high pulp/peel ratio, high titratable acidity and high amylopectin content) similar or close to those of female parents *Kabucuragye, Nakawere* and *Enzirabahima* (quadrant A).

The correlation (F 1 45.7 %) between dry matter, starch content and hard texture suggested that cultivars with high starch content and high dry matter exhibited a hard texture, dry and rough mouth feel, and were not easy to mould with the hand. The correlation (F 2 33.3%) between polyphenols and sugars & taste suggested that the levels of phenolic compounds significantly ($p < 0.05$) reduces the taste of cooked bananas (Ssemwanga and Thompson, 1994; Nowakunda et al., 2000).

# CHAPTER FIVE:

# CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORK

## 5.1 Conclusions

A comprehensive scope of this work was to establish the determinants of sensory quality characteristics in local and hybrid bananas and to identify hybrids that are most similar to local cooking bananas on the basis of sensory qualities. Results described in chapter 4 indicate that specific objectives of the study in chapter 1 have been achieved. The originality of the work is that significantly marked physical, chemical and sensory properties of local and hybrid cooking bananas have been established.

Furthermore, a correlation of physicochemical properties and sensory characteristics of selected local and hybrid cooking bananas was developed showing the effect of physico-chemical properties of cooking bananas on sensory quality characteristics for breeding hybrids that meet consumer expectations. Major conclusions are:

- Hybrids were generally significantly superior to local cooking bananas on the basis of physical characteristics (long fingers, thin peels and high pulp\peel ratio) therefore Ugandan consumers of cooking bananas will appreciate them for these benefits they present.
- Chemical properties (pH, TSS & TA) of hybrids N17, N24, M30, M32 and M33 are similar to those of local cooking bananas.
- Local cooking bananas have better proximate composition than the hybrid cultivars.
- Hybrid cooking bananas are richer in essential mineral nutrients and polyphenols than local cooing bananas.

- According to the PCA, flavonoids and ash content are correlated with astringency, stickiness, mouldability & smoothness of hybrids N8, N21, & 17914S-24.
- Total tannins and amylopectin content are correlated with moistness of cooked bananas as observed in *Nakitembe*, M32, and *Enzirabahima*.
- Sourness is correlated with high total phenols content and pH in hybrids N11, NI5.
- The large finger circumference is explained by the high dry matter and high amylose content in N11 & N15.
- Firmness and hardness are explained by high starch content mainly in hybrids N2, N6, M9 & M33 and a local cultivar *Nfuuka*.
- *Matooke* taste, sweetness & a yellow homogeneous colour are correlated with high titratable acidity & high TSS.
- Hybrids N14, N17, N24 and M32 were similar to female parents *Kabucuragye, Nakawere* and *Enzirabahima* in terms of physicochemical properties (thick peels, long fingers, high pulp/peel ratio, high titratable acidity and high amylopectin content)

## 5.2 Recommendation

1. Physicochemical characteristics of TTS, TA, tannins, pH, phenols, tannins, starch, amylose, moisture and minerals composition were associated with a yellow homogeneous colour, sweet taste, *Matooke* taste, low astringency, low sourness, moist soft mouldable texture with a smooth mouth feel. Therefore biotechnologists should breed for these attributes for enhanced adoption and consumption of hybrid cooking bananas. Knowing the determinants of sensory quality characteristics of cooking bananas, breeders will hopefully be able to improve the eating qualities of the existing hybrids and/ or breed better bananas that meet *Matooke* consumer's expectations.

2. Hybrids N14, N17, N24, M32, M9 and M33 had physicochemical properties and sensory characteristics similar and/or close to those of local cooking bananas in the study therefore they could be adopted as cooking bananas by Ugandan consumers.

### 5.3 Further work

As a result of this work, the following are the areas that weren't addressed by the present study but could be focused on by future studies;

1. The inhibitory effect of phytochemical compounds on the bioavailability of mineral elements in cooked *Matooke*.
2. The effect of different amylose/ amylopectin ratios on the cooling rate and hardening of cooked *Matooke* products.
3. The effect of water absorption during cooking on the TSS of cooked *Matooke* products.

## REFERENCES


Abbas, F. M. A., Saifullah, R., & Azhar, M. E. (2009). Assessment of physical properties of ripe banana flour prepared from two varieties: Cavendish and Dream banana. *International Food Research Journal*, *16*(2), 183–189.

Agunbiade, S. O., Olanlokun, J. O., & Olaofe, O. A. (2006). Quality of Chips Produced from Rehydrated Dehydrated Plantain and Banana. *Pakistan Journal of Nutrition*, *5*(5), 471–473. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.487.8622&rep=rep1&type=pdf

Akankwasa, K. (2014). *Evaluating farmers' and consumers' acceptance of new cooking banana hybrids in Uganda: micro-economic analysis and policy implications (Doctoral dissertation)*. Retrieved from http://ukzn-dspace.ukzn.ac.za/handle/10413/12845

Aked, J., & Kyamuhangire, W. (1996). Postharvest aspects of highland bananas in Uganda. *Tropical Science (United Kingdom)*.

Alothman, M., Bhat, R., & Karim, A. A. (2009). UV radiation-induced changes of antioxidant capacity of fresh-cut tropical fruits. *Innovative Food Science and Emerging Technologies*, *10*(4), 512–516. https://doi.org/10.1016/j.ifset.2009.03.004

Amri, F. S. Al, & Hossain, M. A. (2018). Comparison of total phenols, flavonoids and antioxidant potential of local and imported ripe bananas. *Egyptian Journal of Basic and Applied Sciences*, *5*(4), 245–251. https://doi.org/10.1016/j.ejbas.2018.09.002

Annor, G. A., Asamoah-Bonti, P., & Sakyi-Dawson, E. (2016). Fruit physical characteristics, proximate, mineral and starch characterization of FHIA 19 and FHIA 20 plantain and FHIA 03 cooking banana hybrids. *SpringerPlus*, *5*(1), 1–12. https://doi.org/10.1186/s40064-016-2465-1

Anuonye, J. C., Ndaliman, M., Elizabeh, O. U., & Yakubu, M. C. (2012). Effect of Blending on the Composition and Acceptability of Blends of Unripe Banana and Pigeon Pea Flours. *Nigerian Food Journal*, *30*(1), 116–123. https://doi.org/10.1016/s0189-7241(15)30020-5

AOAC. (2004). Official method of Analysis of the Association of Analytical Chemists. Retrieved September 29, 2020, from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=AOAC+%282004%29.+Official+method+of+Analysis+of+the+Association+of+official+Analytical+chemists.+15th+Ed.%2C+Washington.+USA.&btnG=

ASTM. (1968). *Manual on Sensory Testing Methods, Sponsored by ASMT Committee E-18 on Sensory Evaluation of Materials and Products*. Retrieved from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=American+Society+for+Testing+and+Materials+%281968%29%2C+Basic+Principles+of+Sensory+Evaluation%2C+ASTM+Special+Technical+Publication+No.+433%2C+ASTM%2C+PA.&btnG=

Aurore, G., Parfait, B., Fahrasmane, L., Aurore, G., & Parfait, L. F. (2009). Bananas , raw materials for making processed food products. *Trends in Food Science & Technology*, *20*(2), 78–91. https://doi.org/10.1016/j.tifs.2008.10.003

Bartkienė, E. (2012). Plant food analysis methods: methodical book. Retrieved from https://www.lsmuni.lt/cris/handle/20.500.12512/90057

Batista, A. L. D., Silva, R., Cappato, L. P., Ferreira, M. V. S., Nascimento, K. O., Schmiele, M., & Cruz, A. G. (2017). Developing a synbiotic fermented milk using probiotic bacteria and organic green banana flour. *Journal of Functional Foods*, *38*, 242–250. https://doi.org/10.1016/j.jff.2017.09.037

Batte, M., Akankwasa, K., Tushemereirwe, W. K., Karamura, E. B., Karamura, D., Kubiriba, J., & Barekye, A. (2016). The performance of East African highland bananas released in farmers' fields and the need for their further improvement. *Acta Horticulturae*, (1114), 231–238. https://doi.org/10.17660/actahortic.2016.1114.32

Belayneh, M., Workneh, T. S., & Belew, D. (2014). Physicochemical and sensory evaluation of some cooking banana (Musa spp.) for boiling and frying process. *Journal of Food Science and Technology*, *51*(12), 3635–3646. https://doi.org/10.1007/s13197-013-0940-z

BeMiller, J., & Dekker, K. H. F. (2008). Carbohydrates (Chapter 4), 4th edn. Marcel, New York.

Bertoft, E. (2017). Understanding Starch Structure: Recent Progress. *Agronomy*, *7*(3), 56. https://doi.org/10.3390/agronomy7030056

Brown, A., Tumuhimbise, R., Amah, D., Uwimana, B., Nyine, M., Mduma, H., & Swennen, R. (2017). Bananas and plantains (Musa spp.). In *Genetic Improvement of Tropical Crops*. https://doi.org/10.1007/978-3-319-59819-2_7

Bugaud, C, Daribo, M. O., & Deverge, E. (2012). Chemical Predictors of Sweetness and Sourness in Banana, 211–216.

Bugaud, Christophe, Maraval, I., Daribo, M. O., Leclerc, N., & Salmon, F. (2016). Optimal and acceptable levels of sweetness, sourness, firmness, mealiness and banana aroma in dessert banana (Musa sp.). *Scientia Horticulturae*, *211*, 399–409. https://doi.org/10.1016/j.scienta.2016.09.016

Bukusuba, J., Muranga, F. I., & Nampala, P. (2008). Original article Effect of processing technique on energy density and viscosity of cooking banana : implication for weaning foods in Uganda, 1424–1429. https://doi.org/10.1111/j.1365-2621.2007.01670.x

Byarugaba-bazirake, G. W. (2008). The Effect Of Enzymatic Processing on Banana Juice and Wine, (Thesis)

Cano, M. P., de Ancos, B., Matallana, M. C., Cámara, M., Reglero, G., & Tabera, J. (1997). Differences among Spanish and Latin-American banana cultivars: morphological, chemical and sensory characteristics. Food Chemistry, 59(3), 411-419.

Commons, C. D., & Albertson, E. (2016). Clark University Adopting new banana varieties in Uganda: the role of gender and head of household status. Retrieved from https://commons.clarku.edu/idce_masters_papers/27

Gaidashova, S. V, Karemera, F., & Karamura, E. B. (2008). Agronomic performance of introduced banana varieties in lowlands of Rwanda. African Crop Science Journal, Vol. 16, No. 1, pp. 9 - 16.

Njuguna, J., Nguthi, F., Wepukhulu, S., Wambugu, F., Gitau, D., Karuoya, M., & Karamura, D. (2008). Introduction and evaluation of improved banana cultivars for agronomic and yield characteristics in Kenya. African Crop Science Journal, 16(1).

Dadzie, B. K., & Orchard, J. E. (1997). Routine post-harvest screening of banana/plantain hybrids: criteria and methods (Vol. 2). Bioversity International.

Dadzie, B. K., & Orjeda, G. (1998). Post-harvest characteristics of black Sigatoka resistant banana, cooking banana and plantain hybrids (Vol. 3). Bioversity International.

Deshmukh, M. H., Pai, S. R., Nimbalkar, M. S., & Patil, R. P. (2009). Biochemical characterization of banana cultivars from Southern India. *International Journal of Fruit Science*, *9*(4), 305–322. https://doi.org/10.1080/15538360903241336

Dotto, J, & Matemu, A. (2019). Nutrient composition and selected physicochemical properties of fifteen Mchare cooking bananas: A study conducted in northern Tanzania. *Scientific African 6 (2019) e00150 Conte.* Retrieved from https://www.sciencedirect.com/science/article/pii/S2468227619307112

Dotto, Joachim, Matemu, A. O., & Ndakidemi, P. A. (2018). Potential of cooking bananas in addressing food security in East Africa International Journal of Biosciences | IJB |. *Int. J. Biosci*, *13*(4), 278–294. https://doi.org/10.12692/ijb/13.4.278-294

Dufour, D., & Gibert, Olivier, Giraldo, Andrès, Sánchez, Teresa, Reynes, Max, Alo, J.-P. P. (2009). Characterisation of bananas and cooking bananas cultivated in Colombia : morphological , and functional differentiation between genetic groups , consumption patterns and preferences.

Dzomeku, B., Darkey, S., & Bam, R., (2007). Sensory evaluation of four FHIA tetraploid hybrids for kaakle (a local dish) in Ghana.*Plant science.*

Edmeades, S., Karamura, D., & Smale, M. (2005). Demand for cultivar attributes and the biodiversity of bananas in Uganda.

Emaga, T., Andrianaivo, R., & Wathelet, B. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Elsevier*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0308814606007023

Fennema's Food Chemistry, Fourth Edition.pg 40-42. (2008).

Fernandes Aquino, C., Carlos, L., Salomão, C., Machado, S., Ribeiro, R., Lopes, D., & Cecon, P. R. (2016). Carbohydrates, phenolic compounds and antioxidant activity in pulp and peel of 15 banana cultivars 1. *Rev. Bras. Frutic., Jaboticabal - SP, v.* 38, n. 4 : e-090 ISSN 0100-29451/11 https://doi.org/10.1590/0100-29452016090

Ferris, R., Adeniji, T., Chukwu, U., & Akalumhe, Y. (1996). Postharvest quality of plantains and cooking bananas. Retrieved from http://biblio1.iita.org/handle/20.500.12478/6480

Ferris, R. S. B. (1991). Effects of damage and storage environment on the ripening of cooking banana with implications for postharvest loss.

Forster, M., Rodríguez Rodríguez, E., Darias Martín, J., & Romero, C. D. (2003). Distribution of

Nutrients in Edible Banana Pulp. *Food Technol. Biotechnol.* 41 (2) 167-171.

Gafuma, S., Byarugaba-Bazirake, G. W., & Mugampoza, E. (2018). Textural Hardness of Selected Ugandan Banana Cultivars under Different Processing Treatments. *Journal of Food Research*, *7*(5), 98. https://doi.org/10.5539/jfr.v7n5p98

Gafuma, S., Mugampoza, D., & Byarugaba-Bazirake, G. W. (2018). Starch and Pectin Affect Hardness of Cooked Bananas. *Journal of Food Research*, *7*(6), 107. https://doi.org/10.5539/jfr.v7n6p107

Gensi, R., Kyamuhangire, W. (1994). Traditional production and characteristics of banana juice in Uganda. *Agris.Fao.Org*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=UG9500136

Hardisson, A., Rubio, C., Baez, A., Martin, M., & Alvarez, R. (2001). Mineral composition of the banana ( Musa acuminata ) from the island of Tenerife, *73*, 153–161.

Haslinda, W. H., Cheng, L. H., Chong, L. C., & Aziah, A. A. N. (2009). Chemical composition and physicochemical properties of green banana (Musa acuminata × balbisiana Colla cv. Awak) flour. *International Journal of Food Sciences and Nutrition*, *60*(SUPPL.4), 232–239. https://doi.org/10.1080/09637480902915525

Hernández, Y., Lobo, M. G., & González, M. (2006). Determination of vitamin C in tropical fruits: A comparative evaluation of methods. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2005.04.012

Heslop-Harrison, J. S. (2011). Genomics, banana breeding and superdomestication. In *Acta Horticulturae* (Vol. 897, pp. 55–62). International Society for Horticultural Science. https://doi.org/10.17660/ActaHortic.2011.897.4

Hilje, L., Costa, H. S., & Stansly, P. A. (2001). Cultural practices for managing Bemisia tabaci and associated viral diseases. *Crop Protection*. https://doi.org/10.1016/S0261-2194(01)00112-0

Homayouni, A., Amini, A., Keshtiban, A. K., Mortazavian, A. M., Esazadeh, K., & Pourmoradian, S. (2014, January). Resistant starch in food industry: A changing outlook for consumer and producer. *Starch/Staerke*. https://doi.org/10.1002/star.201300110

IITA Crop Improvement Division; Plantain and Banana improvement program: Annual Report (1993). Retrieved September 25, 2020, from http://biblio1.iita.org/handle/20.500.12478/4471

Islam, M. Z., Hoque, M. M., & Monalisa, K. (2014). Effects of Drying on the Physicochemical and Functional Properties of Green Banana ( Musa sapientum ) Flour and Development of Baked Product, *2*(4), 128–133. https://doi.org/10.12691/ajfst-2-4-4

Issue, I. N. T. (2000). The International Magazine on Banana and Plantain, *9*(December).

Janick, J. (1996). *Plant breeding reviews. Volume 14*. John Wiley & Sons, Inc.

Jenny, C., Tomekpe, K., Bakry, F., & Escalant, J. V. (2002). Conventional breeding of bananas. Mycosphaerella leaf spot diseases of bananas: present status and outlook, 199.

Joslyn, M. A., & Goldstein, J. L. (1964). Astringency of fruits and fruit products in relation to phenolic content. *In Advances in food research* (Vol. 13, pp. 179-217). Academic Press Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14280866

Nowakunda, K., & Tushemereirwe, W. (2004). Farmer acceptance of introduced banana genotypes in Uganda. African Crop Science Journal, 12(1), 1-6.

Kabahenda, M., & Kapiriri, M. N. (2010). Analysing agricultural science and technology innovation systems: A Case Study of the Banana Sub-sector in Systems : Technology.

Kachru, R. P., Kotwaliwale, N., & Balasubramanian, D. (1995). Physical and mechanical properties of green banana (Musa paradisiaca) fruit. Journal of food engineering, 26(3), 369-378.

Kang, G. Z., Xu, Y. Y., Tao, J., Sun, G. C., & Wang, Z. X. (2002). Effects of H_2O_2 and CaCl_2 on chilling-resistance capabilities in banana seedlings [J]. Subtropical Plant Science, 1

Karamura, E, Mussane, C., Fraser, C., Blomme, G., Uazire, A., Pillay, M., & Staver, C. (2011). Preliminary evaluation of improved banana varieties in Mozambique. *African Crop Science Journal*, *16*(1), 17–25. https://doi.org/10.4314/acsj.v16i1.54325

Karamura, Eldad, Frison, E., Karamura, D. A., & Sharrock, S. (1998). Banana production systems in eastern and southern Africa. *Bananas and Food Security*, (January 2015), 401–412.

Keijbets, M. J. H., Pilnik, W., & Vaal, J. F. A. (1976). Model studies on behaviour of pectic substances in the potato cell wall during boiling. *Potato Research*, *19*(3), 289–303. https://doi.org/10.1007/BF02365723

Khawas, P., J. Das, A., Sit, N., S. Badwaik, L., & C. Deka, S. (2014). Nutritional Composition of Culinary Musa ABB at Different Stages of Development. *American Journal of Food Science and Technology*. https://doi.org/10.12691/ajfst-2-3-1

Kibazohi, O., Kyamuhangire, W., Kaunga, D. L., & Rokoni, C. (2017). African Journal of Food Science Process improvement for mechanical extraction of low-viscosity clear banana juice. *Academicjournals.Org*, *11*(8), 291–295. https://doi.org/10.5897/AJFS2017.1604

Kiiza, B., Abele, S., & Kalyebara, R. (2004). Market opportunities for Ugandan banana products : National , regional and global perspectives, (February), 743–749.

Kikulwe, E. M. (2010). *On the introduction of genetically modified bananas in Uganda: Social benefits, costs, and consumer preferences*. Retrieved from https://library.wur.nl/WebQuery/wurpubs/fulltext/133252

Kuala, U. S., Teknik, F., Kimia, J. T., & Aceh, B. (2012). Total phenolics , flavonoids and antioxidant activity of banana pulp and peel flours : influence of variety and stage of ripeness, *19*(3), 1041–1046.

Kumar, K. P. S., Bhowmik, D., Duraivel, S., & Umadevi, M. (2012). Traditional and Medicinal Uses of Banana, *1*(3), 51–63.

Kyamuhangire, W., Krekling, T., Reed, E., & Pehrson, R. (2006). The microstructure and tannin content of banana fruit and their likely influence on juice extraction, *1915*(May 2005), 1908–1915. https://doi.org/10.1002/jsfa

Lawless, H. T., Popper, R., & Kroll, B. J. (2010). A comparison of the labeled magnitude (LAM) scale, an 11-point category scale and the traditional 9-point hedonic scale. *Food Quality and Preference*, *21*(1), 4–12. https://doi.org/10.1016/j.foodqual.2009.06.009

Le Leu, R. K., Brown, I. L., Hu, Y., Morita, T., Esterman, A., & Young, G. P. (2007). Effect of dietary resistant starch and protein on colonic fermentation and intestinal tumourigenesis in rats. *Carcinogenesis*. https://doi.org/10.1093/carcin/bgl245

Lim, Y. Y., Lim, T. T., & Tee, J. J. (2007). Food Chemistry Antioxidant properties of several tropical fruits : A comparative study, *103*, 1003–1008. https://doi.org/10.1016/j.foodchem.2006.08.038

Linehan, D. J., & Hughes, J. C. (1969). Texture of cooked potato: III.—Intercellular adhesion of chemically treated tuber sections. *Journal of the Science of Food and Agriculture*, *20*(2), 119–123. https://doi.org/10.1002/jsfa.2740200213

Marocco, I., Mukiibi, E., Nsenga, R., Sardo, P., Marocco, I., Mukiibi, E., … Whitney, C. (2018). Uganda From Earth to Table.

Mascitelli, L., Disease, M. G.-P. in H. H. and, & 2014, undefined. (n.d.). Inhibition of iron absorption by polyphenols as an anticancer mechanism. *Elsevier*. Retrieved from https://www.sciencedirect.com/science/article/pii/B9780123984562000979

McComber, D. R., Homer, H. T., Chamberlin, M. A., & Cox, D. F. (1994). Potato Cultivar Differences Associated with Mealiness. *Journal of Agricultural and Food Chemistry*, *42*(11), 2433–2439. https://doi.org/10.1021/jf00047a013

Menezes, E. W., Tadini, C. C., & Tribess, T. B. (2015). Chemical Composition and Nutritional Value of Unripe Banana Flour ( Musa Chemical Composition and Nutritional Value of Unripe Banana Flour ( Musa acuminata , var . Nanicão ), (September 2011). https://doi.org/10.1007/s11130-011-0238-0

Morris, V. J., Kirby, A. R., Quesada, M. A., Paniagua, C., Posé, S., Morris, V. J., … Mercado, J. A. (2014). Fruit softening and pectin disassembly : an overview of nanostructural pectin modifications assessed by atomic force microscopy. *Annals of Botany*. https://doi.org/10.1093/aob/mcu149

Muchui, M. N., Njoroge, C. K., Kahangi, E. M., & Onyango, C. A. (2010). Determination of maturity indices of tissue cultured bananas (Musa spp.) "williams" and "grande naine." *Acta Horticulturae*, *879*, 425–430. https://doi.org/10.17660/ActaHortic.2010.879.47

Mugisha, J., Akankwasa, K., Tushemereirwe, W., & Ragama, P. (2008). Urban consumer willingness to pay for introduced dessert bananas in Uganda. African Crop Science Journal, 16(4). Retrieved from https://www.ajol.info/index.php/acsj/article/view/54399

Muranga, F. I., Mutambuka, M., Nabugoomu, F., & Lindhauer, M. G. (2010). Optimisation of raw tooke flour, vital gluten and water absorption in tooke/wheat composite bread: Effect of raw tooke flour and vital gluten on wheat flour physicochemical and dough rheological

properties (Part I). *African Journal of Food Science*, *4*(5), 223–230. Retrieved from http://www.academicjournals.org/ajfs

Muranga, F. I., Nabugoomu, F., & Katebarirwe, J. G. (2011). Effect of optimal incorporation of hybrid banana flours on acceptability of soy fortified banana flour based products, *10*(85), 19788–19795. https://doi.org/10.5897/AJB11.2417

Nazarudin, A., Roseli, M., Fui, T., Tsan, Y., Ying, F., Othman, R., Ding, P.D.P., & Othman, Y. R. (2011). *The Role Of Plant Physiology The Role of Plant Physiology In Climate Change Adaptation And Mitigation Trans. Malaysian Soc. Plant Physiol. 19 First Published.* First Published.

Ni, L., Lin, D., & Barrett, D. M. (2005). Pectin methylesterase catalyzed firming effects on low temperature blanched vegetables. *Journal of Food Engineering*. https://doi.org/10.1016/j.jfoodeng.2004.10.009

Nowakunda, K. (2001). Determination of consumer acceptability of introduced bananas. Unpublished master's thesis, Makerere University, Uganda.

Nowakunda, K., Rubaihayo, P. R., Ameny, M. A., & Tushemereirwe, W. (2000). Consumer acceptability of introduced bananas in Uganda. Infomusa, 9(2), 22-25

Nowakunda, K., Barekye, A., Ssali, R. T., Namaganda, J., Tushemereirwe, W. K., Nabulya, G., Batte, M., & Karamura, D. (2015). 'Kiwangaazi'(syn 'KABANA 6H') Black Sigatoka nematode and banana weevil tolerant 'Matooke'hybrid banana released in Uganda. HortScience, 50(4), 621-623.

Karamura, D. A. (1998). Numerical taxonomic studies of the East African highland bananas (Musa AAA-East Africa) in Uganda.

Nyombi, K. (2013). Towards sustainable highland banana production in Uganda: opportunities and challenges. African Journal of Food, Agriculture, Nutrition and Development, 13(2).

Ohizua, E. R., Adeola, A. A., Idowu, M. A., Sobukola, O. P., Afolabi, T. A., Ishola, R. O., & Falomo, A. (2017). Nutrient composition, functional, and pasting properties of unripe cooking banana, pigeon pea, and sweetpotato flour blends. *Food Science and Nutrition*, *5*(3), 750–762. https://doi.org/10.1002/fsn3.455

Omulo, G., Banadda, N., & Kiggundu, N. (2015). Harnessing of banana ripening process for banana juice extraction in Uganda. African Journal of Food Science and Technology, 6(4), 108-117.

Pain, J. P., Fernández, A., Sánchez, T., Gibert, O., González, A., Giraldo, A., & Reynes, M. (2009). Differentiation between Cooking Bananas and Dessert Bananas. 1. Morphological and Compositional Characterization of Cultivated Colombian Musaceae ( Musa sp.) in Relation to Consumer Preferences . *Journal of Agricultural and Food Chemistry*, *57*(17), 7857–7869. https://doi.org/10.1021/jf901788x

Perdon, A. A., Siebenmorgen, T. J., Buescher, R. W., & Gbur, E. E. (1999). *Starch Retrogradation and Texture of Cooked Milled Rice During Storage. 828 Journal of food science* (Vol. 64).

*Philippine Men of Science*. (2012). Retrieved from http://webdb.stii.dost.gov.ph

Ploetz, R. C., & Evans, E. A. (2006). Banana Production. *Science*, *ns-17*(433), 289–290. https://doi.org/10.1126/science.ns-17.433.289

Pothavorn, P., Kitdamrongsont, K., Swangpol, S., Wongniam, S., Atawongsa, K., Savasti, J., & Somana, J. (2010). Sap phytochemical compositions of some bananas in Thailand. *Journal of Agricultural and Food Chemistry*, *58*(15), 8782–8787. https://doi.org/10.1021/jf101220k

Qi, B., Moore, K. G., & Orchard, J. (2000). Effect of cooking on banana and plantain texture. *Journal of Agricultural and Food Chemistry*, *48*(9), 4221–4226. https://doi.org/10.1021/jf991301z

Ratnayake, W. S., & Jackson, D. S. (2006). Gelatinization and solubility of corn starch during heating in excess water: New insights. *Journal of Agricultural and Food Chemistry*. https://doi.org/10.1021/jf0529114

Reed, J. D., McDowell, R. T. E., van Soest, P. J., & Horvath, P. R. J. (1982). Condensed tannins: A factor limiting the use of cassava forage. *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.2740330302

Sabiiti, G.,Ininda, J. M., Ogallo, L., Opijah, F., Nimusiima, A., Otieno, G., & Basalirwa, C. (2016). Empirical Relationships between Banana Yields and Climate Variability over Uganda. *Journal of Environmental and Agricultural Sciences Journal of Environmental & Agricultural Sciences*, *7*(7), 3–13. https://doi.org/( ISSN: 2313-8629)

Salunkhe, D. K., and K. (1995). *Handbook of Fruit Science and Technology*. CRC press.

Santo, A., &, Cartolano, N.(2012). Fibers from fruit by-products enhance probiotic viability and fatty acid profile and increase CLA content in yoghurts. *Elsevier*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0168160511007525

Schanderi, S. H. (1970). Methods in food analysis. *New York: Academic*, *709*.

Sharma, M. K., Isleib, D. R., & Dexter, S. T. (1959). The influence of specific gravity and chemical composition on hardness of potato tubers after cooking. *American Potato Journal*, *36*(3), 105–112. https://doi.org/10.1007/BF02851649

Simmonds, N. W. (2007). Notes on Banana Taxonomy. *Kew Bulletin*. https://doi.org/10.2307/4114778

Simmonds, N. W., & Shepherd, K. (1952). An Asian Banana (Musa acuminata) in Pemba, Zanzibar Protectorate. *Nature*. https://doi.org/10.1038/169507a0

Simmonds, N. W., & Shepherd, K. (1955). The taxonomy and origins of the cultivated bananas. *Journal of the Linnean Society of London, Botany*. https://doi.org/10.1111/j.1095-8339.1955.tb00015.x

Singhal, M., & Ratra, P. (2013). Antioxidant Activity , Total Flavonoid and Total Phenolic Content of Musa acuminate Peel Extracts, *7*(2), 118–122. https://doi.org/10.5829/idosi.gjp.2013.7.2.72158

Sozer, N., Dalgıç, A. C., & Kaya, A. (2007). Thermal, textural and cooking properties of

spaghetti enriched with resistant starch. *Journal of Food Engineering*, *81*(2), 476–484. https://doi.org/10.1016/j.jfoodeng.2006.11.026

Ssali, R. T., Nowankunda, K., Barekye Erima, R., Batte, M., & Tushemereirwe, W. K. (2010). On-farm participatory evaluation of east African highland banana "matooke" hybrids (Musa spp.). *Acta Horticulturae*, *879*, 585–592.

Ssemwanga, J. K. (1995). Quality attributes of matooke banana cultivars according to farmers and traders in Uganda. Musa Africa (NGA), 7, 7–9

Ssemwanga, J., (United, A. T.-A. of A. B., & 1994, undefined. (n.d.). Investigation of postharvest and eating qualities likely to influence acceptability of Matooke banana cultivars to be introduced in Uganda. *Agris.Fao.Org*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=GB9520737

Ssemwanga, J. K. (1995). Quality attributes of matooke banana cultivars according to farmers and traders in Uganda. *Musa Africa (NGA)*, *7*, 7–9.

Ssemwanga, James K., Thompson, A. K., & Aked, J. (2000). Quality and acceptability of the new banana cultivar fhia 3 compared to indigenous Uganda cultivars for matooke preparation. In *Acta Horticulturae*. https://doi.org/10.17660/ActaHortic.2000.540.61

Ssemwanga, James K, Thompson, A. K., & Aked, J. (2000). Spp., Color, Consumer and Taste Panels, Flavor, Markets, Measurement, Texture, 561–567.

Ssonko, U. L., & Muranga, F. I. (2017). Partial characterization of starches from major banana (matooke) cultivars grown in Uganda. *Food Science and Nutrition*, *5*(6), 1145–1153. https://doi.org/10.1002/fsn3.505

Stewart, D., McDougall, G. J., Sungurtas, J., Verrall, S., Graham, J., & Martinussen, I. (2007). Metabolomic approach to identifying bioactive compounds in berries: Advances toward fruit nutritional enhancement. *Molecular Nutrition and Food Research*, *51*(6), 645–651. https://doi.org/10.1002/mnfr.200700056

Stover, R. H., & Simmonds, N. W. (1987). Bananas (No. Ed. 3). Longman Scientific & Technical.

Taylor, P., Arvanitoyannis, I. S., & Mavromatis, A. (2008). Banana Cultivars , Cultivation Practices , and Physicochemical, (May 2013), 37–41. https://doi.org/10.1080/10408390701764344

Thakur, B. R., Singh, R. K., & Handa, A. K. (1997). Chemistry and Uses of Pectin - A Review. *Critical Reviews in Food Science and Nutrition*. https://doi.org/10.1080/10408399709527767

Thiele, G., Khan, A., Heider, B., Kroschel, J., Harahagazwe, D., Andrade, M., … Dangles, O. (2017). Roots, Tubers and Bananas: Planning and research for climate resilience. *Open Agriculture*, *2*(1), 350–361. https://doi.org/10.1515/opag-2017-0039

Tomekpe, K., Herent, M.-F., Larondelle, Y., Passo Tsamo, C. V., Rogez, H., Happi Emaga, T., & Andre, C. (2014). Phenolic profiling in the pulp and peel of nine plantain cultivars (Musa sp.). *Food Chemistry*, *167*, 197–204. https://doi.org/10.1016/j.foodchem.2014.06.095

Trinh, T., Tuoc, K., & Glasgow, S. (2012). On the texture profile analysis test. Institute of Food Nutrition and Human Health, Massey University, New Zealand.

Tumuhimbise, R., Barekye, A., Kubiriba, J., Akankwasa, K., Arinaitwe, I. K., & Karamura, D. (2018). New High-yield Cooking Banana Cultivars with Multiple Resistances to Pests and Diseases (' NAROBan1 ', ' NAROBan4 ') Released in Uganda, *53*(9), 1387–1389. https://doi.org/10.21273/HORTSCI13207-18

Tumuhimbise, R., Buregyeya, H., Barekye, A., Ssali, R. T., Kubiriba, J., Muhangi, S., ... Karamura, E. (2016). Selection of cooking banana genotypes for yield and black Sigatoka resistance in different locations in Uganda, *8*(5), 60–71. https://doi.org/10.5897/JPBCS2016.0559

Tushemereirwe, W.; Batte, M.; Nyine, M.; Tumuhimbise, R.; Barekye, A.; Tendo, S.; Talengera, D.; Kubiriba, J.; Lorenzen, J.; Swennen, R.; Uwimana, B. (2015). Performance of NARITA banana hybrids in the preliminary yield trial for three cycles in Uganda. *International Institute of Tropical Agriculture (IITA); NARO*, (November), 35. Retrieved from http://dialogues.cgiar.org/blog/ banana- staple-food-for-500-million-people/

Tushemereirwe, W., & Walugembe, J. (2020). Genetically engineered east african highland bananas-proximate analysis and effect of cooking on the enhanced provitamin a levels. *Afr. J. Food Agric. Nutr. Dev*, *20*(1), 15205–15221. https://doi.org/10.18697/ajfand.89.19005

van Asten, P. J. A., Fermont, A. M., & Taulya, G. (2011). Drought is a major yield loss factor for rainfed East African highland banana. *Agricultural Water Management*, *98*(4), 541–552. https://doi.org/10.1016/j.agwat.2010.10.005

Van Buggenhout, S., Sila, D. N., Duvetter, T., Van Loey, A., & Hendrickx, M. (2009). Pectins in processed fruits and vegetables: Part III - Texture engineering. *Comprehensive Reviews in Food Science and Food Safety*. https://doi.org/10.1111/j.1541-4337.2009.00072.x

Vysetti, B., Vummiti, D., Roy, P., Taylor, C., Kamala, C. T., & Satyanarayanan, M. (2014). Analysis of Geochemical Samples by Microwave Plasma-AES, 35(2), 65-78.

Waard, M. A., Georgopoulos, S. G., Hollomon, D. W., Ishii, H., Leroux, P., Ragsdale, N. N., & Schwinn, F. J. (2003). Chemical Control of Plant Diseases: Problems and Prospects. *Annual Review of Phytopathology*. https://doi.org/10.1146/annurev.py.31.090193.002155

Wang, S., Li, C., Copeland, L., Niu, Q., & Wang, S. (2015). Starch Retrogradation: A Comprehensive Review. *Comprehensive Reviews in Food Science and Food Safety*. https://doi.org/10.1111/1541-4337.12143

Wheal, M., & Palmer, L. T. (2011). Analytical Methods Paper, (December). https://doi.org/10.1039/c1ay05430a

William, H. (2000). Official Methods of Analysis of AOAC International. *AOAC Official Method 985.29*. Retrieved from https://ci.nii.ac.jp/naid/10018907904

Zerihun, M., & Minuye, M. (2019). Physicochemical Profiling of Different Released and Improved Desert and Cooking Banana Varieties. *Bioprocess Engineering*, *3*(2), 12–21. https://doi.org/10.11648/j.be.20190302.13

Zhang, P., Whistler, R. L., BeMiller, J. N. and, & Hamaker, B. (2005). Banana starch: production, physicochemical properties, and digestibility—a review. *Carbohydrates Polymers*, *59*(7), 443–458. Retrieved from https://www.sciencedirect.com/science/article/pii/S0144861704004023

Zhishen, J., Mengcheng, T., & Jianming, W. (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry 64, 555-559.* Retrieved from https://www.sciencedirect.com/science/article/pii/S0308814698001022

# APPENDICES

## APPENDIX I: Summary statistics (LS mean for local and hybrid cultivars)

Physical Composition

| Cultivar | Finger length (cm) | Finger circumference (cm) | Peel thickness (mm) | Pulp:peel |
|---|---|---|---|---|
| Hybrids | 19.49[a] | 12.46[b] | 2.52[b] | 1.75[a] |
| Local | 17.89[b] | 14.46[a] | 3.91[a] | 1.43[b] |
| Pr > F(Model) | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |
| Significant | Yes | Yes | Yes | Yes |
| Pr > F(Type) | | | | |
| Significant | Yes | Yes | Yes | Yes |

Chemical Composition

| | pH | TSS oBrix | Titaratable acidity (g/L) | L | a | b+ | Dry Matter (%) |
|---|---|---|---|---|---|---|---|
| Hybrids | 5.740 [a] | 0.611 [a] | 0.123 [a] | 44.602 [a] | -14.970 [b] | 29.275 [a] | 24.708 [a] |
| Local | 6.867 [a] | 0.594 [a] | 0.115 [b] | 40.783 [b] | -12.983 [a] | 28.972 [a] | 23.975 [b] |
| Pr > F(Model) | 0.496 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |
| Significant | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Pr > F(Type) | | | | | | | |
| Significant | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Nutrient Composition

| | % Ash | % Crude fat | % Protein | % Dietary Fibre | Carbohydrates (mg/100g) | % Starch | Amylose (mg/100 g) | Amylopectin (mg/100 g) |
|---|---|---|---|---|---|---|---|---|
| Local | 3.404 [a] | 0.620 [a] | 3.358 [a] | 1.768 [a] | 69.267 [a] | 69.838 [a] | 27.124 [a] | 42.714 [b] |
| Hybrids | 3.202 [b] | 0.517 [b] | 3.289 [b] | 1.568 [b] | 64.867 [b] | 68.236 [b] | 23.733 [b] | 44.503 [a] |
| Pr > F(Model) | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |
| Significant | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Significant | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Texture

| | Hardness (N) | Cohesiveness | Adhesiveness |
|---|---|---|---|
| Hybrid | 3.473 [a] | 0.577 [a] | -0.745 [a] |
| Local | 3.090 [b] | 0.580 [a] | -0.922 [b] |
| Pr > F(Model) | < 0.0001 | < 0.0001 | < 0.0001 |
| Significant | Yes | Yes | Yes |
| Pr > F(Type) | | | |
| Significant | Yes | Yes | Yes |

| | Phenolics (mg GAE/100g) | Flavonoids (mg CEQ/100g) | Tannins (mg CEQ/100g) | Zn | Ca | Fe | K | Mg | Na |
|---|---|---|---|---|---|---|---|---|---|
| Hybrid | 30.269 [b] | 35.498 [a] | 50.607 [a] | 11.705 [a] | 196.459 [a] | 9.954 [a] | 6962.766 [a] | 953.001 [a] | 46.335 [a] |
| Local | 31.674 [a] | 27.039 [b] | 50.263 [a] | 6.369 [b] | 158.038 [b] | 8.723 [b] | 6652.533 [a] | 751.132 [b] | 47.214 [a] |
| Pr > F(Model) | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | 0.002 | 0.008 | < 0.0001 | < 0.0001 |
| Significant | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Pr > F(Type) | | | | | | | | | |
| Significant | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Obs. = Observations, TA = Titratable acidity, CHO = Carbohydrates (mg/100g), PT = Peel thickness (mm), FN = Finger number, FC = Finger circumference (cm), DF = Dietary Fibre, FL = Finger length (cm)

**APPENDIX II: Summary statistics for ANOVA (Qualitative data for physicochemical data):**

| Variable | Categories | Counts | Frequencies | % |
|---|---|---|---|---|
| Cultivars | 17914S-24 | 3 | 3 | 4.412 |
| | Enzirabahima | 3 | 3 | 4.412 |
| | Kabucuragye | 3 | 3 | 4.412 |
| | Kibuzi | 3 | 3 | 4.412 |
| | M 30 | 3 | 3 | 4.412 |
| | M 32 | 3 | 3 | 4.412 |
| | M 33 | 3 | 3 | 4.412 |
| | M 9 | 3 | 3 | 4.412 |
| | Mbwazirume | 3 | 3 | 4.412 |
| | Mpologoma | 3 | 3 | 4.412 |
| | Muvubo | 3 | 3 | 4.412 |
| | N 11 | 3 | 3 | 4.412 |
| | N 14 | 3 | 3 | 4.412 |
| | N 15 | 3 | 3 | 4.412 |
| | N 17 | 3 | 3 | 4.412 |
| | N 2 | 3 | 3 | 4.412 |
| | N 21 | 3 | 3 | 4.412 |
| | N 24 | 3 | 3 | 4.412 |
| | N 6 | 3 | 3 | 4.412 |
| | N 8 | 2 | 2 | 2.941 |
| | Nakawere | 3 | 3 | 4.412 |
| | Nakitembe | 3 | 3 | 4.412 |
| | Nfuuka | 3 | 3 | 4.412 |

**APPENDIX III: Summary statistics for ANOVA (Quantitative data for minerals and photochemical):**

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| TP | 45 | 0 | 45 | 22.385 | 49.220 | 30.896 | 7.775 |
| TF | 45 | 0 | 45 | 17.340 | 103.404 | 32.340 | 22.483 |
| TT | 45 | 0 | 45 | 46.508 | 55.069 | 50.473 | 2.013 |
| Zn | 45 | 0 | 45 | 0.010 | 25.480 | 9.734 | 5.538 |
| Ca | 45 | 0 | 45 | 2.310 | 394.630 | 183.181 | 83.948 |
| Fe | 45 | 0 | 45 | 0.100 | 13.000 | 9.415 | 2.124 |
| K | 45 | 0 | 45 | 63.460 | 8702.430 | 6796.990 | 1213.238 |
| Mg | 45 | 0 | 45 | 6.790 | 1215.950 | 870.877 | 203.231 |
| Na | 45 | 0 | 45 | 0.400 | 111.050 | 46.610 | 16.445 |

Obs. = Observations, TT = Total tannins (mg CEQ/100g), TP = Total Phenols (mg GAE/100g), TF = Total flavonoids (mg CEQ/100g), Zn = Zinc (mg/100g), Ca = Calcium (mg/100g), Fe = Iron (mg/100g), K = Potassium (mg/100g), Mg = Magnesium (mg/100g) and Na = Sodium (mg/100g)

**APPENDIX IV: Summary statistics for ANOVA (Qualitative data for minerals and phytochemicals):**

| Variable | Categories | Counts | Frequencies | % |
|---|---|---|---|---|
| **Cultivars** | 17914S-24 | 2 | 2 | 4.444 |
| | Enzirabahima | 2 | 2 | 4.444 |
| | Kabucuragye | 2 | 2 | 4.444 |
| | Kibuzi | 2 | 2 | 4.444 |
| | M 30 | 2 | 2 | 4.444 |
| | M 32 | 2 | 2 | 4.444 |
| | M 33 | 2 | 2 | 4.444 |
| | M 9 | 2 | 2 | 4.444 |
| | Mbwazirume | 2 | 2 | 4.444 |
| | Mpologoma | 1 | 1 | 2.222 |
| | Muvubo | 2 | 2 | 4.444 |
| | N 11 | 2 | 2 | 4.444 |
| | N 14 | 2 | 2 | 4.444 |
| | N 15 | 2 | 2 | 4.444 |
| | N 17 | 2 | 2 | 4.444 |
| | N 2 | 2 | 2 | 4.444 |
| | N 21 | 2 | 2 | 4.444 |
| | N 24 | 2 | 2 | 4.444 |
| | N 6 | 2 | 2 | 4.444 |
| | N 8 | 2 | 2 | 4.444 |
| | Nakawere | 2 | 2 | 4.444 |
| | Nakitembe | 2 | 2 | 4.444 |
| | Nfuuka | 2 | 2 | 4.444 |

**APPENDIX V: Summary statistics for PCA (Quantitative data):**

| Variable | Observations | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| Yellow | 20 | 0 | 20 | 0.889 | 9.083 | 6.344 | 2.499 |
| Homogeneity of colour | 20 | 0 | 20 | 1.875 | 9.472 | 6.976 | 2.193 |
| Firmness | 20 | 0 | 20 | 1.667 | 7.556 | 4.302 | 1.694 |
| Moisture | 20 | 0 | 20 | 2.889 | 7.889 | 5.943 | 1.270 |
| Smoothness | 20 | 0 | 20 | 2.333 | 8.778 | 6.463 | 1.671 |
| hardness | 20 | 0 | 20 | 1.556 | 8.222 | 4.206 | 1.944 |
| Moldability | 20 | 0 | 20 | 2.444 | 8.889 | 6.539 | 2.094 |
| Stickiness | 20 | 0 | 20 | 2.556 | 7.222 | 5.141 | 1.192 |
| Sweetness | 20 | 0 | 20 | 0.704 | 4.222 | 2.365 | 0.849 |
| Astringency | 20 | 0 | 20 | 0.667 | 2.889 | 1.604 | 0.548 |
| Sourness | 20 | 0 | 20 | 0.259 | 1.667 | 0.910 | 0.410 |
| Matooke | 20 | 0 | 20 | 2.049 | 7.778 | 5.224 | 1.732 |
| Finger length (cm) | 20 | 0 | 20 | 13.400 | 22.500 | 18.775 | 2.266 |
| Finger circumference (cm) | 20 | 0 | 20 | 11.100 | 21.500 | 13.280 | 2.224 |
| No. of fingers | 20 | 0 | 20 | 8.500 | 22.000 | 17.150 | 3.179 |
| Peel thickness (mm) | 20 | 0 | 20 | 1.810 | 4.415 | 3.115 | 0.734 |
| Pulp:peel | 20 | 0 | 20 | 1.181 | 2.034 | 1.631 | 0.231 |
| pH | 20 | 0 | 20 | 5.500 | 31.300 | 7.028 | 5.717 |
| TSS oBrix | 20 | 0 | 20 | 0.000 | 1.300 | 0.603 | 0.297 |
| Titaratable acidity | 20 | 0 | 20 | 0.090 | 0.173 | 0.123 | 0.023 |
| Dry Matter Raw (%) | 20 | 0 | 20 | 20.863 | 28.091 | 24.570 | 2.311 |
| % Ash | 20 | 0 | 20 | 2.614 | 3.582 | 3.139 | 0.294 |
| % Starch | 20 | 0 | 20 | 63.895 | 74.128 | 68.705 | 2.738 |
| Amylose (mg/100 g) | 20 | 0 | 20 | 9.449 | 25.964 | 20.324 | 3.888 |
| Amylopectin (mg/100 g) | 20 | 0 | 20 | 42.152 | 54.883 | 48.381 | 3.751 |
| Phenolics (mg GAE/100g) | 20 | 0 | 20 | 23.005 | 48.394 | 30.519 | 7.521 |
| Flavonoids (mg CEQ/100g) | 20 | 0 | 20 | 19.255 | 95.745 | 33.186 | 23.837 |
| Tannins (mg CEQ/100g) | 20 | 0 | 20 | 46.855 | 53.681 | 50.043 | 1.686 |
| L | 20 | 0 | 20 | 23.700 | 48.000 | 44.895 | 5.130 |
| a | 20 | 0 | 20 | -16.900 | -9.150 | -14.648 | 1.890 |
| b+ | 20 | 0 | 20 | 20.250 | 33.150 | 29.933 | 2.750 |
| c | 20 | 0 | 20 | 22.200 | 35.550 | 33.390 | 2.899 |
| h | 20 | 0 | 20 | 109.200 | 121.400 | 116.120 | 3.212 |

**APPENDIX VI: Summary statistics (Qualitative data PCA for sensory and physicochemical data):**

| Variable | Categories | Counts | Frequencies | % |
|---|---|---|---|---|
| Q1 | Kibuzi | 1 | 1 | 5.000 |
| | N 2 | 1 | 1 | 5.000 |
| | N 11 | 1 | 1 | 5.000 |
| | N 15 | 1 | 1 | 5.000 |
| | Muvubo | 1 | 1 | 5.000 |
| | N 8 | 1 | 1 | 5.000 |
| | M 32 | 1 | 1 | 5.000 |
| | Nakitembe | 1 | 1 | 5.000 |
| | N 21 | 1 | 1 | 5.000 |
| | N 24 | 1 | 1 | 5.000 |
| | N 17 | 1 | 1 | 5.000 |
| | N 14 | 1 | 1 | 5.000 |
| | Kabucuragye | 1 | 1 | 5.000 |
| | Nakawere | 1 | 1 | 5.000 |
| | 17914S-24 | 1 | 1 | 5.000 |
| | N 6 | 1 | 1 | 5.000 |
| | M 33 | 1 | 1 | 5.000 |
| | M 9 | 1 | 1 | 5.000 |
| | Nfuuka | 1 | 1 | 5.000 |
| | Enzirabahima | 1 | 1 | 5.000 |

**APPENDIX VII: Summary statistics (PCA correlation between mineral elements and phytochemicals):**

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Min | Max | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| TP | 23 | 0 | 23 | 23.005 | 48.394 | 30.828 | 7.752 |
| TF | 23 | 0 | 23 | 17.340 | 95.745 | 32.063 | 22.444 |
| TT | 23 | 0 | 23 | 46.855 | 54.375 | 50.482 | 1.837 |
| Zn | 23 | 0 | 23 | 1.295 | 25.265 | 9.636 | 5.556 |
| Ca | 23 | 0 | 23 | 101.730 | 385.905 | 181.125 | 81.745 |
| Fe | 23 | 0 | 23 | 4.630 | 12.515 | 9.452 | 1.921 |
| K | 23 | 0 | 23 | 3082.940 | 8770.475 | 6829.933 | 1075.642 |
| Mg | 23 | 0 | 23 | 329.040 | 1209.545 | 872.957 | 193.496 |
| Na | 23 | 0 | 23 | 18.275 | 109.185 | 46.567 | 16.025 |

Obs. = Observations, Min = Minimum, Max = Maximum, TT = Total tannins (mg CEQ/100g), TP = Total Phenols (mg GAE/100g), TF = Total flavonoids (mg CEQ/100g), Zn = Zinc (mg/100g), Ca = Calcium (mg/100g), Fe = Iron (mg/100g), K = Potassium (mg/100g), Mg = Magnesium (mg/100g) and Na – Sodium (mg/100g)

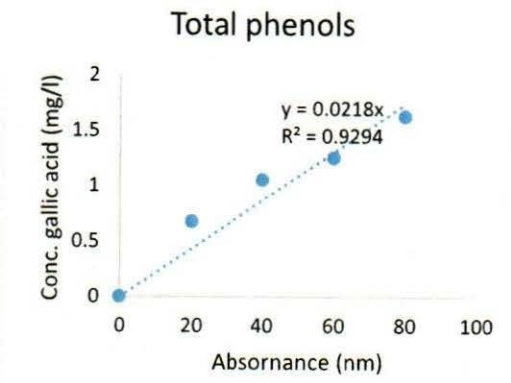
**Correlation matrix (Pearson (n)):**

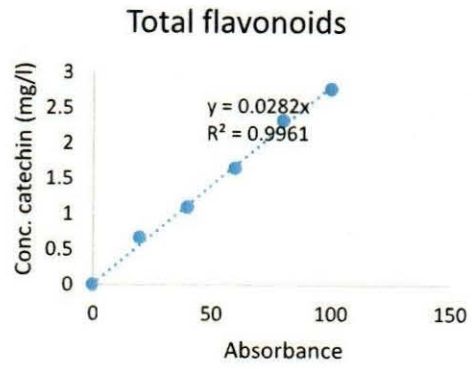
| Variables | TP | TF | TT | Zn | Ca | Fe | K | Mg | Na |
|---|---|---|---|---|---|---|---|---|---|
| TP | 1 | 0.034 | 0.342 | 0.061 | 0.044 | -0.102 | -0.349 | -0.139 | -0.142 |
| TP | 0.034 | 1 | 0.157 | 0.129 | -0.326 | 0.134 | 0.327 | 0.030 | 0.140 |
| TT | 0.342 | 0.157 | 1 | -0.101 | 0.331 | 0.093 | -0.090 | 0.052 | 0.171 |
| Zn | 0.061 | 0.129 | -0.101 | 1 | 0.499 | 0.570 | 0.251 | 0.706 | 0.078 |
| Ca | 0.044 | -0.326 | 0.331 | 0.499 | 1 | 0.483 | -0.038 | 0.458 | 0.047 |
| Fe | -0.102 | 0.134 | 0.093 | 0.570 | 0.483 | 1 | 0.631 | 0.718 | 0.108 |
| K | -0.349 | 0.327 | -0.090 | 0.251 | -0.038 | 0.631 | 1 | 0.542 | 0.466 |
| Mg | -0.139 | 0.030 | 0.052 | 0.706 | 0.458 | 0.718 | 0.542 | 1 | 0.295 |
| Na | -0.142 | 0.140 | 0.171 | 0.078 | 0.047 | 0.108 | 0.466 | 0.295 | 1 |

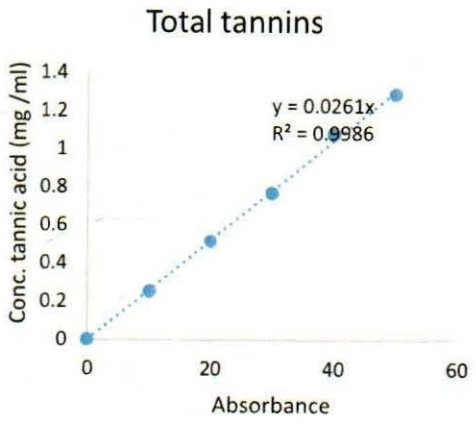
**Eigenvalues:**

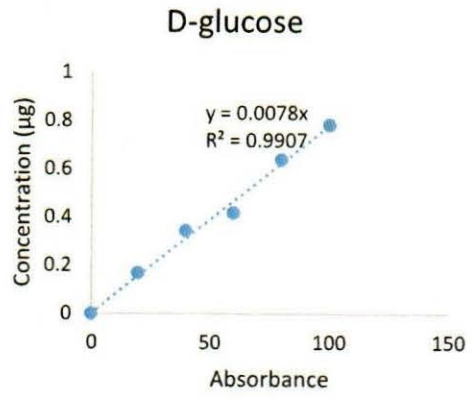
| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
|---|---|---|---|---|---|---|---|---|---|
| Eigenvalue | 3.146 | 1.741 | 1.382 | 1.035 | 0.676 | 0.515 | 0.276 | 0.123 | 0.106 |
| Variability (%) | 34.960 | 19.345 | 15.356 | 11.502 | 7.509 | 5.719 | 3.062 | 1.371 | 1.176 |
| Cumulative % | 34.960 | 54.304 | 69.660 | 81.162 | 88.671 | 94.391 | 97.453 | 98.824 | 100.000 |

APPENDIX VIII: Standard curves

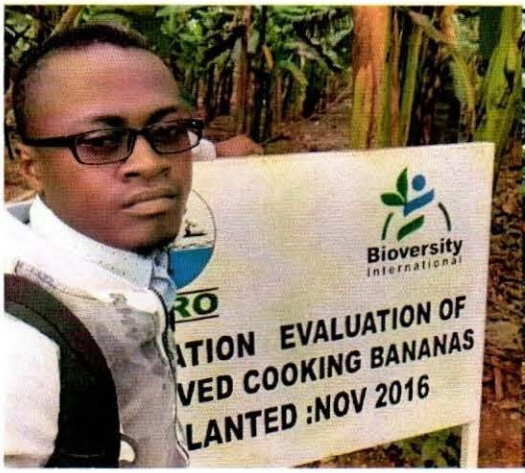


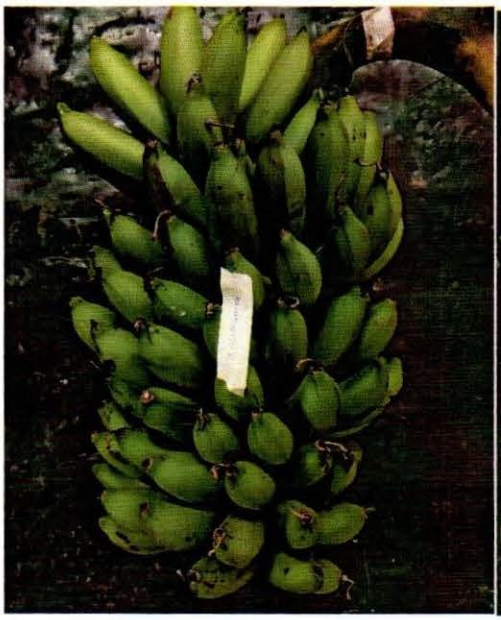



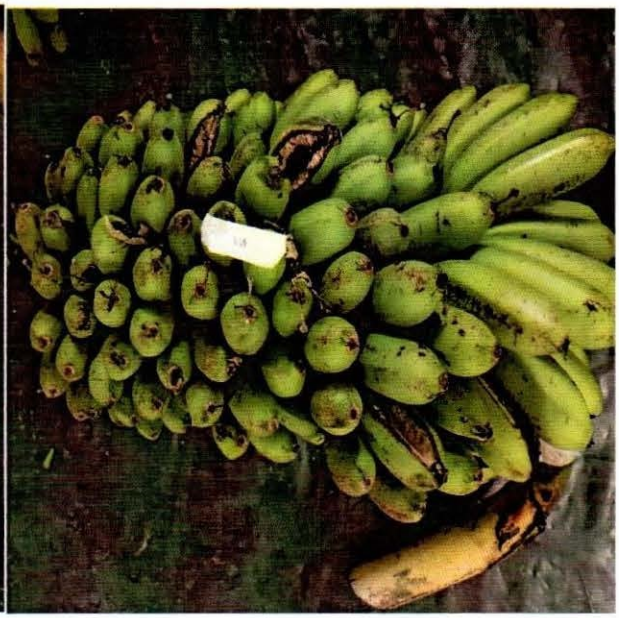



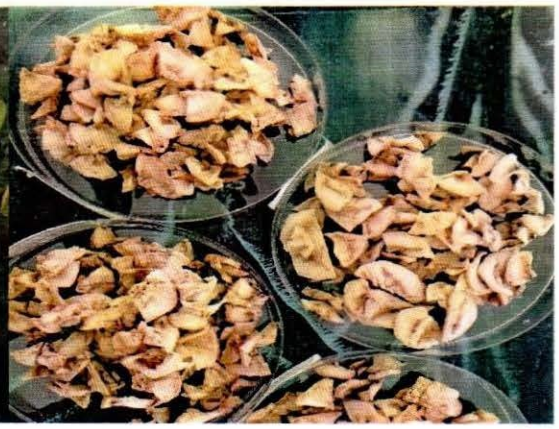
APPENDIX IX: Photographic report

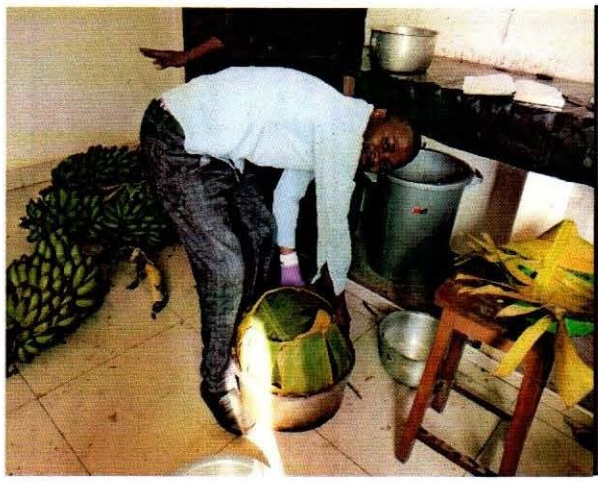


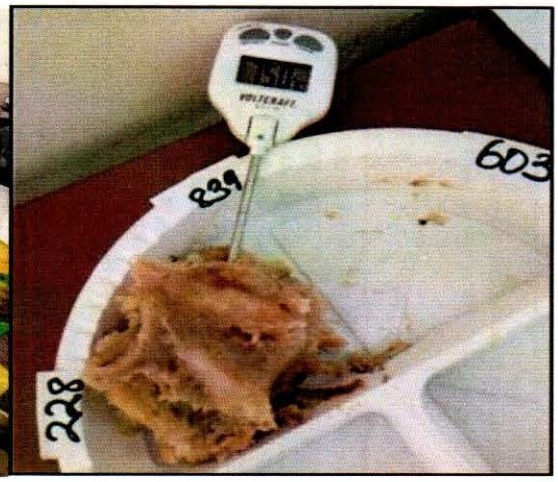


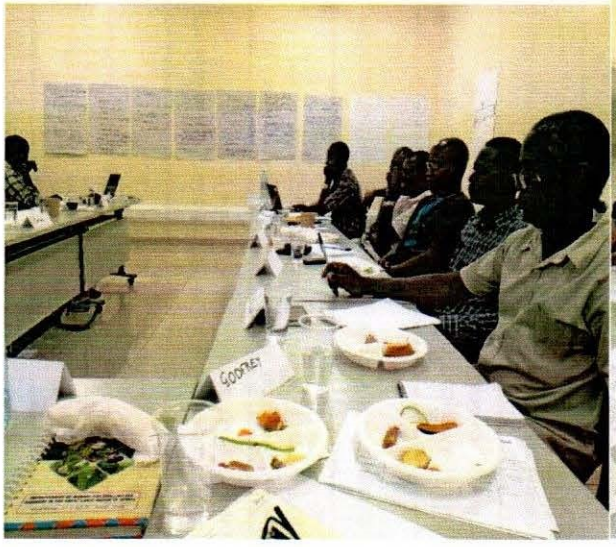


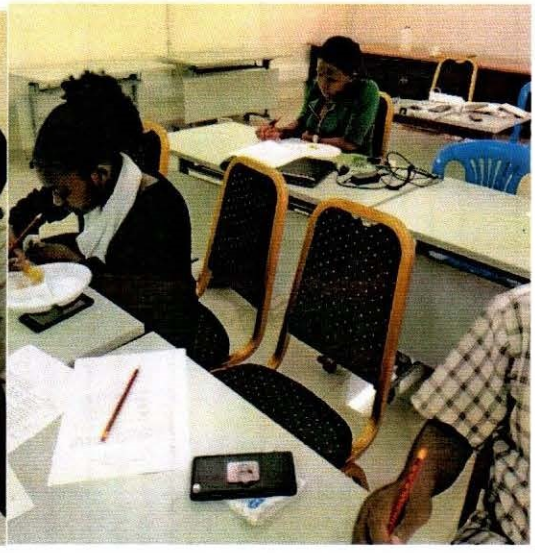


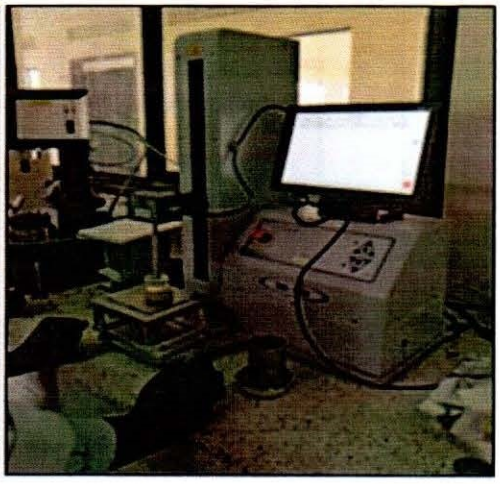





603
839
228


GODFREY





| Type | Attributes | Definition | How to measure? | Scale |
|---|---|---|---|---|
| **Appearance** | Yellow | Color of the surface of the sample from light yellow to bright yellow | When you receive the sample, observe the surface and evaluate the intensity of the color and its homogeneity | 0: very light yellow<br>10:bright yellow |
| | Homogeneity of colour | Uniformity of color of the surface of the sample | | 0 : heterogeneous<br>10 : homogeneous |
| **Texture in mouth** | Firmness | Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of a product. | Put a part of the sample in your mouth, evaluate during the first bite (between molars) how hard the sample is. | 0: soft<br>5 : firm<br>10: hard |
| | Moisture | Perception of moisture content of a food by the tactile receptors in the mouth and also in relation to the lubricating properties of the product | Put a part of the sample in the mouth, chew and evaluate the quantity of water within the sample. | 0: Dry<br>10: Moist |
| | Smoothness | Geometrical textural attribute relating to lack of presence of particles in a product | Put a part of the sample in mouth, chew it and after 5 chews, evaluate between tongue and palate the number and the size of the particles. | 0: lumpy<br>5 : grainy<br>10: smooth |
| **Texture by touch** | hardness | Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of a product. | Take a part of the sample between fingers and evaluate how hard the sample is | 0: soft<br>5 : firm<br>10: hard |
| | Moldability | Mechanical textural attribute relating to the degree to which a substance can be deformed before it breaks | Try to make a ball (agglomerate) of the sample and evaluate how easy it is to deform or break the sample | 0: crumbly<br>10: moldable |
| | Stickiness | Mechanical textural attribute relating to the force required to remove material that sticks to the mouth | Put a part of the sample between thumb and index fingers and using tapping motions, evaluate the amount of product adhering on them | 0: non sticky<br>10: sticky |
| **Taste** | Sweetness | Basic taste produced by dilute aqueous solutions of natural or artificial substances such as sucrose | Put a part of the sample in the mouth and evaluate the intensity of taste of sugar | 0 : no intensity<br>5 : medium intensity<br>10 : high intensity |
| **Impression** | Astringency | Complex sensation, accompanied by shrinking, drawing or puckering of the skin or mucosal surface in the mouth, produced by substances such as kaki tannins or sloe tannins | Put a part of the sample in the mouth and evaluate the intensity of astringency impression due to the sample | 0 : low intensity<br>5 : medium intensity<br>10 : high intensity |
| | Sourness | Gustatory complex sensation, generally due to presence of organic acids | Put a part of the sample in the mouth and evaluate the intensity of the sourness | 0 : low intensity<br>5 : medium intensity<br>10 : high intensity |
| **Aroma** | Matooke | Aroma of the local matooke | Put a part of the product and by retro-olfaction evaluate the presence and the intensity of this specific aromas | 0 : no intensity<br>5 : medium intensity<br>10 : high intensity |
| | Pumpkin | Aroma of pumpkin | | YES/NO |
| | Grassy | Aroma of fresh grass | | YES/NO |