EVALUATING THE POTENTIAL OF PUREED FRESH GREEN MATURE BANANAS AS A FUNCTIONAL INGREDIENT FOR PRODUCTION OF BREAD

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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

AUGUST 2021

DECLARATION

I, Nankya Norah (Reg. No. 18/U/GMFT/19495/PD), declare that this dissertation is original work and has never been submitted to any University or Institution of Higher Learning for any academic award.

Signed..

Date....24/08/2021....................................

APPROVAL

This is to certify that Norah Nankya wrote this dissertation titled "Evaluating the potential of pureed fresh green mature bananas as a functional ingredient for production of bread" under our supervision. We approve the submission of the dissertation for the award of the degree of Master of Science in Food Technology.

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To my family for their continued support in my professional and social life.

ACKNOWLEDGEMENT

My sincere thanks go to God the Almighty who has generously gifted me with knowledge, wisdom, financial and emotional support to get to this point of the research process. I am grateful to my supervisors Dr. Khadijah Nakyinsige and Assoc. Prof. Ediriisa Mugampoza who were selflessly supervising me for timely accomplishment of my Masters' degree. Their technical guidance, encouragement, and constructive reproach enabled me complete this dissertation. This dissertation would not have been written if it was not for them. Special thanks also go to classmates Kamukama Liberty and Willy Nelson Kisenyi for their encouragement during the trying moments of the course. May God richly bless you. This work was partially funded by Kyambogo University Business Incubation Centre for which I am indeed very grateful.

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List of Abbreviations

ANOVA	Analysis of variance
FAO	Food and Agriculture Organization of the United Nations
N23	Banana hybrids developed by NARO for good agronomic attributes
NARO	National Agricultural Research Organization
PCA	Principal component analysis
Prmax	Maximum resistance to pressure/deformation
RS	Resistant starch
UBOS	Uganda Bureau of Statistics
WAC	Water absorption capacity

ABSTRACT

The nutritional value of green mature cooking bananas is mainly attributed to their resistant starch and dietary fibre content. This study aimed at developing bread using a composite mixture of wheat (70%) and pureed fresh green mature cooking bananas (30%) purposely to enhance its health benefits attributable to improved resistant starch and dietary fibre content, and to reduce postharvest banana losses which currently stand at 40% in Uganda.

Eight treatments of wheat-banana composite bread were formulated as: (1) pureed fresh whole *Mpologoma* fingers, (2) pureed fresh *Mpologoma* pulp, (3) whole *Mpologoma* flour, (4) *Mpologoma* pulp flour, (5) pureed fresh whole N23 fingers, (6) pureed fresh N23 pulp, (7) whole N23 flour and (8) N23 pulp flour. Bread made from 100% wheat was used as the control. Alveograph and consistograph properties for each of the composite doughs were determined. Resultant bread was baked using the straight dough method, and analysed for physical attributes, as well as moisture, resistant starch and dietary fibre content using standard methods. All bread samples were assessed for sensory acceptability on a 9-point hedonic scale using 30 untrained panellists. The effect of addition of different forms (pureed fresh vs flour) and varieties of bananas on dough rheology and bread quality characteristics was evaluated by principal component analysis using XLSTAT software.

Addition of pureed fresh and/or powdered bananas increased the mixing time required to reach maximum dough consistency. *Mpologoma* variety mostly increased the water absorption capacity of the composite mixture in pureed fresh and flour forms compared with other treatments, as it increased the amount of water needed for optimum dough production. Addition of bananas to wheat flour also reduced resistance to deformation (prmax) resulting in poor dough handling behaviour and low dough tolerance in the fermentation stage. Whereas all composite doughs generally had poor alveograph profiles suggesting low potential for using bananas in bread production, *Mpologoma* pureed fresh whole fingers had better rheological properties than all other composite samples highlighting its potential for application in the bread making process up to a (30%) substitution level. Additionally, dough samples containing bananas exhibited lower baking strength and resistance to mechanical mixing compared to the control indicating that the former were weaker doughs.

The general appearance of bread obtained from banana-wheat composite doughs was appealing and comparable to that of the wheat alone control. High-quality bread was obtained from each of the treatments including pureed fresh or flour, whole fingers or pulp and different varieties which was contrary to alveographic and consistographic prediction data. Loaf volume ranged from 1137.97 cm^3 to 1410.00 cm^3 in samples formulated from 30% N23 pureed fresh pulp and 30% N23 pureed fresh whole fingers, respectively. There was general increase in baking loss for bread formulated with banana flour compared with that made using pureed fresh bananas. Bread samples containing 30% *Mpologoma* pureed fresh pulp had the highest cross-sectional area while that from 30% N23 hybrid whole finger flour had the lowest. Loaf weight was highest in the 30% *Mpologoma* pulp flour (613.50 g), and lowest in the sample containing 30% N23 whole finger flour (544.00 g). Crust and crumb browning increased with the addition of 30% bananas in comparison to the control. Composite bread exhibited reduced hardness, cohesiveness and adhesiveness compared to the control. Bread formulated using *Mpologoma* had highest moisture content while that made using N23 hybrid had the lowest. Overall, *Mpologoma* variety had higher contribution to resistant starch of the bread than the N23 hybrid, irrespective of pureed fresh or flour forms. Bread formulated from whole bananas had higher dietary fibre content than that made from banana pulp. *Mpologoma* whole fingers had the highest contribution to dietary fibre content of bread compared to all other treatments. Addition of bananas caused significant decrease in the sensory quality attributes of the composite breads compared to the control. Interestingly, bread made from 50% pureed fresh *Mpologoma* whole fingers was more appreciated for its general appearance close to that of the control. The blend of 30% *Mpologoma* pulp flour was most appreciated for colour. Bread texture generally hardened whereas flavour and taste decreased with the addition of bananas. It was therefore concluded that *Mpologoma* and N23 bananas could be added at a rate of 30-50% in pureed fresh or flour forms to formulate bread with high resistant starch and dietary fibre content. Addition of 30% banana pulp flour produced the best composite bread in terms of taste and flavour, irrespective of variety, and could have better prospects for commercial application compared with other treatments.

CHAPTER ONE: INTRODUTION

1.1 Background

Bread is a fermented wheat-based product made by mixing basic ingredients; water, wheat flour, yeast, and salt (Ndife et al., 2011). Bread consumption has continuously increased in many developing countries due to changing eating habits, steadily growing population, good taste and convenience (Noorfarahzilah et al., 2014). Bread is consumed by about 65% of Ugandans in urban settings and 31% of people in rural areas as a breakfast snack, in sandwiches and other culinary preparations (Anna et al., 2014).

Bananas are the world's fourth dietary staple food and most important agricultural commodity after corn, rice and wheat (Subbaiah et al, 2013; Sarawong et al., 2014a). Uganda is the highest producer of cooking bananas in Africa and ranks 2nd in the world after India (UBOS, 2010). Uganda produces approximately 10.5 million metric tons of plantains, 0.5 million metric tons of dessert bananas and 4.34 million metric tons of cooking bananas (FAO, 2019). Green mature bananas contain high levels of starch (22%) and low levels of natural sugars (1%), proteins (less than 1%) and lipids (0.15 to 0.58%) (Hapi et al., 2007; Gafuma, 2018). The banana fruit is also rich in vitamins A, B1, B2 and C (Balwinder et al., 2016) and alkali-forming essential minerals such as potassium, magnesium, calcium and sodium (Aurore et al., 2009; Chong & Noor, 2010).

Thus, the health benefits of green mature bananas are largely attributed to their high content of carbohydrates consisting of resistant starch, fiber, hemicellulose and pectin (Fasolin et al., 2007; Happi et al., 2007; Aurore et al., 2009; Ovando-Martinez et al., 2009). Resistant starch in processed and raw food materials has attracted a lot of research interest because of its positive effects in the human colon and improvements on health (Fuentes-Zaragoza et al., 2011). Resistant starch is defined by the Flair Concentrated Action of Resistant Starch (EURESTA) as the sum of starch and products of starch degradation not absorbed in the small intestine (Asp & Bjork, 1992). Resistant starch has reduced caloric content and possesses characteristic physiological properties that improve lipid and cholesterol metabolism and reduce the risks of colorectal cancer, coronary heart disease, type II diabetes and other diseases (Fuentes-Zaragoza et al., 2011). Resistant starches are not digested in the human small intestine but are fermented by bacteria or microbiota in the gut or large bowel, which promotes the generation of short chain fatty acids that can lower the gut pH and consequently reduce the formation of cancerous tumors (Asp & Bjork, 1992).

Like resistant starch, dietary fibers are edible portions of food plants which are resistant to digestion and absorption in the small intestine, with complete or partial fermentation in the gut (Gallaher & Schneeman 2001). Dietary fiber is also a suitable substrate for bacterial fermentation in the colon, which helps to maintain its structure and proper function (Drzikova et al., 2005). Dietary fiber consists of cellulose, hemicellulose, lignin, pectin, β-glucans and gums that can retain water and swell slightly, preventing digestion and absorption of toxic substances in the intestine (Brown et al., 1999; Figuerola et al., 2005; Gallaher & Schneeman, 2001). High dietary fiber intake improves physiological and metabolic functions of the body (Champ & Guillon, 2000; Drzikova et al., 2005). Dietary fiber also buffers acid in the stomach, increases faecal softness, faecal bulk, water binding capacity, organic binding capacity, stimulates intestinal evacuation, reduces intestinal transit time and binds diverse substances including cholesterol all of which enhance removal of stagnant or potentially detrimental materials from the bowels (Lattimer & Haub, 2010; Dhingra et al., 2012). Together with resistant starch, dietary fiber also provides a favorable environment for growth of intestinal flora and increases intestinal microbial fermentation thereby enhancing colon health (Jenkins et al., 1998; Jiménez-Escrig & Sánchez-Muniz, 2000; AACC, 2001b). These properties have been reported to play an important role in the prevention and treatment of obesity, atherosclerosis, coronary heart disease, colorectal cancer and diabetes (Jenkins et al., 1998).

There is a need for innovations involving processing of fresh green mature bananas into value-added products such as bread and confections in order to enhance the health benefits of banana due to its improved composition of functional ingredients including resistant starch and dietary fiber (Ovando-Martinez et al., 2009; Ramli et al., 2010). Use of fresh green mature bananas in bread production could also reduce postharvest banana losses which currently stand at 40% in Uganda (Bezerra et al., 2013). Gafuma (2018) highlighted that fresh green mature cooking bananas in Uganda are high in starch (4 to 15.2%; of which 38-68% is resistant starch), and could, therefore, potentially be used to formulate cheaper functional bread which is high in resistant starch. Moreover, the banana peel largely contains fiber and, could be a potential source of dietary fiber in functional breads.

Although bananas have limited application in bread formulation due to lack of gluten (Al-mussali & Al-gahri, 2009), they have been previously composited with wheat flour for production of bread (Shittu et al. 2014), cakes and pasta. Wheat composite breads have also been successfully produced from other crops that lack gluten such as corn (Siddiq et al., 2009), cassava (Shittu et al., 2007), guava (Castelo-Branco et al., 2016), sorghum, chickpea (Mariera, 2018), barley, oat (Rieder et al., 2012), yam (Amandikwa et al., 2015), malted rice (Veluppillai et al., 2010) and pumpkin (Wongsagonsup et al., 2015) at non-wheat inclusion levels of 5-75%.

The effect of green mature banana flour to bread quality (Pacheco-Delahaye & Testa, 2005; Juarez-Garcia et al., 2006; Muranga et al., 2010; Zuleta et al., 2012) and green mature bananas with their peels as a raw material for bread making (Garzón et al., 2011; Gomes et al., 2016) has been previously investigated. However, little is known about prospects of Ugandan cooking banana varieties in production of bread with high resistant starch and dietary fiber content. This study aimed at developing bread with high resistant starch and dietary fiber content using pureed fresh green mature bananas and wheat composite mixture.

1.2 Problem statement and justification

Cooking bananas are the main staple food in Uganda grown on approximately 40% of the total arable land by 75% of the country's farmers (Ariho et al., 2015). Despite its high domestic production, the crop is highly perishable amidst underutilization as a staple food and animal feed leading to 22 to 45% postharvest losses (Muranga et al., 2010). This therefore creates a gap for value addition of cooking bananas to reduce their postharvest losses.

One of the possible uses of fresh green mature bananas could be their application in formulation of composite bakery products such as bread to reduce production costs, and the proportion of wheat in bread for gluten intolerant persons (Muranga et al., 2010; Aziah et al., 2012; Gomes et al., 2016; Gafuma, 2018). The banana-based composite bread could also have high potential to enhance the nutritional quality of the product since fresh green mature cooking bananas are a good source of resistant starch (Gafuma, 2018) and dietary fiber, which could be added in different food products (Cummings et al., 1996).

Cooking bananas are used for production of thermally stable resistant starch III (up to 84% yield upon retrogradation) at about 145°C (Lehmann et al., 2002). Retrograded resistant starch III produces short-chain fatty acids with a high proportion of butyrate upon fermentation by intestinal microflora such as *Eubacteria* (Sharp & Macfarlane, 2000). Butyrate is a substrate and signal metabolite for activation of proliferation of probiotic microbes in the gut (Velazquez & Lederer, 1996; Sharp & Macfarlane, 2000). Thus, the bananas could be incorporated in bakery products to boost their resistant starch III content in order to enhance the above probiotic functions.

There is limited information on application of fresh green mature bananas for supplementation of resistant starch in bakery products in Uganda. In this study, *Mpologoma*, an indigenous cooking banana variety and N23 a hybrid variety with similar agronomic attributes to the latter but has low consumer acceptability were selected due to their high resistant starch content (68%) (Gafuma, 2018; Kisenyi, 2020) and high bunch weight indicating their potential for high product yield. Until this study, *Mpologoma* and N23 varieties have been mainly consumed in fresh form as cooking bananas; they are therefore prone to postharvest losses. Fresh green mature bananas have been used to a limited extent as a source of resistant starch III which is poorly degraded to short chain fatty acids by intestinal microflora (Englyst, & Cummings, 1986; Faisant et al., 1995). This study therefore, aimed at exploiting pureed fresh green mature bananas as a functional ingredient for the production of bread.

1.3 Significance of the study

East African Highland bananas are the main staple food in Uganda contributing to food security in the country. However, because of the crop's perishability, much of these fruits are lost especially in peak harvest seasons leading to postharvest losses due to underutilization in value-added food products. Partial substitution of wheat with fresh green mature bananas would not only improve the functional properties of bread such as boosting its resistant starch III content but could also reduce the production cost of bread since most of the wheat used in Uganda is imported. Flour and water are the most important ingredients in a bread recipe as they affect the crumb structure and texture, volume, weight, chemical composition and sensory attributes (Zanon & Peri, 1993; Dowell et al., 2008). The ideal flour for bread making is wheat due to its gluten content which contributes to the structure and texture of the product. However, in Uganda, wheat is expensive because most of it is imported making bread production costly.

Results will inform food processers of the available opportunity to exploit Ugandan fresh green mature cooking bananas for the production of functional composite bread. Consequently, this will not only reduce postharvest banana losses in Uganda but also lower the cost of bread production.

1.4 Objectives of the study

1.4.1 General objective

To evaluate the potential of pureed fresh green mature bananas as a functional ingredient for production of bread.

1.4.2 Specific objectives

1. To evaluate the rheological properties (mixing time, water absorption, elasticity, extensibility, baking strength and mixing stability) of the banana-wheat composite dough.
2. To determine the chemical (moisture, resistant starch and dietary fiber content) and physical (loaf volume, loaf weight, baking loss, cross sectional area, colour of crust & crumb and texture) properties of the banana-wheat composite bread.
3. To determine the sensory acceptability (appearance, colour, flavor, taste, texture and general acceptability) of the banana-wheat composite bread.

1.5 Hypotheses

1. There is no difference in rheological properties of the dough obtained from banana-wheat composite mixture and that of the wheat alone control.
2. There is no difference in chemical and physical properties of bread produced from banana-wheat composite mixture and that of the wheat alone control.
3. There is no difference in sensory properties of bread produced from banana-wheat composite mixture and that of the wheat alone control.

CHAPTER TWO: LITERATURE REVIEW

2. Botanical description and production of bananas

Bananas and plantain (*Musa* spp.) are monocotyledonous flowering plants belonging to the genus *Musa* that produces edible fruits known as fingers grouped into clusters (Karamura et al., 1998). Bananas are an important food crop worldwide and are considered as the fourth most important food crop globally after rice, wheat, and maize (Tripathi et al., 2007). It is an instrumental food and crop in more than 135 countries in tropical and subtropical regions of the world (Brown et al., 2017). The annual global production of bananas is estimated at 166.79 million metric tons with India as the leading producer accounting for 27% of the global production (FAO, 2019). East African region produces 20 million tons of bananas annually and this contributes to about a fifth of total calorie consumption per capita in the region (Tumuhimbise et al., 2016).

Uganda is the second leading producer of bananas in the world where different cultivars of the crop are grown mainly for food consumption with an annual output of 9.84 million tonnes accounting for 11.18% of the world's total production and a total per capita consumption ranging 250 kg to 480 kg in Uganda (Kabahenda & Kapiriri, 2010). In Uganda, bananas are mainly produced in Central and Western regions of the country mainly as a food and cash crop (Komarek, 2010). The main types grown have been categorised as cooking bananas (*Musakala*,*Nakabululu*, *Nakitembe*, and *Nfuuka* clone sets, roasting bananas (*Gonja*), sweet bananas (*Ndiizi* and *Bogoya*) and brewing bananas (*Kisubi* and *Mbidde*) (Karamura et al., 1998; Nyombi, 2013; Byarugaba et al., 2014).

2.2 Consumption and value addition of bananas

Consumption of bananas in Uganda is mainly determined by the type of the bananas and they have been grouped into four main types depending on usage as dessert, beer, roasting and cooking bananas (Karamura et al., 1998). Cooking bananas are the main staple food in most parts of the country and they are steamed in banana leaves, pressed and simmered to make a paste locally known as *Matooke* (Karamura et al., 1998). Sometimes the fingers are just boiled with a source to make a local delicacy called *Katogo*. Examples of cooking bananas include *Kibuzi*, *Nakitembe*, and *Kabucuragye* among others. Dessert bananas are ripened and eaten raw at full ripeness characterized by a yellow peel colour and attractive sweet flour and they include *Ndizi* and *Bogoya*. Local brew (*Tonto*), wines and juices are usually made from the beer bananas such as *Kayinja*, *Kisubi* and *Musa*) which are ripened after harvest and used for juice extraction (Simmonds, 2007). The juice can be fermented for production of *Tonto* in the central region of the country. *Kisubi* (AB) is an example of a beer banana. Roasting bananas (plantain) are mainly consumed along highways and are locally known as *Gonja*. They are harvested at green maturity, ripened and roasted for consumption (Simmonds, 2007).

Bananas are perishable crops therefore, there is a need to process then into different shelf stable products. Different value-added products are produced from bananas and these include beverages such as local brew (*Tonto*), banana wine, & juice, banana soup & porridge and snacks such as banana biscuits, pan cakes, and chips.

Banana juice and wine are mainly produced from over ripe bananas due to their high sugar content needed for the taste of the juice and as food to the fermentative yeasts to produce alcohol needed for the taste of the wines. Banana beer is made from ripe beer bananas which are extracted for their juice under a wooden drum using the feet. Sprouted sorghum is added and the juice is fermented to produce a weak hazy beer called *Ntonto* (Simmonds, 2007).

Bread is also made from raw banana flour fortified with vital gluten (Muranga et al., 2010). Pan cakes are made from mashed dessert bananas blended with cassava flour to make a paste. The paste is shaped into cylindrically shaped cookie-like products that are then deep fried to the golden colour of pan cakes. To make banana cakes, ripe dessert bananas are mashed into a paste. Wheat flour, baking powder, sugar, and eggs are added while mixing. The cake may be flavored and the batter is baked in greased tins.

Banana flour is obtained from any cultivar of the processor's choice and has been commercially utilized for the production of banana-based products such as cookies and bread. The unripe green mature bananas are peeled, sliced, dried and milled into flour. Banana chips are preferably made from *Gonja* or *Ndizi* due to their sweet taste. The desert banana is peeled, sliced into cylindrical slices and deep-fried to a golden colour then packed.

2.3 Banana breeding in Uganda

Due to environmental and biotic factors such as drought & low soil fertility and pests & diseases causing high banana field losses, National Agricultural Research Organization (NARO) and its partners such as International Institute of Tropical Agriculture (IITA) have bred hybrid bananas such as NARITA 23, NARITA 14, NARITA 21, NARITA 7 which are resistant to pests and diseases (Tumuhimbise et al., 2016).

The breeding program focusses on enhancing yield characteristics, abiotic stress resistance, biotic stress resistance, post-harvest characters and market attributes (Heslop-Harrison, 2011). Banana breeding using convention methods that use genetic maps and DNA markers to identify useful genes, combine desirable traits or resistance genes and accelerate selection (Heslop-Harrison, 2011). The process begins with cross pollination of the susceptible female fertile banana clones with improved disease resistant diploid male parents (Janick, 1996). The resultant hybrids usually have host resistance to banana pests & diseases and have better agronomical yields (Simmonds, 2007; Tumuhimbise et al., 2016). However, some of them such as N23, FHIA 03 and N21 have low consumer acceptability due to poor eating qualities despite their high bunch yields and therefore could be rejected as food crops (Ssemwanga et al., 2000; Nowakunda et al., 2015; Tumuhimbise et al., 2016). Therefore, the use of such high yielding and disease resistant hybrid bananas for production of composite breads would add value to hybrid bananas with poor eating qualities as well as reducing postharvest losses of bananas in Uganda.

2.4 Nutrient composition of bananas

Bananas are a good source of nutrients such as resistant starch, proteins, vitamins, dietary fiber and minerals (Ohizua et al., 2017). Carbohydrates particularly starch are the principal nutrient in bananas on dry matter basis, comprising of both resistant starch and non-starches responsible for the dietary fiber component (Ovando-Martinez et al., 2009). Resistant starch is indigestible in the human gut hence contributing to the dietary fiber content of the bananas while non-resistant starch has a low glycemic index yielding less sugars on digestion making it ideal for victims of diabetes mellitus (Menezes et al., 2011). Due to a high carbohydrates content, bananas are a rich source of energy ranging 67 to 137 cal/100g fruit (Ohizua et al., 2017). Bananas contain low amounts of fats (below 1%) and proteins (3.8 to 4.2%) therefore addition of bananas to wheat flour would complement the fat and protein content of the banana flour in the final composite bread since wheat is rich in proteins and fat (Ohizua et al., 2017).

There are substantial amounts of minerals such as potassium, magnesium, calcium and phosphorus in the banana pulp which can supplement the mineral content of wheat flour in banana-wheat composite breads (Ohizua et al., 2017). Minerals are needed for enhancing enzyme activity, protection of cells against free radical attack and in osmoregulation in the body. Bananas are also a rich source of phytochemical compounds including phenols, flavonoids, vitamin C, A, B_6, and

B_{12} with antioxidant potential against free radicals in the body as well as regulation of blood sugar levels and therefore can go well with wheat breads since most of the breads on the Ugandan market are made from refined wheat flour hence yielding a lot of sugars on digestion (Ohizua et al., 2017). Table 1 below shows the proximate composition of bananas.

Table 1. Nutrient composition (g/100 g) of bananas

Variety	Moisture	Protein		Carbohydrate	Fat Ash	Fibre	Reference
EAHB	75-80	0.6-1.3	13.5-18.6	0.05-1.6	3.1-3.8	0.7-2.9	Dotto et al. (2019)
EAHB	65-75	0.6-1.8	22-30	0.09-0.53	0.7-1.5	0.9-2.8	Dotto et al. (2019)
EAHB	7.8-9.6	0.9-1.4	84-86	1.04-1.24	1.3-2.0	2.1-2.9	Dotto et al. (2019)
EAHB	10-30	1.1-4.7	16.1-80	0.40-4.20	2.4-11.7	6.0-7.5	Dotto et al. (2018)
Hybrids	53-75	2.5-3.4	-	0.00-0.30	2.0-2.9	4.0-6.7	Annor et al. (2016)
Hybrids: FHIA03, FHIA19, FHIA20 and Apantu pa	53-75	2.5-3.1	-	0.00-0.20	2.0-3.1	3.9-6.7	Annor et al. (2016)

2.5 Bread ingredients and their functional roles in baking

2.5.1 Wheat flour

There are two types of wheat flour which include strong and weak flour. Strong flour is made from hard wheat varieties and contains more gluten than other types of flour which gives it its elasticity and enables the dough to rise with good structure (Belton, 1999). Weak flour or soft flour which is often divided into cake and pastry flour (Bennion & Bamford, 1997). It is low in gluten and gives products a finer texture than baked goods made with hard flour (Belton, 1999). Wheat flour consist of gluten protein comprising of two functional units of gliadins and glutenin (Wieser, 2007). Glutenin is an aggregated protein occurring in amounts of 20 to 40 mg/g of wheat and has molecular weight ranging 500,000 to more than 10 million (Wieser, 2007). Glutenin influences the elasticity, consistency and baking volume of the dough (Belton, 1999; Wieser, 2007). On the other hand, gliadin is a low molecular weight polymer (molecular weights are between 28,000 and 55,000) and contributes to the softness of the dough hence responsible for the viscosity and extensibility of the dough (Khatkar et al., 1995). Therefore, during the addition of fresh bananas and banana flour to obtain a wheat composite mixture, caution must be taken on the extensibility, elasticity and consistence of the dough to balance the elasticity and viscosity of the composite dough.

2.5.2 Yeast

Yeast cells particularly *Saccharomyces cerevisiae* commonly known as baker’s yeast breakdown the sugars into alcohol, carbon dioxide and organic acids which contributes to the flavor of bread (Ali, Shehzad, Khan, Shabbir, & Amjid, 2012). As the carbon dioxide escapes, it pushes the gluten network and as a result of the viscoelastic properties of the dough, this results into increase in bread volume which sets during bread baking (Zanoni & Peri, 1993).

2.5.3 Common salt/sodium chloride

Salt control yeast fermentation, toughens the dough by interacting with gluten making it less sticky, extends dough development and mixing time, improves elasticity and extensibility, enhances the dough mixing tolerance and increases the dough resistance to deformation (Maforimbo et al., 2007).

2.5.4 Fats and oils

Fats and oils shorten the gluten strands resulting into a tender texture, moist mouth feel, color and enhanced flavor in baked products (Brooker, 1996). Shortenings also influence the sensory properties of baked goods by improving the oven spring, increasing loaf volume, contributing to softer crumb with less crisp crust and better shelf life of the bread (Zanoni & Peri, 1993).

2.5.5 Sugar

Sucrose is the commonly used sugar in bread making and it provides the initial glucose and fructose for growth of yeasts and also acts as an anti-staling ingredient inhibiting starch recrystallization (Gerrard, Every, Sutton, & Gilpin, 1997). Due to its osmotic potential, sugar binds water contributing to the moistness of the bread prolonging its freshness (Ali, Shehzad, Khan, Shabbir, & Amjid, 2012). Upon heating above its melting point, sugars undergo caramelization and react with proteins in presence of moisture contributing to non-enzymatic browning of breads and an attractive aroma (Zanoni & Peri, 1993).

2.5.6 Water

Water is used for hydrating the powdered ingredients such as flour, sugar, yeast and salt during bread making (Schiraldi, & Fessas, 2012). It is a solvent for dispersion of baking ingredients and the amount of water added to the flour depends on the flour quality in terms of amounts of damaged starch in the flour (Zeleznak & Hoseney, 1986). During fermentation, carbon dioxide produced dissolves in water forming carbonic acid that provides a favorable pH medium for action of gluten enzymes and yeasts as well as strengthening the gluten network (Schiraldi, & Fessas, 2012). Starch and proteins absorb water and undergo gelatinization and denaturation respectively, resulting into an extensive dough easy to mold into bread loaves with enhanced volumes (Zeleznak & Hoseney, 1986). If too little water is added to the dough, the dough becomes firm and difficult to mould producing a small loaf while if a lot of water is added, a softer dough results producing heavier and excessively soft breads with poor texture (Schiraldi, & Fessas, 2012).

2.6 Principles of bread production

Bread is commonly made by the straight dough method (Figure 1) as described by Greene & Bovell-Banjamin (2004). The process involves sieving of flour to remove any coarse particle & impurities and to make the flour more aerated and homogenous (Dobraszczyk& Morgenstern, 2003). The ingredients including flour, sugar, salt, yeast, calcium propionate, fat and water are weighed Fand transferred into a mixer (Rosell, 2011). Water is added to hydrate the dry ingredients and the dough is mechanically kneaded to develop the gluten network. During mixing the ingredients are uniformly blended and hydrated (Dobraszczyk& Morgenstern, 2003). Dough development also takes place. The dough is then divided, weighed and knocked back by manually punching and hitting it against work tables to facilitate the development of gluten networks through stretching and folding (Rosell, 2011). The process also introduces atmospheric oxygen into the dough which stimulates yeast activity and increases gas retaining capacity of the dough (Greene & Bovell-Banjamin, 2004). The dough is then rounded to facilitate the development of a continuous matrix which increases gas retention in the dough and also reduces its stickiness making it easier to handle (Rosell, 2011). This unit operation is followed by sheeting or flattening of the dough for degassing and to make it easier to manipulate during the subsequent curling/ rolling into a cylindrical shape (Dobraszczyk & Morgenstern, 2003).

The molded dough pieces are immediately placed in greased baking pans and allowed to ferment inside a proofer where the bread dough raises to double its initial volume under humid conditions of 85% relative humidity for about 45 min (Rosell, 2011). During proofing the yeast ferments the carbohydrates producing carbon dioxide and ethanol. The carbon dioxide causes leavening of the dough that results in the dough increasing in volume (Greene & Bovell-Banjamin, 2004). The high relative humidity during proofing prevents excessive water loss and also contributes to maintaining the dough surface wet and flexible such that the dough can expand without the skin tearing. The bread is then baked in an oven at 200^{o}C for 30 min and then cooled on cooling racks for overnight before slicing (Dobraszczyk & Morgenstern, 2003).

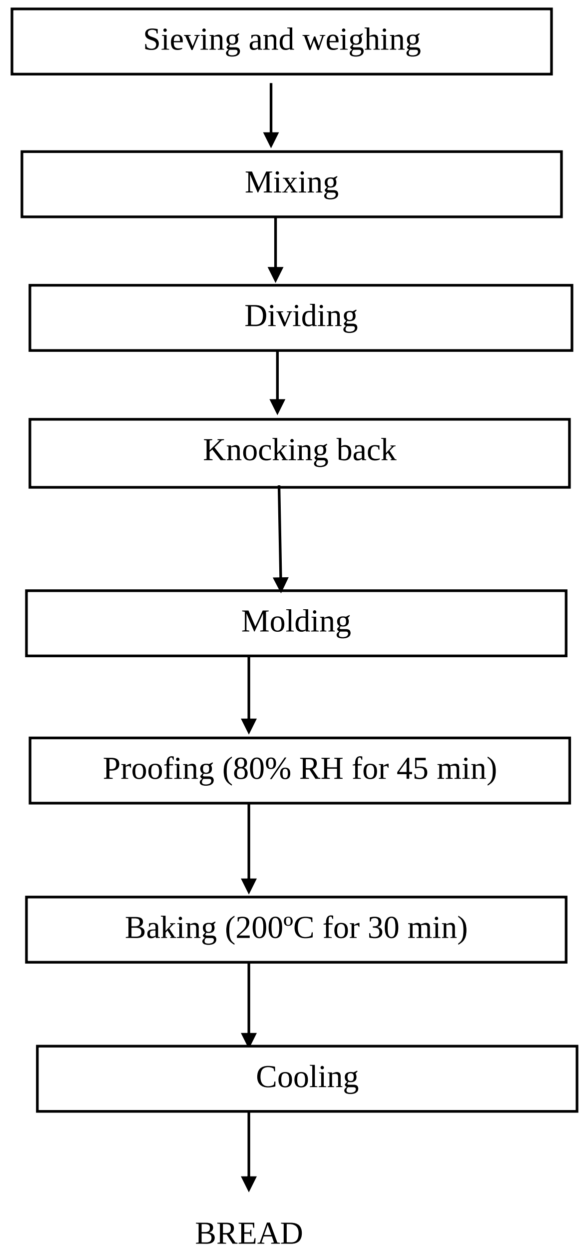

Figure 1. Flow diagram for bread making

2.7 Measurement of dough rheological properties

Rheology refers to the measure of the way in which food samples such as dough respond to applied stress and for dough samples, rheological properties are measured using rapid visco-analyser, farinographs, consistograph, alveograph and the mixolab (Mirsaeedghazi et al., 2008; Alava et al., 2007; Fustier et al., 2008; Marco & Rosell, 2008; Ozturk et al., 2008). Rheological properties are used to predict the baking qualities of wheat and composite flours. Pasting temperatures for instance guides the food processor about the temperature required to cook the flour beyond its gelatinization point (BeMiller, 2011). During this heating phase, starch in the dough absorbs water swells and bursts resulting into increased viscosity, translucency of the food matrix and increased solubility (Shimelis et al., 2006). The maximum viscosity attained during the heating phase is referred as the peak viscosity and it influences the texture of the composite bread (Bakare et al., 2016). The peak viscosity also measures the alpha amylase activity and other contributory factors such as the inherent susceptibility of the starch to amylase and the starch gel strength (Watson, 1984; Meera, 2010). Holding strength is an indicator of the ability of the starch granules to maintain their gelatinized structure when the paste is held at 95°C for 2min 30s under mechanical shearing stress (Bakare et al., 2016).

Bread dough is a wet mass developed after mixing of wheat flour, water and other ingredients. Mixing therefore aims at bringing about changes in the physical properties of the dough (resistance to deformation, extensibility, elasticity, and stickiness) that would improve the ability of the dough to retain the carbon dioxide gas that would be produced during yeast fermentation.

On a farinograph, arrival time refers to the time required to reach the nearest one- half minutes required for the top of the curve to reach the point of greatest torque after the commencement of mixing (500 BU consistency line) and also it is a measure of the rate at which water is taken up by the flour (Shuey, 1990). On the other hand, Dough Stability Time (DST), is a measure of the extent to which the flour can tolerance the flour either under mixing or excessive mixing without breaking down (Schiller, 1984). Composite breads normally have DST in the ranges of 0.78 to 9.15 min according to different scholars (Olatunji & Akinrele, 1978 Michiyo et al., 2004; Bakare et al., 2016).

Water is responsible in hydrating the flour constituents such as starches, fiber from non-wheat source, damaged starch, protein fibrils and facilitating the interactions between the proteins cross-links with the disulfide bonds during dough mixing. The water absorption is the amount of water required to develop dough to the point of greatest torque when, for wheat flour, the gluten would have been fully developed (Malomo et al., 2013). Therefore, depending on the composition of wheat and substitute flours, the optimum amount of water needed to develop cohesive, viscoelastic dough with optimum gluten strength varies. Partial substitution of wheat with composite flours in bread making has been reported to cause increase in water absorption of the composite flours (Doxastakis et al., 2002; Malomo et al., 2013). Mixing tolerance index (MTI) is an indication of the dough stability during mixing and usually flours with good tolerance to mixing have low MTI; the higher the MTI value, the weaker the flour while breakdown Time is an index of the relative strength of flours (Shuey, 1990).

The alveograph measures the resistance to expansion and extensibility of a dough by providing the measurement for maximum over pressure, average abscissa at rupture, index of swelling, and deformation energy which are critical in the evaluation of the quality of wheat flours for bread, biscuit and cookie making (Bettge et al., 1989; Janssen et al., 1996; Indrani & Rao, 2007). The alveograph impacts strain rates of 0.1–1 sec^{-1}, which are about 100-fold higher than those occurring in actual baking processes (Chin & Campbell, 2005). The Peak height (P) indicates the resistance the dough is offered to deformation and it is related the tensile strength or stability that the dough exhibits during the proofing stage of bread making (Pyler, 1988; Mepba et al., 2007). The length (L) indicates the extensibility of the dough while the curve P/L is referred to as the configuration ratio and is an index of gluten behavior. Higher values of curve configuration ratio may indicate strong wheat flour as observed by Pyler (1988). The energy (W) required for deformation is an indication of the baking strength of the dough and is measured in joules (Pyler, 1988; Mepba et al., 2007). The elasticity (G) value indicates the relative abilities of the dough to be inflated for maximum development until it eventually bursts and it is therefore a measure of the magnitude of the total response of the dough to the biaxial stress and strain imposed on it by the instrument (Mepba et al., 2007).

2.8 Bread quality characteristics

The amount of absorbed water to form dough of consistent quality for baking influences increase with substitution of non-wheat flour depending on other baking ingredients in the composite flour and is usually lower than the farinograph water absorption resulting into higher dough yields with composite flours (El-Dash et al., 1977; Shuey, 1990). Loaf volume is used as a criterion to measure the quality of fresh bread in research quality control in industry and by consumers (Chin & Campbell, 2005; Zuwariah & Aziah, 2009). On the other hand, specific volume of loaves of bread provide a uniform basis for comparing results of various studies (Oyeku et al., 2008). Specific volume is an indication of the gluten content of the bread (Van Hall, 2000) but other constituents such as starch and fiber also contribute to the specific volume of bread. Research shows that bread made from soft wheat flour usually yields lower loaf volumes. It has also been shown that the difference between weak and strong flours can be explained by differences in the molecular mass distribution of their proteins (MacRitchie, 1973). Abundance of glutenin molecules with long chains was observed to have made the protein phase, and consequently the dough, highly extensible (Bloksma, 1990).

During bread proofing and baking, there is usually weight loss which could be due to both fermentation losses brought about by amylases of starch and utilization of soluble sugar by yeast and also by evaporation of moisture during baking (Bakare et al., 2016). However, weight loss has been reported to decrease with increase in non-wheat flour substitution in composite flours which could be attributed to higher weights due to their ability to form a viscous dough while imbibing large amount of water which are lost during the baking (Bakare et al., 2016).

2.9 Sensory properties of composite bread

Bread is normally appreciated for its sensory properties of appearance (crust and crumb color, cell size, and cell uniformity), flavor (characteristic taste of bread, wheat smell and aroma), and texture (moth feel, lightness, crumb stability and softness). For crust colour, the preferred color is a light golden brown colour while the crumb should be a typical white color of bread (Greene & Bovell-Benjamin, 2004). Good bread has a characteristic taste of a typical wheat flour bread with a wheaty aroma. The aroma separates slowly when pulled apart imparting a chewiness associated with freshly baked bread (Greene & Bovell- Benjamin, 2004; Indrani & Rao, 2007; Bakare, 2008).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Source and preparation of materials

Two (02) bunches of green mature bananas; *Mpologoma* a local variety and N23 a hybrid variety with similar agronomic characteristics (Appendix I) were selected for the study. *Mpologoma* was selected for this study because it has high bunch weight and hence flour yield as well as contains high starch content (Gafuma et al., 2018). N23 hybrid has similar agronomic characteristics to *Mpologoma* and was therefore included to compare their performance in bread production.

The samples were purchased from National Agricultural Research Organization (NARO), Kawanda and immediately transported to Kyambogo University Food Laboratory. The bananas were de-clustered, sorted according to finger size and washed in portable water. Each of the banana samples was subdivided into four sets and used to prepare the following sub-samples (1) Pureed Fresh Whole Banana Fingers (FWB), (2) Pureed Fresh Banana Pulp (FBP), (3) Whole Banana Finger Flour (WBF) and, (4) Banana Pulp Flour (BPF). Wheat flour was purchased from a local milling company (Azam Uganda Ltd). Active dry yeast (Saf-instant plus, B1591757) and other ingredients were purchased from local supermarkets.

3.2 Preparation of banana flour

Banana flour was prepared according to the methods of Gomes et al. (2016) and Nakisozi (2018). Sub-samples (3) and (4) in section 3.1 were sliced to approx. 5 cm thickness using a stainless-steel knife and soaked in a solution of 1 g/100 ml citric acid for 5 min to prevent browning. The slices were placed on a tray and dried in a conventional air oven at 55°C for 72 h (Nakisozi, 2018). The dried sample was finely ground into a flour, sieved through a 3 mm screen (mrc, 108041501) and stored in an airtight bag at kept at ambient temperature until use.

3.3 Formulation of the banana-wheat composite dough mixtures

Banana bread was prepared using the pureed green mature banana – wheat composite mixture as shown in Table 2. The substitution rate for wheat flour (30%) was adopted from Sarawong et al., (2014b) and Nakisozi (2018) as the optimal inclusion level.

Table 2. Formulations used in the production of banana-wheat composite bread

Sample	Wheat (g)	Bananas (g)	Water (ml)	Sugar (g)	Yeast (g)	Salt (g)	DM
1	210	90 (BPF)	1000	120	4.0	3.0	ND
2	210	90 (WBF)	1000	120	4.0	3.0	ND
3	210	90 (FBP/Mpo)	930	120	4.0	3.0	19.05
4	210	90 (FBP/N23)	930	120	4.0	3.0	23.85
5	210	90 (FWB/Mpo)	930	120	4.0	3.0	22.21
6	210	90 (FWB/N23)	930	120	4.0	3.0	25.54
7	300	0.00 (control)	1000	120	4.0	3.0	ND

BPF, banana pulp flour; WBF, whole banana finger flour; FBP, pureed fresh banana pulp; FWB, pureed fresh whole banana fingers; DM, dry matter content; ND, not determined

3.4 Measurement of rheological properties of the dough

3.4.1 Consistograph characteristics

Dough consistency behaviour was studied following the official method no. 173 (ICC, 2006). First, the moisture content of the sample was determined as described in section 3.7.1. The amount of the water to be added for hydration of the sample was automatically calculated by the equipment based on the moisture content of the flour sample. Then, the mixer hook was inserted into the mixing bowel of the consistograph followed by 250 g of the sample. Mixing of the flour sample ensued as the water dosing unit of the consistograph started adding water automatically. Mixing proceeded for 5 min and the consistograph simultaneously generated a consistographic curve (Appendix II) and accompanying dough rheology properties.

3.4.2 Alveograph properties

The indices for dough resistance to extension (P), dough extensibility (G), and dough/baking strength (W) were determined using a Chopin alveograph according to method no. 54-30 (AACC, 2001a). The alveograph characteristics herein are defined as the maximum over-pressure (P) needed to blow the dough bubble, the average abscissa (G) at bubble rupture, the deformation energy (W) which relates to the surface under the curve indicating the necessary work input needed to inflate the dough, and the P/L ratio.

The kneader hook was inserted into the mixing bowel of the alveograph followed by the dough sample obtained in section 3.4.1. Kneading of the dough started as the water was added automatically, and proceeded for 8 min. The dough was extracted out of the mixer, laminated to uniform thickness and cut into 5 uniform dough pellets (5x5 cm). The pellets were placed in the resting chamber for 15 min and thereafter subjected to alveographic analysis as follows, to obtain five different curves: the standard Chopin+ protocol at 80 rpm mixing speed was followed: initial equilibrium at 30°C, 8 min, heating to 90°C, 7 min (at a rate of 4°C/min), holding at 90°C for 7 min, cooling to 50°C, 5 min (at a rate of 4°C/min), and holding at 50°C for 5 min. Of the five curves obtained, only three most similar curves were selected, from which an average curve (Appendix III) and accompanying rheology properties were generated.

3.5 Baking of the composite bread

Bread was baked using the straight-dough method no. 10-09 (AACC, 2001a) with some modifications. The ingredients in Table 1 were weighed using a digital scale and mixed with the required amount of water in a Macadams dough mixer (SM 201S/1917220822, South Africa) for 15 min. After mixing, the dough was divided into 500 g portions, rounded, fermented (knocked back), molded into a loaf shape and placed in a lightly greased bread tin. The tin was placed in a proofer (MP01-05906-05/19, South Africa) for 30 min at 40ºC and 80% relative humidity. The proofed dough was baked in a preheated Macadams rotary oven (M120, MR04-0263505/19, South Africa) at 200ºC for 20 min. A wheat flour alone, 50:50 wheat: fresh banana pulp control breads were prepared simultaneously under similar conditions. After baking, the bread was cooled for 24 h, placed in low-density polyethylene bag and analyzed for physical, chemical and sensory properties as described in sections 3.6-3.8.

3.6 Determination of physical properties of the bread

3.6.1 Loaf volume

This was determined by the rapeseed displacement method after cooling at room temperature for 1 h (Nakisozi, 2018). Rapeseeds were replaced by millet seeds because the latter are readily available in Uganda and their size is generally similar to that of rapeseeds. A container was filled with millet grains and levelled using a meter-ruler. The millet seeds were withdrawn from the container into the measuring cylinder and their volume recorded. The bread to be measured was placed in the container. The millet grains were gently poured into the container until the bread was covered and levelled again. The volume of the remaining millet grains displaced by the bread was measured using a measuring cylinder and was considered as the volume of the bread expressed in cubic millimetres.

3.6.2 Loaf weight

This was measured using a digital analytical balance (PA423, Ohaus, Switzerland), 1 hour after the loaf was removed from the oven (Nakisozi, 2018).

3.6.3 Baking loss

Baking loss was determined by the difference between the weight of bread dough before baking and weight of baked bread taken 24 hours after baking.

3.6.4 Cross sectional area of the loaf slice

The length and width of the bread slice cut from the centre of the loaf were measured and used to calculate cross sectional area as follows:

Area (cm^2) = length x width

3.6.5 Crumb and crust colour

Crust and crumb colour was measured using a Lovibond Tintometer (CR-10, Minolta, Japan). The bread sample was cut into a 2 x 2 mm cross section and placed onto the optical glass and measured for the degree of blackness, whiteness, greenness, redness, blueness and yellowness using the L*a*b* colour notation where L* measures the lightness of the sample, the higher the value the lighter the sample; a* measures the red-green colour axis, where +a* is red and –a* is green; and b* measures the yellow-blue axis, where +b* is yellow and –b* is blue.

3.6.6 Texture analysis

Bread crumb texture was determined after 24 hours of baking a using a TVT Texture Analyser (TVT6700, Perten, Australia) equipped with a 5 kg load according to AACC method no. 74-09 (AACC, 2001a). Texture profile analysis was carried out using a cylindrical aluminium probe with 25 mm diameter. A 2 cm thick bread slice was obtained from the centre of the loaf and subjected to double cycle of compression. Two measurements were taken on the slice crumb at pre-selected locations under the parameters; cycle until count, test speed 1.0 mm/s, post-test speed 2.0 mm/s and maximum deformation, 50%. The Texture Analyser software was used to obtain results of maximum force at peak, area to first and second peak and time taken to reach peaks for each measurement.

Texture properties of the sample were calculated using the obtained data as follows; (1) **hardness**; maximum force at peak of the first compression, (2) **cohesiveness**; area during the second compression divided by area during first compression, (3) **springiness**; time in seconds to second compression divided by distance covered during first compression and, (4) **chewability**; hardness × cohesiveness × springiness.

3.7 Determination of chemical properties of the bread

3.7.1 Moisture content

Moisture content was determined using the air oven method after 24 hours of baking. A clean dish was placed in an oven at 105°C for 1 hour. The dish was weighed using an analytical balance (Ohaus PA423, USA) after cooling in a desiccator for 30 min and the weight recorded. Bread crumbs (5 g) were obtained from two bread samples, homogenised and placed in the dish. The dish plus sample was placed in the oven (Memmert D-91126, Germany) at 105°C overnight until constant weight and then cooled for 30 min in a desiccator. The weight of the dish containing the dry sample was measured and recorded. Moisture content was calculated as the difference between the weight of the sample before and after drying and expressed as a percent of the original sample weight.

3.7.2 Dietary fiber

Acid dietary fiber determination (ADF) solution was prepared by mixing 70 ml of sulphuric acid and 50 g of cetyltrimethyl ammonium bromide to make up to 2500 ml using distilled water.

Then, 1.5 g of defatted bread sample was weighted into Erlenmeyer flask and 100 ml ADF solution added to it. The flask was placed on an electric hot plate at 130^{o}C. The contents were brought to boil within 1 minute, digested for 1 hour and vacuum filtered through a linen cloth. The residue was washed twice with boiling water and transferred to a clean crucible with a spatula. The crucible with its content was dried in an oven at 105^{o}C overnight, cooled in a desiccator and weighed. The loss in weight was calculated as the dietary fibre content and was expressed as a percentage of the initial weight of the sample.

3.7.3 Resistant starch content

Resistant starch content was determined using the Megazyme resistant starch assay kit by the enzymatic hydrolysis procedure according to the method of Gafuma (2018). A 0.1 g bread sample was weighed into a 15 ml Falcon tube and mixed with 10 ml of 1 M NaCl/0.5 M HCl containing 10 mg/ml alpha amylase. The flask was incubated at room temperature (25^{o}C) for 40 min to hydrolyze digestible starch. The mixture was centrifuged at 6000 rpm for 10 min at 4^{o}C to obtain an insoluble sediment. Then, 3 ml of Tris – maleate buffer (pH 4.75) was added and the sediment solubilized. The solubilized sediment was heated in a water bath at 90°C for 30 minutes to gelatinize the starch. The starch gel formed was homogenized and 120 µl of amyloglucosidase solution added and mixed thoroughly on a vortex. The mixture was incubated at 60°C for 45 minutes at pH 4.75. It was then centrifuged at 6000 rpm for 10 min at 4°C and the resulting supernatant used to analyze for resistant starch content. The supernatant (0.5 ml) was taken into a test tube and 0.5 ml phenol added. Then, 1 ml of distilled water and 1 ml conc. H_2SO_4 were added and kept for 10 minutes in the dark for color development. The absorbance was determined using a spectrophotometer (3047, Jenway, England) at 490 nm.

3.8 Sensory evaluation

A semi-trained panel comprising thirty persons was used to assess the sensory characteristics of the bread samples. A nine-point hedonic scale (Appendix IV) was used to score the different organoleptic properties of the bread including appearance, colour, flavour, taste, texture and general acceptance of the presented bread samples.

3.9 Statistical analysis

All chemical data were standardized by conversion to dry weight basis. Parametric statistics (means and standard deviations) were analysed for variance (ANOVA) using the Statistical Package for Social Scientists (SPSS) software. Pair-wise comparison of the data were performed using XLSTAT trial version 2021. Differences were considered significant at $p<0.05$. The relationship between pureed green mature banana addition, dough rheology and bread quality characteristics were evaluated by principal component analysis (PCA) using the Unscrambler software.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Rheological properties of the banana-wheat composite dough

The addition of pureed bananas to wheat resulted into changes in the rheological properties during mixing as measured using a consistograph and alveograph.

4.1.1 Consistograph properties

The amount of water absorbed during flour mixing enhances the hydration and distribution of ingredients in the dough and facilities optimum gluten development. The consistograph curve begins at high pressure due to the absence of water in the dried flour which exerts high pressure on the sensor. When water is added, pressure drops and when the dough develops, pressure further increases (Figure 2). The dry flours initially exert a lower pressure on the sensor which uniformly increases to the maximum.

The addition of pureed fresh and/or powdered bananas significantly increased ($p<0.05$) the time required to reach maximum consistency as shown in the consistograph analysis (Figure 2). Among the pureed fresh samples, *Mpologoma* whole fingers mostly reduced the amount of water (water absorption, WA) needed for optimum production of dough while this parameter remained unaffected for other samples (Table 3). Moreover, pureed fresh *Mpologoma* contained more moisture compared to the hybrid variety N23 (section 4.5). Thus, WA indices and the pressure (prmax) obtained in all curves involving N23 were generally higher than those of *Mpologoma* variety, which could be related to the higher dry matter content of N23 than the latter (Figure 2).

For flours, *Mpologoma* significantly ($p<0.05$) had the highest WA (Table 3) implying that addition of *Mpologoma* flour to wheat flour increased the amount of water needed for optimum dough production. Each of the hybrid N23 whole finger and pulp flours were almost similar to their respective fresh samples therefore, the consistograph did not show significant differences ($p>0.05$) in consistograph properties for this banana variety. Furthermore, addition of bananas to wheat reduced resistance to deformation (prmax) (Table 3). This could be due to protein weakening and results into poor dough handling behavior and low dough tolerance in the fermentation stage for all the composite samples (Koksel et al., 2009).

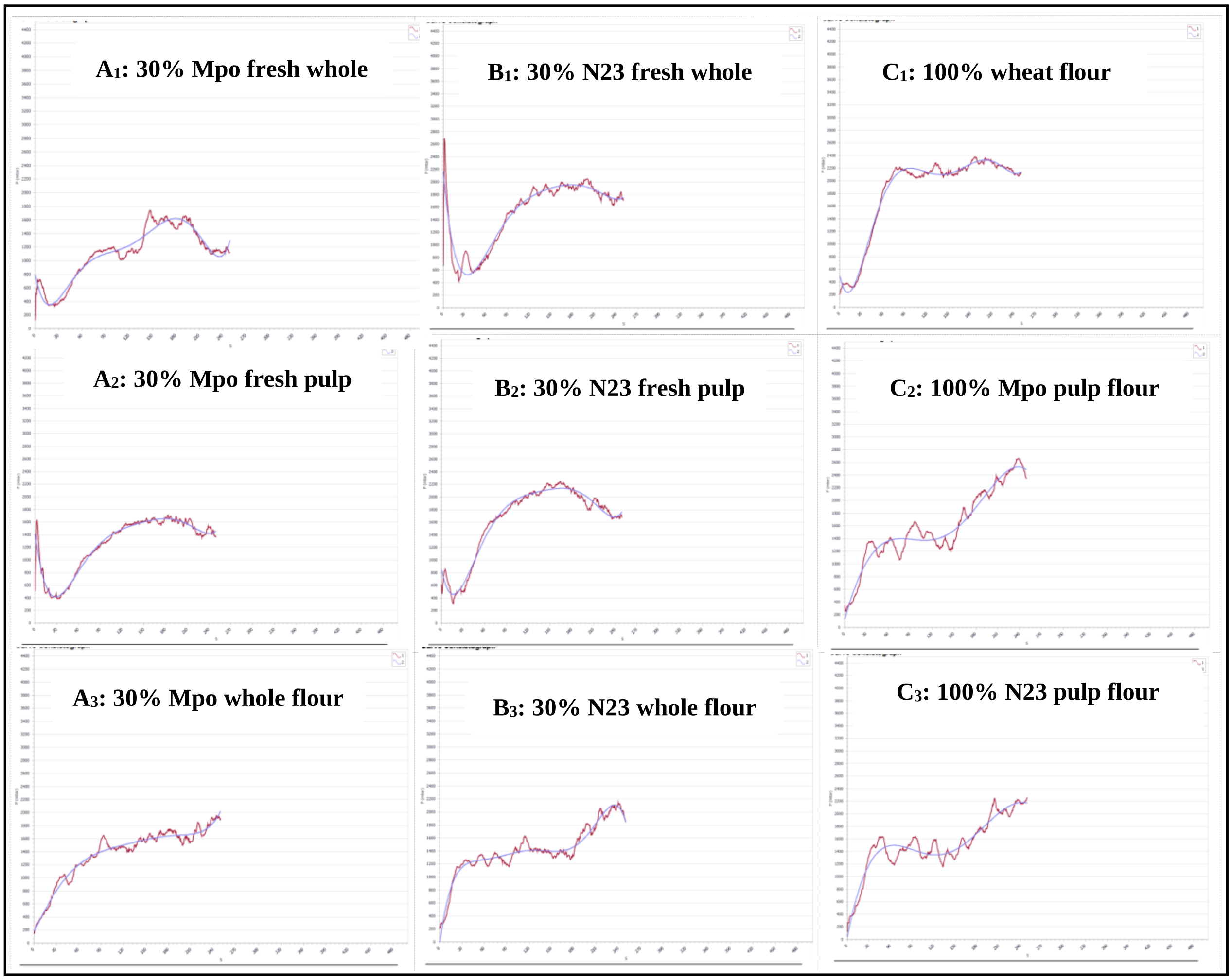

Figure 2. Changes in consistograph properties of dough obtained from wheat flour (70%) composited with different forms (pureed fresh vs flour, whole finger vs pulp) and varieties (*Mpologoma* a local variety vs N23 a hybrid variety) of green mature cooking bananas (30%). *Mpologoma*: pureed fresh whole finger (A_1), fresh pulp (A_2) and whole flour (A_3). N23 hybrid: pureed fresh whole finger (B_1), fresh pulp (B_2) and whole flour (B_3). 100% wheat flour (C_1), 100% *Mpologoma* pulp flour (C_2) and 100% N23 pulp flour (C_3). Different colored lines represent the values for different replicates of the test sample. The thick purple line represents the mean values.

Table 3. Rheological properties of dough obtained from wheat flour (70%) composited with different forms and varieties of pureed green mature cooking bananas (30%)

Type of sample	Variety/ formulation	Alveograph properties				Consistograph properties	
		Configuration ratio	Elasticity index	Baking strength	Extensibility index	Water absorption	Prmax
Fresh	30:70 (MpoW:Wh)	1.80	8.10	221	88	51.1	1622
	30:70 (MpoP:Wh)	4.31	0.00	129	26	51.3	1655
	30:70 (N23W:Wh)	1.60	10.2	222	95	53.5	2160
	30:70 (N23P:Wh)	1.40	10.7	2.15	102	53.4	2139
Flour	30:70 (MpoW:Wh)	5.95	0	136	20	52.9	2022
	30:70 (MpoP:Wh)	6.26	0	125	19	55.2	2529
	30:70 (N23W:Wh)	5.32	0	109	19	53.3	2107
	30:70 (N23P:Wh)	6.00	0	98	17	53.6	2179
Control	100% Wheat flour	1.40	54.1	262	67	53.4	2328
	30:70 Bf:Wh	1.14	15.9	229	123	ND	ND

MpoW: *Mpologoma* whole finger, MpoP: *Mpologoma* pulp, N23W: N23 hybrid variety whole finger, N23P: N23 hybrid pulp, Wh: wheat flour, Bf: banana flour, HPWh: high protein wheat flour, ND: not determined.

4.1.2 Alveograph properties

Pureed fresh whole finger or pulp banana samples (Figure 3) had relatively similar alveograph profiles to that of wheat flour control implying prospects for applying pureed fresh bananas in bread formulation. In contrast, composite dough containing banana flour samples had poor alveograph profiles suggesting low potential for using banana flour in bread production. In general, hybrid N23 pureed fresh samples had better rheological properties than *Mpologoma* counterparts (Figure 3). However, *Mpologoma* pureed fresh whole fingers had better rheological properties than all composite samples (Figure 3) highlighting its potential for application in the bread making process. The rheological properties could be attributed to its greater consistency due to the swelling of starch molecules and leaching out of amylose on heating hence increasing the consistency of the dough due to starch gelatinization (Koksel et al., 2009).

When the P/L value exceeds a critical value, the elasticity index value reduces to zero. The lower the configuration ratio, the better the elasticity index hence a higher baking strength which is desirable (Pena et al., 2006). From this study, elasticity of the dough decreased with addition of bananas with the lowest observed where banana flours were added (Table 3). Generally, flours had lower elasticity indices compared to pureed fresh samples hence, very low configuration ratios (P/L) and low/zero elasticity indices producing low baking strengths (Table 3). In comparison, all pureed fresh banana samples had higher elasticity indices compared to the control, except for the addition of 30% N23 pureed fresh whole fingers. Overall, the elasticity indices of the composite mixtures were lower than that of the control suggesting that the substitution level of bananas (30%) applied in the composite mixture was relatively high. Moreover, dough samples containing bananas exhibited lower baking strength and resistance to mechanical mixing compared to the control sample (Table 3) indicating that the former were weaker doughs.

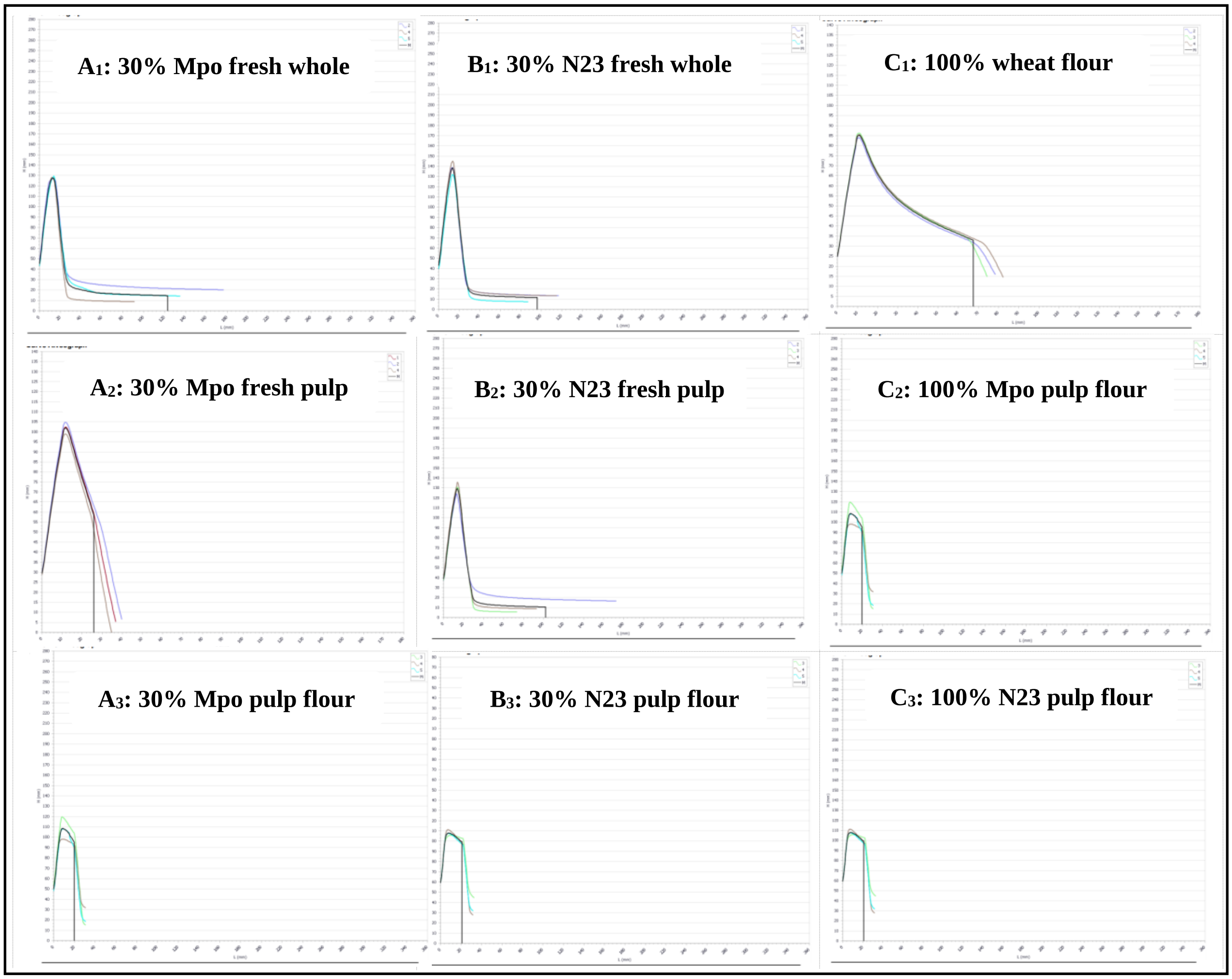

Figure 3. Changes in alveograph properties of dough obtained from wheat flour (70%) composited with different forms (pureed fresh vs flour, whole finger vs pulp) and varieties (*Mpologoma* a local variety vs N23 a hybrid variety) of green mature cooking bananas (30%). *Mpologoma*: pureed fresh whole finger (A_1), pureed fresh pulp (A_2) and pulp flour (A_3). N23 hybrid: pureed fresh whole finger (B_1), pureed fresh pulp (B_2) and pulp flour (B_3). Controls: 100% wheat flour (C_1), 100% *Mpologoma* pulp flour (C_2) and 100% N23 pulp flour (C_3). Different colored lines represent the values for different replicates of the test sample. The thick purple line represents the mean values.

Higher WA indicates higher amounts of water to be added to flour yielding a higher proportion of the dough which is desirable for bread production (Dhaka et al., 2012). Increase in WA due to addition of bananas could be attributed to the more soluble constituents in the latter which could have higher affinity for water requiring less amount of water for hydration compared to the constituents in the wheat alone dough system (Dervas et al., 1999; El-Soukkary, 2001; Doxastakis et al., 2002). Pureed fresh samples had lower WA indices than flour samples. This could be explained by the high moisture content in the fresh samples resulting into lower amounts of water needed to hydrate the composite flours (El-Soukkary, 2001).

Low baking strength is undesirable for bread making. The low indices of baking strength observed for banana – wheat composite doughs could be attributed to weakening of the gluten structure by entrapment of the banana particles into the gluten network structure (Dervas et al., 1999; Doxastakis et al., 2002; Güemes-Vera et al., 2004).

Resistance to deformation (prmax) is used to predict dough handling behavior and tolerance in the fermentation stage. All banana-wheat composite doughs in this study had low prmax values probably due to gluten dilution thereby reducing the extensibility of the bread dough (Paraskevopoulou et al., 2010).

The reduced elasticity of the banana-wheat composite dough could be explained by the fact that the non-gluten chemical constituents in bananas do not readily bind with those of gluten to enhance dough elasticity thereby not enhancing the gluten network (Maforimbo et al., 2007; Roccia et al., 2009).

4.2 Physical and chemical characteristics of the banana-wheat composite bread

The dough samples were processed into bread using the straight dough method. The bread loaves obtained and their respective cross sections of the crumb are shown in Figure 4. Interestingly, the general appearance of bread obtained from banana-wheat composite doughs was appealing and comparable to that of the wheat alone control. *Mpologoma* pureed fresh finger and flour samples had brighter crumb appearance and texture close to that of the 100% wheat control compared to all other samples tested (Figure 4). Interestingly, whereas rheological data in section 4.1 suggested that pureed fresh banana pulp and pulp flour at inclusion ratio of 30% had low prospects of bread formulation, results from this part of the study proved otherwise. Bread was obtained from each of the treatments including pureed fresh or flour, whole fingers or pulp and different varieties (*Mpologoma* and N23) showing the potential of the banana industry for confectionery application. In fact, fairly good quality bread was also obtained when the inclusion level was raised further to 50% pureed fresh banana pulp as shown in Figure 4 (C_2-C_3).

However, incorporation of whole banana fingers gave a duller crumb appearance compared to pulp. The effect was more pronounced in the hybrid variety N23 (Figure 4 B_1) than in *Mpologoma* (Figure 4 A_1). Flour samples generally had brighter crumb appearance except for *Mpologoma* whole finger flour (Figure 4 A_2). Whereas crumb colour was generally dull for whole banana finger samples, there is a growing market for brown breads in Uganda, and as such fresh whole finger bananas can find application in production of these types of breads. Crumb pore consistency was generally better and more even in treatments involving *Mpologoma* than the hybrid N23, irrespective of the inclusion ratio i.e., 30 or 50%. These crumb pore characteristics did not depend on whether fresh or flour samples were applied. Overall, it was evident that green mature bananas could play a significant role in production of bread.

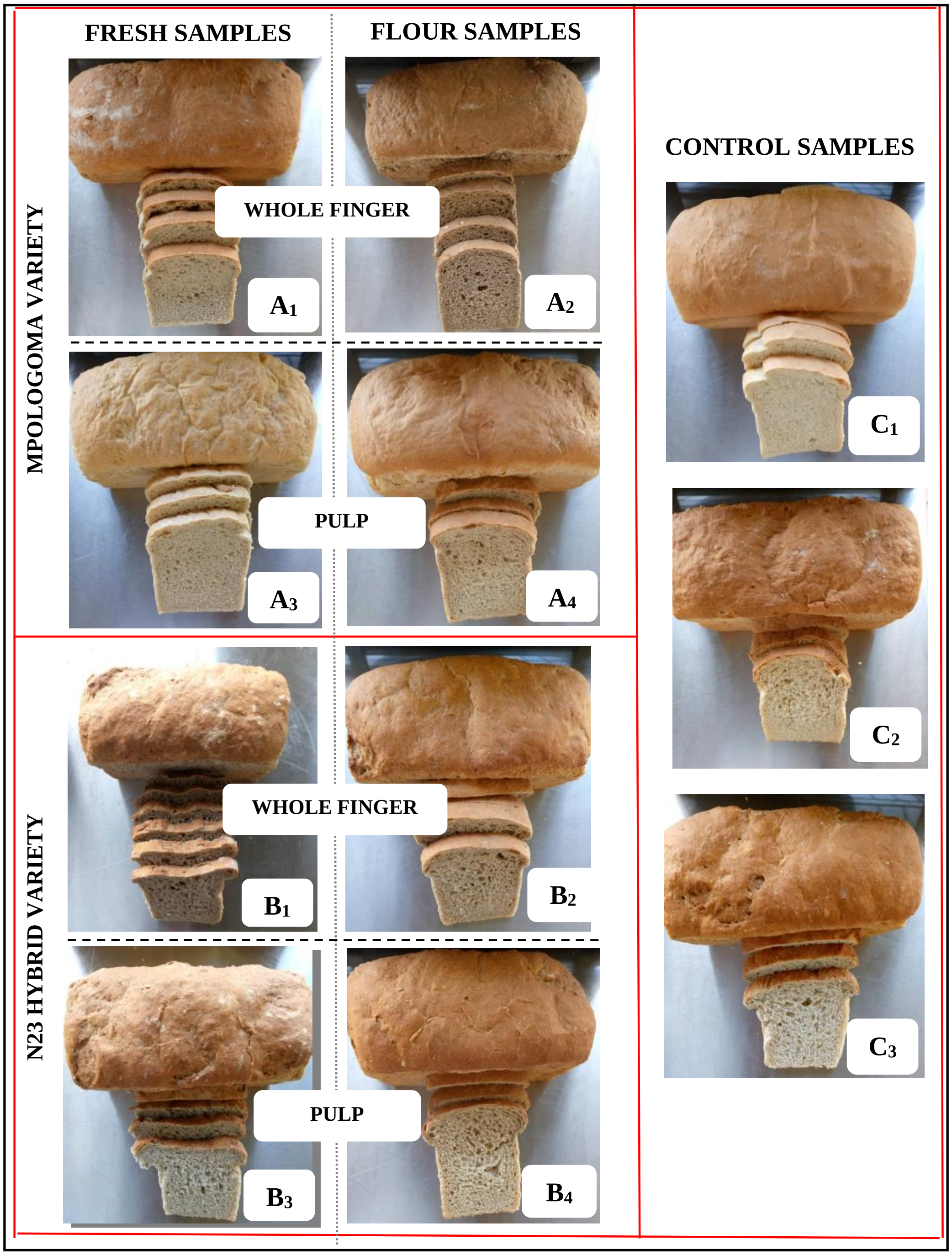

Figure 4. Image analysis of bread obtained from wheat flour (70%) composited with different forms (pureed fresh vs flour, whole finger vs pulp) and varieties (*Mpologoma* a local variety vs N23 a hybrid variety) of green mature cooking bananas (30%). *Mpologoma*: pureed fresh whole finger (A_1), whole finger flour (A_2), pureed fresh pulp (A_3) and pulp flour (A_4). N23 hybrid: pureed fresh whole finger (B_1), whole finger flour (B_2), pureed fresh pulp (B_3) and pulp flour (B_4). Controls: 100% wheat flour (C_1), 50% Wheat: 50% *Mpologoma* pureed fresh pulp (C_2) and 50% Wheat: 50% N23 fresh pulp (C_3)

4.2.1 Physical properties

Results of pan bread volumes obtained from the banana-wheat composite mixture are shown in Table 4. As expected, the volume of the control (100% wheat) bread was significantly higher ($p<0.05$) than that of the samples containing pureed bananas. For breads containing pureed bananas, loaf volume ranged from 1137.97 cm^3 to 1410.00 cm^3 in samples formulated from 30% N23 pureed fresh pulp and 30% N23 pureed fresh whole fingers, respectively.

With the exception of bread made using *Mpologoma* pureed fresh pulp, there was significant ($p<0.05$) increase in baking loss for all bread formulated with banana flour compared with that made using pureed fresh bananas (Table 4). Baking loss was highest in the 50:50% banana: wheat composite bread and lowest in the 100% wheat alone control sample. These results suggest that fresh green mature bananas yield lower baking losses compared to banana flour, when used for production of composite banana-wheat bread.

Cross sectional area of the breads ranged from 85.76 cm^2 to 610.28 cm^2 with the sample containing 30% *Mpologoma* pureed fresh pulp having the highest cross-sectional area while that formulated from 30% N23 hybrid whole finger flour had the lowest (Table 4). Loaf weight was highest in the 30% *Mpologoma* whole finger (607.0 g) and pulp (613.50 g) flours, and lowest in the sample containing 30% N23 whole finger flour (544.00 g). The control bread (100% wheat) had a cross sectional area of 119.23 cm^2. The low cross-sectional area in bread made with 30% N23 hybrid whole finger flour compared to the control sample could be attributed to the higher baking loss in the former.

Crust and crumb browning increased significantly ($p<0.05$) with the addition of 30% pureed bananas in comparison to the 100% wheat alone control probably due to enhanced Maillard reaction (Lee & Brennand, 2005).

Table 4. Physical properties of bread obtained from wheat flour (70%) composited with different forms and varieties of pureed **green mature cooking bananas (30%)**

Type of sample	Formulation	Baking loss	Cross sectional area (cm^2)	Loaf weight (g)	Loaf volume (cm^3)	Color of crumb/ crust					
						L	a	b	L	a	b
						Crust			Crumb		
Fresh	30:70 (MpoW:Wh)	7.97[d]	534.93[a]	572.50 [ab]	1169.71[bc]	20.25[bc]	-3.75[abc]	26.40 [d]	22.25[c]	-6.00[a]	28.05[bcd]
	30:70 (MpoP:Wh)	6.69[d]	610.28[a]	578.00 [ab]	1314.79[bcd]	20.60[bc]	-2.05[abc]	29.80[bcd]	26.75[abc]	-5.70[a]	32.75[abc]
	30:70 (N23W:Wh)	9.25[cd]	109.02[a]	579.00 [ab]	1305.72[bcd]	23.75[bc]	-0.40[a]	29.70[bcd]	22.15[c]	-7.25[a]	27.00[d]
	30:70 (N23P:Wh)	13.63[abc]	85.85[a]	577.50 [ab]	1410.00[bc]	20.00[c]	-1.40[ab]	26.60[d]	24.25[bc]	-7.60[ab]	29.55[bcd]
Flour	30:70 (MpoW:Wh)	15.56[ab]	90.64[a]	607.00 [a]	1156.11[d]	23.95[bc]	-4.15[bc]	31.05[bc]	25.20[abc]	-7.55[ab]	29.75[bcd]
	30:70 (MpoP:Wh)	12.73[bc]	102.77[a]	613.50 [a]	1137.97[d]	32.45[a]	-5.10[c]	35.80[a]	30.85[ab]	-10.40[b]	29.65[bcd]
	30:70 (N23P:Wh)	7.97[d]	115.67[a]	571.00 [ab]	1310.26[bcd]	21.45[bc]	-0.30[a]	27.30[cd]	24.30[bc]	-5.45[a]	32.20[abcd]
	30:70 (N23W:Wh)	14.91[ab]	85.76[a]	544.00 [b]	1410.00[bc]	23.95[bc]	-0.95[ab]	30.05[bcd]	24.85[bc]	-8.25[ab]	27.45[cd]
Control	100% Wh	7.71[d]	119.23[a]	570.00 [ab]	1439.33[bcd]	27.85[ab]	-3.20[abc]	32.40[ab]	32.45[a]	-6.00[a]	35.65[a]
	50:50 (MpoP:Wh)	16.07[ab]	112.67[a]	582.00 [ab]	1328.39[bcd]	23.55[bc]	-0.20[a]	30.25[bcd]	27.10[abc]	-5.75[a]	33.75[ab]
	50:50 (N23P:Wh)	18.00[a]	94.87[a]	530.50 [b]	1360.13[bcd]	21.65[bc]	-1.70[abc]	26.70[d]	23.95[bc]	-7.55[ab]	28.40[bcd]

MpoW: *Mpologoma* whole finger, MpoP: *Mpologoma* pulp, N23W: N23 hybrid variety whole finger, N23P: N23 hybrid pulp, Wh: wheat flour. Values in columns with similar superscript letters are not significantly different at p>0.05. Values are means of two independent replicates.

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Baking loss due to addition of banana could be attributed to the higher water retention capacity of banana especially for whole *Mpologoma* flour which also had significantly higher moisture content of baked breads from composite flours due to higher amounts of water added during the baking process according to consistograph results (Table 3). The higher baking loss in composite flours could also be attributed to the fact that banana flour (particularly *Mpologoma* flour) has a higher water absorption capacity than wheat flour according to consistograph results in section 4.1.1. This was also exhibited in the composite bread made from the 30% *Mpologoma* flour which had the highest loaf weight and a relatively low baking loss (Table 4).

Addition of 30% *Mpologoma* pulp flour led to production of the lowest bread volume which was attributed to gluten dilution and mechanical disruption of the gluten network structure resulting into reduced dough elasticity (Doxastakis et al., 2002; Paraskevopoulou et al., 2010). The differences in bread volumes may be attributed to increased resistance to extension of the dough which is in turn, determined by differences in technological characteristics of bananas and wheat in terms of bread making (Dobraszczyk & Salmanowicz, 2011).

van Vliet et al. (1992) reported that the dough becomes firmer, stiffer, more elastic and solid as a consequence of addition of non-wheat ingredients, thus reducing the leavening process. This resistance to expansion could be due to strengthening effect of bananas on the gluten matrix. Moreover, during proofing, the gluten matrix undergoes expansion producing an increase in the dough volume (Dobraszczyk & Salmanowicz, 2011). Thus, it is possible that incorporation of bananas could have reduced the gluten content of the composite mixture weakening the gluten matrix thereby hindering dough expansion (Paraskevopoulou et al., 2010). This could be confirmed true because, the control bread produced using high gluten wheat exhibited the best rheological and baking properties highlighting the positive effect of gluten level on bread baking properties. Thus, the volume of banana – wheat composite bread could be improved by supplementation of the composite flour with gluten, or by using wheat flour with higher gluten content than the one employed in this study.

The control sample showed the L* value of 27.85 and 32.45 which indicates the whiteness of crumb and crust bread slice, respectively (Table 4). There was a decrease in the lightness of the bread crumb and crust with the incorporation of pureed fresh bananas and banana flour. Although this trend was similar in the breads made with both pureed fresh and powdered *Mpologoma* and N23, breads made with pureed fresh pulp and banana flour had higher values of lightness compared to breads made from pureed fresh and dried whole fingers (Table 4). Martínez-Castaño et al. (2019) also reported the brownest colour in crust for gluten free bread made with partial banana flour substitution (15%). Control sample (100% wheat flour) and 30% *Mpologoma* pulp flour showed higher crumb yellowness and a more intense crust browning compared to bread with 30% N23 pulp samples ($p < 0.05$). The presence of different xanthophylls and phenolic compounds might be associated with the yellowish-brownish colour of the banana bread samples (Kurhade et al., 2016). Also, Mohamed et al. (2010) mentioned that for fruits like bananas that contain high levels of polyphenol oxidase, they exhibit enzymatic oxidation of mono-phenolic compounds and releases o-diphenols and o-quinones.

4.2.2 Textural properties

Textural properties of the baked bread were determined by double compression method on the bread slice samples and the results are presented in Table 5.

Table 5. Textural properties of bread obtained from wheat flour (70%) composited with different forms and varieties of green mature cooking bananas (30%)

Type of sample	Sample formulation	Firmness (N)	Resilience	Springiness	Cohesiveness (N)
Fresh	30:70 (MpoW:Wh)	3.83±1.10[ab]	0.46±0.01[ab]	0.68±0.00[c]	0.47±0.01[ab]
	30:70 (MpoP:Wh)	5.34±0.51[a]	0.45±0.05[ab]	0.71±0.06[bc]	0.46±0.06[ab]
	30:70 (N23W:Wh)	3.69±0.84[ab]	0.54±0.00[a]	0.78±0.00[abc]	0.55±0.01[a]
	30:70 (N23P:Wh)	2.42±0.52[bc]	0.54±0.05[a]	0.78±0.05[abc]	0.55±0.03[a]
Flour	30:70 (MpoW:Wh)	3.71±0.09[ab]	0.38±0.04[b]	0.73±0.03[abc]	0.39±0.04[b]
	30:70 (MpoP:Wh)	3.61±0.17[ab]	0.48±0.08[ab]	0.81±0.06[abc]	0.47±0.07[ab]
	30:70 (N23W:Wh)	1.96±0.11[bc]	0.53±0.00[a]	0.80±0.03[abc]	0.54±0.01[a]
	30:70 (N23P:Wh)	1.39±0.14[c]	0.50±0.00[ab]	0.84 ±0.01[a]	0.50±0.04[ab]
Controls	100% Wh	3.30±0.04[abc]	0.57±0.02[a]	0.82±0.03[ab]	0.57±0.03[a]
	50:50 (MpoP:Wh)	4.03±0.38[ab]	0.47±0.01[ab]	0.74±0.01[abc]	0.46±0.01[ab]
	50:50 (N23P:Wh)	3.08±0.78[bc]	0.53±0.00[a]	0.80±0.01[abc]	0.53±0.01[a]

MpoW: *Mpologoma* whole finger, MpoP: *Mpologoma* pulp, N23W: N23 whole finger, N23P: N23 pulp, Wh: wheat flour

Composite bread made from 30% N23 whole finger flour and 30% N23 pulp flour had the lowest firmness/hardness (1.96 N and 1.39 N, respectively) which was significantly different ($p<0.05$) from that exhibited by the samples made from 30% *Mpologoma* pureed fresh whole fingers (3.83 N) and 30% *Mpologoma* pureed fresh pulp (5.34 N) (Table 5). The trend in the observed crumb firmness could be attributed to starch retrogradation and the thickening of the crumb walls surrounding the air cells and the strengthening of the crumb structure by the particles of the composite dough (Davidou et al., 1996; Zobel & Kulp, 1996; Paraskevopoulou et al., 2010). Alternatively, addition of N23 flours at higher amounts of 30-50% could have reduced firmness in bread probably due to their high-water retentions which could have inhibited amylopectin retrogradation (Biliaderis et al., 1995). Bread samples containing bananas exhibited reduced cohesiveness (0.39 N to 0.55 N), and resilience (0.38 and 0.54) compared to the 100% wheat alone control (0.57 N and 0.57, for cohesiveness and resilience, respectively), yet for the 30% N23 pureed fresh pulp (0.55 N and 0.54) and 30% N23 pulp flour samples (0.54 N and 0.53, respectively) the same textural attributes were enhanced close to the wheat alone control (Table 5).

Springiness is the elastic recovery property of the dough after removal of first deforming force (Adegoke et al., 2016). Bread made from 30% *Mpologoma* pulp flour and 30% N23 pulp flour produced springiness close to that of the wheat alone control sample. This could be explained by the higher gluten elasticity in wheat producing larger cells in the bread that enables cell expansion by gas pressure during fermentation and oven spring creating a springy bread texture (Paraskevopoulou et al., 2010). Bread made from the 30% *Mpologoma* pureed fresh pulp and 30% *Mpologoma* pureed fresh whole fingers significantly produced lower springiness (0.71 and 0.68, respectively) compared to the wheat alone control sample (0.82) (Table 5; $p<0.05$). This could be due to the fact that fresh bananas are not as elastic as wheat gluten which forms a complex network for facilitating cell expansion so that the crumb becomes less compact and springy.

4.2.3 Chemical properties

The data obtained for moisture, resistant starch and dietary fiber content of bread obtained from wheat flour composited with different forms and varieties of green mature cooking bananas are shown in Table 6. Moisture content was variable among the samples studied with the bread formulated using 30% pureed fresh whole *Mpologoma* having the highest moisture content (61%) while that made using 30% pureed fresh whole N23 hybrid had the lowest (56.5%, $p<0.05$; Table 6). A similar trend in moisture content was observed among the flour samples.

Resistant starch content ranged from 1.08 g/100g in the wheat alone control bread to 3.59 g/100g in bread containing 50% pureed fresh *Mpologoma* pulp ($p<0.05$; Table 6). In general, bread made from pureed fresh banana pulp had more resistant starch content than its counterpart formulated from pureed fresh whole banana fingers. In the case of flours, a reverse trend was observed whereby whole banana finger bread had higher resistant starch content than banana pulp flour bread. This could be attributed to the retrogradation process resulting into the formation of the amylo-lipid bonds creates RS type 3 and 5, respectively (Martínez et al., 2019). Similar results were reported by Amir et al. (2020) who used whole green banana flour. Overall, *Mpologoma* variety had higher contribution to resistant starch of the bread than the N23 hybrid, irrespective of pureed fresh or flour forms (Table 6). This could be due to its starch chemical properties (Amir et al., 2020).

Dietary fiber was highest (1.76%) in bread made from 30% pureed fresh *Mpologoma* whole fingers and was lowest in the 100% wheat alone control bread ($p<0.05$; Table 6). As expected, bread formulated from whole bananas had higher dietary fiber content than that made from banana pulp. This is due to the fact that the peel in whole banana has more dietary fiber compared to the flour from banana pulp and wheat (Amir et al., 2020). Similar to results of resistant starch, *Mpologoma* whole fingers had the highest contribution to dietary fiber content of bread compared to all other treatments. In fact, increasing the proportion of banana pulp to 50% did not pose significant increase in the fiber content of the bread (Table 6) implying that banana peel is the major contributory factor for enhancing the dietary fiber content of bread.

Table 6. Chemical composition of bread composited with different cooking banana varieties at mature green stage

Type of sample	Sample formulation	Moisture (%)	Resistant starch g/100 g "as is"	Dietary fiber (%)
Fresh	30:70 (MpoW:Wh)	61.53±0.50[a]	2.12±0.05	1.76±0.16
	30:70 (MpoP:Wh)	57.17±0.30[c]	2.25±0.05	1.31±0.01
	30:70 (N23W:Wh)	56.45±0.10[c]	1.44±0.15	1.20±0.25
	30:70 (N23P:Wh)	60.40±0.20[a]	1.59±0.08	0.68±0.13
Flour	30:70 (MpoW:Wh)	58.78±0.02[b]	2.27±0.08	1.48±0.26
	30:70 (MpoP:Wh)	56.78±0.02[c]	1.50±0.03	0.64±0.03
	30:70 (N23W:Wh)	56.63±0.03[c]	1.70±0.04	1.95±0.01
	30:70 (N23P:Wh)	57.50±0.03[bc]	1.59±0.08	1.52±0.18
Controls	100% Wheat	61.67±0.40[a]	1.08±0.01	0.57±0.05
	50:50 (MpoP:Wh)	58.71±0.50[b]	3.59±0.21	0.60±0.29
	50:50 (N23P:Wh)	60.65±0.20[a]	2.21±0.01	0.65±0.12

MpoW: *Mpologoma* whole finger, MpoP: *Mpologoma* pulp, N23W: N23 whole finger, N23P: N23 pulp, Wh: wheat flour.

The high moisture content of 30% pureed fresh whole *Mpologoma* composite bread could be attributed to presence of more hydrophilic chains due to the banana addition resulting into higher water absorption capacities (Ho et al., 2013). The increase in moisture content can also be explained by the presence of more soluble constituents such starch and dietary fiber in this banana variety as evidenced in the results (Table 6). These substances have higher affinity for water requiring less amount of water for hydration compared to the constituents in the dough system (Dervas et al., 1999; El-Soukkary, 2001; Doxastakis et al., 2002). This was congruent with the results of consistographic analysis (section 4.1.1) in which it was observed that addition of 30% fresh *Mpologoma* whole fingers led to the lowest water absorption of the composite dough.

According to Goni et al. (1996) and Anil (2007), wheat flour has been reported to contain very low resistant starch (≤1% dry matter) and dietary fiber (2.7%, dry basis) (Goni et al., 1996; Anil, 2007) which are mostly lost during milling, it was possible to conclude that the relatively high resistant starch observed in bread in this study was mainly due to incorporation of bananas. The high levels of resistant starch in banana-wheat composite breads compared to wheat alone control, is also attributed to the high starch contents in the green bananas (70-80%, dry weight basis) and the presence of high level of insoluble residues of dietary fiber in the banana flour (Goni et al., 1996; Anil, 2007). These factors may partly explain the results obtained from this study.

Addition of bananas resulted into higher levels of dietary fiber and resistant starch compared to the control sample. These results were in agreement with the findings of other scholars (Juarez-Garcia et al., 2006; Ovando-Martinez et al., 2009; Noor et al., 2012) who reported that fiber, ash, and resistant starch content of banana flour incorporated products were higher than that control without addition of banana flour. High dietary fiber intake is associated with enhanced human health due to facilitated removal of potentially detrimental materials from the bowels by increasing fecal softness, fecal bulk, water binding capacity, organic binding capacity and reducing intestinal transit time (Champ & Guillon, 2000). Increasing dietary fiber intake also increases lactic acid bacteria fermentation in colon producing short chain fatty acids with protective effects to the body against colon cancer (AACC, 2001b). Based on the results from this study, consumption of banana bread especially one developed from *Mpologoma* variety could have positive contribution to the above listed effects. However, there is a need for studies to demonstrate these effects *in vivo* in humans.

Moreover, raw green bananas contain resistant starch type II (RS II), which is resistant to acid and enzyme attack due to its crystalline properties that protect the starch from being digested (FAO, 1998). On cooking the bananas at about 145°C, RS type II is converted to thermally stable resistant starch III (up to 84% yield upon retrogradation) (Lehmann et al., 2002). Since the breads were baked at 200^{o}C, the obtained RS in this study could therefore mainly be the retrograded RS III which has been reported to produce short-chain fatty acids with a high proportion of butyrate upon fermentation by intestinal microflora (Sharp & Macfarlane, 2000). Butyrate is a substrate and signal metabolite for activation of proliferation of probiotic microbes in the gut hence consumption of the banana-wheat composite bread could result into enhanced human health against colon cancer due to improved probiotic activity in the gut (Sharp & Macfarlane, 2000).

4.3 Sensory acceptability of the banana-wheat composite bread

Table 7 indicates results of mean scores of sensory acceptability of the banana-wheat composite bread. Generally, the addition of bananas caused significant decrease ($p<0.05$) in the sensory quality attributes of the composite breads compared to the wheat alone control sample. This could be attributed to the polyphenol compounds in the bananas contributing to a sappy taste negatively influencing the overall taste of the composite bread. Bread made from 30% N23 pulp flour and 50% pureed fresh *Mpologoma* whole fingers was more appreciated for its general appearance close to that of the wheat alone control sample, while bread from 30% *Mpologoma* whole finger flour and 30% pureed fresh N23 whole fingers was rejected due to its inferior appearance (Table 7).

The mean scores for the colour of the breads ranged from 4.15 to 7.80 with the control sample having the highest mean score while the 50% pureed fresh N23 pulp bread had the lowest. The blend of 30% *Mpologoma* pulp flour was most appreciated for colour which was not significantly different (p>0.05) from that of the wheat alone control sample.

Flavor and taste of the composite breads significantly decreased (p<0.05) with the addition of bananas compared to the wheat alone control sample. Among the composite breads, 30% *Mpologoma* pulp and 30% N23 pulp flours were the most appreciated for taste and flavor while bread from pureed fresh *Mpologoma* whole fingers was least appreciated for these attributes (Table 7).

The texture of breads hardened with the addition of bananas. However, bread made from 30% pureed fresh whole bananas exhibited softer texture which was not significantly different (p>0.05) from that of the wheat alone control sample. Mean scores for general acceptability ranged from 3.93 to 7.05 with the wheat alone control and 30% *Mpologoma* whole finger flour having the highest and lowest scores, respectively (Table 7). Bread produced from the composite of 30% pureed fresh *Mpologoma* pulp had the highest score for general acceptability even at 30 and 50% incorporation.

Table 7. Sensory attributes of bread obtained from composited wheat flour with different cooking banana varieties at mature green stage

Type of sample	Sample formulation	Appearance	Color	Flavor	Taste	Texture	General acceptability
Fresh	30:70 (MpoW:Wh)	5.55 ± 1.88^{bc}	5.83±2.04^{bc}	4.83±1.87^{b}	4.85±1.93^{bc}	5.01±1.93^{ab}	4.95±2.01^{b}
	30:70 (MpoP:Wh)	5.50 ±2.15^{bc}	5.45±1.87^{bcd}	4.82±1.62^{b}	5.03±2.28^{ab}	6.00±2.48^{ab}	5.28±2.24^{b}
	30:70 (N23W:Wh)	4.58±1.87 ^{c}	5.03±2.03^{cd}	4.90±2.13^{b}	4.60±1.85^{bc}	4.65±2.05^{b}	4.53±2.11^{b}
	30:70 (N23P:Wh)	5.05 ±1.87^{bc}	5.45± 1.89^{bcd}	4.98±2.07^{b}	4.95±1.84^{bc}	4.80±1.90^{b}	4.93±1.90^{b}
Flour	30:70 (MpoW:Wh)	4.48±2.56^{c}	4.15±2.70^{d}	4.60± 2.30^{b}	4.15±2.49^{bc}	4.95±2.65^{ab}	3.93±2.31 ^{b}
	30:70 (MpoP:Wh)	5.83±2.10^{bc}	6.65±1.96^{ab}	5.13±1.70^{ab}	4.85±2.12^{bc}	5.60±2.07^{ab}	5.13±2.20^{b}
	30:70 (N23W:Wh)	6.15±1.85^{b}	5.73±2.14^{bc}	4.38±1.75^{b}	3.50±2.17^{c}	4.88±2.34^{b}	4.63±2.05^{b}
	30:70 (N23P:Wh)	5.30±2.04^{bc}	5.20±2.26^{bcd}	5.35±1.87^{ab}	4.98±1.86^{abc}	5.25±1.94^{ab}	5.10±1.96^{b}
Controls	100% Wh	7.90±1.15^{a}	7.80±1.44^{a}	6.45±1.89^{a}	6.45±.97 ^{a}	6.48±1.95^{a}	7.05±1.83^{a}
	50:50 (N23P:Wh)	5.03±2.13^{bc}	4.88±2.17^{cd}	4.85±1.94^{b}	4.83±2.18^{bc}	4.90±2.20^{b}	4.53±2.03^{b}
	50:50 (MpoP:Wh)	6.08±1.38^{b}	5.70±2.07^{bc}	5.05±1.78^{b}	4.88±1.79^{bc}	5.80±1.87^{ab}	5.23±1.97^{b}

MpoW; *Mpologoma* whole, MpoP; *Mpologoma* pulp, N23P; N23 pulp, N23W; N23 whole, Wh; wheat

4.4 Principal component analysis

The principal component analysis (PCA) plot below indicates the relative contribution of the major rheological properties of the dough to the physical and sensory attributes of the bread (Figure 5). A positive interaction indicates that the rheological property that has a significant positive impact ($p<0.05$) on the associated sensory properties of the composite bread. Principal component 1 (32.65%) contrasted breads 597, 647, 671, 756, 476 and 291 which had a high loaf weight, high cross-sectional area and high firmness due to a high configuration ratio of the dough (Figure 5). Principal component 2 (29.61%) contrasted breads 849 and 514 with good appearance, flavor, taste, texture, springiness, specific volume, cohesiveness, moistness, low baking loss and general acceptability being contributed by the high extensibility, water absorption, elasticity index, dough strength, and dough tenacity (Figure 5).

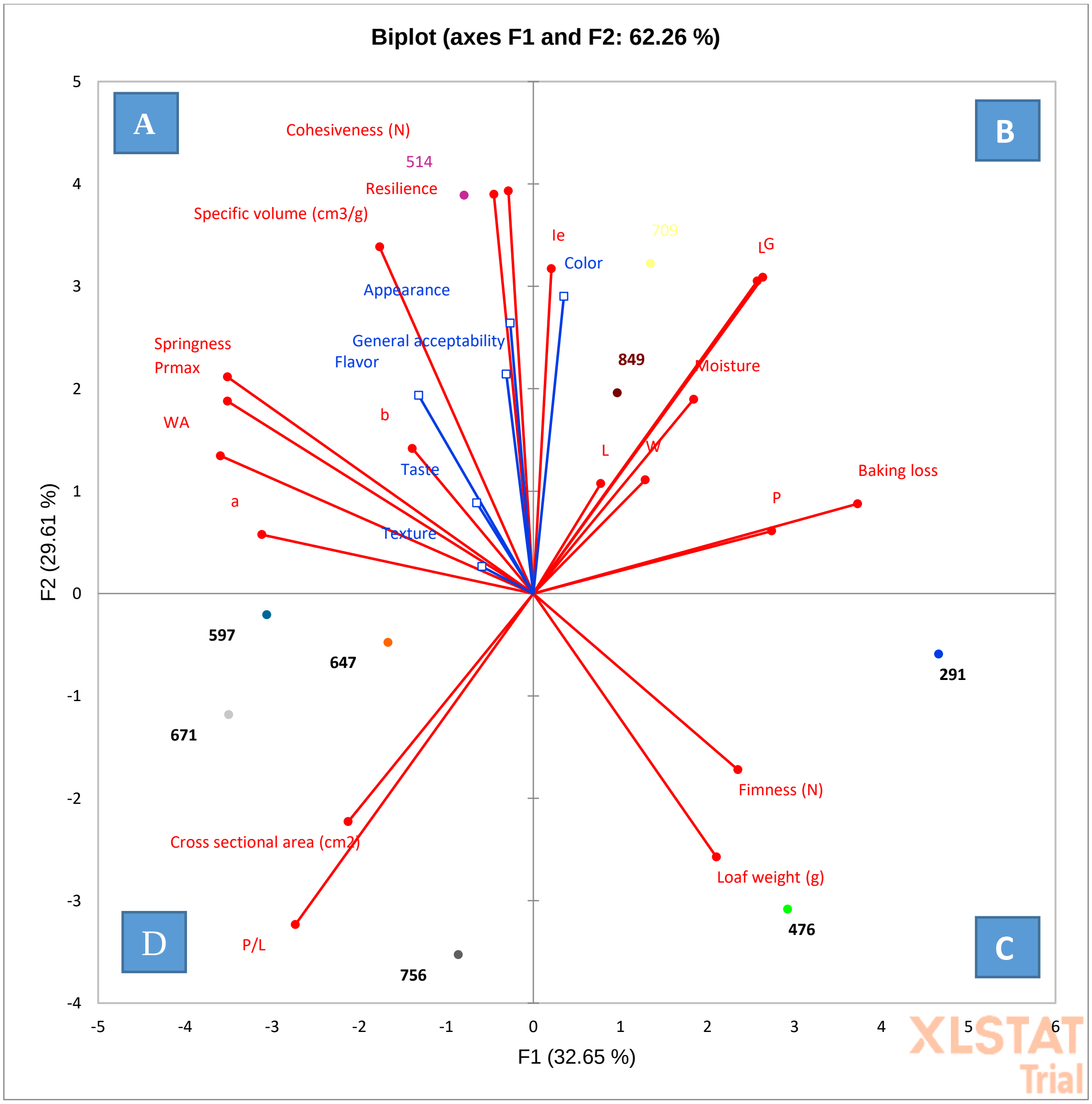


Figure 5. Principal component analysis of rheological, physical and sensory properties of bread obtained from wheat flour (70%) composited with different forms (pureed fresh vs flour, whole finger vs pulp) and varieties (*Mpologoma* vs N23) of green mature cooking bananas (30%). P = peak height, L = dough extensibility, P/ L = tenacity-to-extensibility ratio, Ie = elasticity index/elastic resistance, G = inflation required for maximum dough development, W = dough strength, PrMax. Bread samples: 597 = 30% N23 pulp flour, 671 = 30% *Mpologoma* pulp flour, 647 = 30% N23 whole banana flour, 756 = 30% *Mpologoma* whole banana flour, 476 = 30% fresh *Mpologoma* pulp, 291 = 30% fresh *Mpologoma* whole finger, 849 = 30% fresh N23 pulp.

The cohesiveness and specific volume are significantly positively correlated ($p<0.05$, r= 70.7) with bread sample 514 whereas resilience and loaf volume were significantly positively correlated ($p<0.05$, r= 69.9) with bread sample 476 (Figure 5). PCA also indicated that the springiness, cohesiveness and resilience of the wheat alone control bread was explained by its dough development time and water absorption which also contributed to its sensory texture, colour, taste, flavor and general acceptability. The effect of water absorption on springiness of the bread also also be explained by gluten dilution due to addition of bananas (Hoseney, 1994). This could be confirmed true because absence of bananas in the 100% wheat bread was associated with increased springiness of the bread due to increase in the dough development time and low fiber content both of which enhance formation of the gluten network in the dough (Callejo et al., 2009; Dachana et al., 2010; Nirmala et al., 2011).

However, bread samples 841's firmness was not correlated (r= 0.20) with its moistness. Quadrant C revealed that bread samples (476 and 291) whose firmness was associated ($p<0.05$, r= 0.660) with high loaf weight compared to the control. This confirms the fact that composite bakery products are firmer than wheat alone counterparts due to incorporation of non-wheat materials such as bananas. Similar results were reported by Crassina et al. (2012) while working with millet flour incorporated in wheat for production of cookies.

Quadrant B showed that the colour, moistness and baking loss in bread made using 30% N23 pulp flour was explained by the dough tenacity, dough strength, mixing tolerance and G indices of the dough (r= 64.4, 54, and 81.9, respectively). Mixing tolerance index contributes to the baking loss of the bread due to the fact that addition of non-wheat components dilutes the gluten content thereby decreasing its tolerance to mixing (Gunathilake et al., 2009).

General acceptance and appearance were significantly positively correlated ($p < 0.05$, r= 86.4 and 71.3, respectively) with b*. The positive yellow colour (b*) of the control bread detected using the colorimeter might be due to the presence of wheat germ which consequently contributes to the perceived overall brown colour of the bread and its general appearance as depicted in the PCA (Figure 5).

Quadrant D showed that the high cross-sectional area of composite breads 597, 647, 671 and 756 was explained by the tenacity-to-extensibility ratio (r= 63.1). Peak height (P) indicates the resistance that the dough offers to deformation and it is related with the tensile strength or stability that the dough exhibits during the proofing stage of bread making (Pyler, 1988; Mepba et al., 2007). The curve configuration ratio (P/L) is an index of gluten behavior. High configuration ratios indicate strong wheat flour as observed by Pyler (1988). However, the strength of composite flour is probably influenced by considerations other than gluten behavior (Adegoke et al., 2016). The above factors may explain in part, the trends observed in the results shown in Figure 5.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this work was to evaluate the potential of pureed fresh and dried green mature bananas as a functional ingredient for production of bread. The baking and confectionery industry should consider:

1. Addition of pureed fresh and/or powdered green mature cooking bananas to increase the time required to reach maximum consistency of the dough irrespective of variety.

2. Inclusion of pureed fresh *Mpologoma* whole fingers to reduce the water absorption capacity (WAC) of the dough which is undesirable, but the latter variety in flour form increases WAC to optimum levels for dough development. N23 a hybrid variety has minimal effect on these parameters.

3. Addition of bananas to reduce dough resistance to deformation and baking strength during handling and fermentation which leads to poor physical attributes of bread. Pureed fresh whole banana fingers or fresh banana pulp had relatively similar alveograph profiles to that of the wheat alone control implying better prospects for applying the latter in bread formulation than their flour counterparts.

4. Pureed fresh *Mpologoma* whole finger produced brighter crumb appearance and texture close to that of the wheat alone control highlighting the potential of this variety for application in the confectionery industry.

5. Overall, addition of 30% banana pulp flour produced the best composite bread in terms of taste and flavor, irrespective of variety, and could have better prospects for commercial application compared with other treatments.

5.2 Recommendations

- Addition of pureed whole bananas (fresh or flour) should be adopted by food processors to increase the resistant starch and dietary fibre content of bread to enhance consumer health.

- *Mpologoma* and N23 bananas should be added at a rate of 30-50% in pureed fresh or flour forms, to formulate bread with high resistant starch, dietary fibre content and good sensory attributes relative to the wheat alone control.

5.3 Further study

Further studies may focus on characterization and quantification resistant starch in banana-wheat composite bread and examine its effect of gut health *in vivo*. There is also a need to examine the potential of these banana varieties in other bakery products such as cakes.

REFERENCES

AACC (2001a). Approved Methods of the American Association of Cereal Chemists, American Association of Cereal Chemists, St Paul, MN.

AACC (2001b). American Association of Cereal Chemists. The definition of dietary fiber. *Cereal Food World* 46, 112-126.

Abang, Z.D.N., Chin, N.L. and Yusof, N.A. (2010). A review on rheological properties and measurements of dough and gluten. *Journal of Applied Sciences* 10, 2478–2490.

Adegoke, H.B, Oluwatooyin, F., Osundahunsi and Joseph, O.O. (2016). Rheological, baking, and sensory properties of composite bread dough with breadfruit (*Artocarpus communis* Forst) and wheat flours. *Food Science and Nutrition* 4, 573–587.

Alava, J.M., Sahi, S.S., Garcia-Alvarez, J., Turo, A., Chavez, J.A. and Garcia, M.J. (2007). Use of Ultrasound for the determination of flour quality. *Ultrasonics* 46, 270–276.

Ali, A., Shehzad, A., Khan, M. R., Shabbir, M. A., & Amjid, M. R. (2012). Yeast, its types and role in fermentation during bread making process-A. Pakistan Journal of Food Sciences, 22(3), 171-179.

Ali, A., Shehzad, A., Khan, M. R., Shabbir, M. A., & Amjid, M. R. (2012). Yeast, its types and role in fermentation during bread making process-A. Pakistan Journal of Food Sciences, 22(3), 171-179.

Al-mussali, M.S. and Al-gahri, M.A. (2009). Nutritive value of commonly consumed bread in Yemen. *E-Journal of Chemistry* 6, 437–444.

Amandikwa, C., Iweb, M.O., Uzomaha, A. and Olawunia, A.I. (2015). Physico-chemical properties of wheat-yamflour composite bread. *Nigerian Food Journal* 33, 12-17.

Anil, M. (2007). Using of hazelnut testa as a source of dietary fiber in breadmaking. *Food Engineering* 80, 61-67.

Anna, V.A., Agrobiznesu, I., Florkowski, W.J., Rubalema, J., Resurreccion, A.V.A. and Chinnan, M.S. (2014). Preferences for bakery products among urban residents in Uganda. Journal of Food and Nutrition Research 58, 72–76.

Annor, G.A., Asamoah-Bonti, P. and 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, 1–12.

Ariho, A., Makindara, J., Tumwesigye, G. and Sikira, A. (2015). Assessment of innovative market access options for banana value chain in Uganda. *Journal of Development and Agricultural Economics* 7, 323–331.

Asp, N.G. and Bjork, I. (1992). Resistant starch. *Trends in Food Science* 3, 111-114.

Aurore, G., Parfait, B. and Fahrasmane, L. (2009). Bananas, raw materials for making processed food products. *Trends in Food Science and Technology* 20, 78-91.

Aziah, L.H., Shazliana. N.A.A. and Rajeev, B. (2012). Quality evaluation of steamed wheat bread substituted with green banana flour. *International Food Research Journal* 19, 869-876.

Bakare, A.H, Osundahunsi, O.F. and Olusanya, J.O. (2016). Rheological, baking, and sensory properties of composite bread dough with breadfruit (*Artocarpus communis* Forst) and wheat flours. *Food Science and Nutrition* 4, 573–587.

Bakare, H.A. (2008). Evaluation of the rheological properties and baking performance of wheat composite flour produced from lye-peeled breadfruit (*Artocarpus communis* Forst) and cassava (Manihot esculenta crantz). PhD Thesis, University of Ibadan, Nigeria.

Balwinder, S., Jatinder, P.S., Amritpal, K. and Narpinder, S. (2016). Bioactive compounds in banana and their associated health benefits: a review. *Food Chemistry* 206, 1-11.

Belton, P.S. (1999). Mini review: On the elasticity of wheat gluten. *Journal of Cereal Science* 29, 103–107.

BeMiller, J.N. (2011). Pasting, paste, and gel properties of starch- hydrocolloid combinations. Carbohydr. *Polym* 86, 386–423.

Bennion, E. B., & Bamford, G. S. T. (1997). The technology of cake making. Springer Science & Business Media.

Bettge, A., Rubenthaler, G.L. and Pomeranz, Y. (1989). Alveograph algorithms to predict functional properties of in bread and cookie baking. *Cereal Chemistry* 66, 81–86.

Bezerra, C.V., Amante, E.R., Oliveira, D.C., Rodrigues, A.M.C. and Silva, L.H.M. (2013). Green banana (*Musa cavendishii*) flour obtained in spouted bed – Effect of drying on physic-chemical, functional and morphological characteristics of the starch. *Industrial Crops and Products* 41, 241-249.

Biliaderis, C.G., Izydorczyk, M.S. and Rattan, O. (1995). Effect of arabinoxylans on bread making quality of wheat flours. *Food Chemistry* 53, 165–171.

Bloksma, A.H. (1990). Rheology of the bread making process. *CFW* 35, 232–236.

Brooker, B. E. (1996). The role of fat in the stabilization of gas cells in bread dough. Journal of Cereal Science, 24(3), 187-198.

Brown, A., Tumuhimbise, R., Amah, D., Uwimana, B., Nyine, M., Mduma, H. and Swennen, R. (Editors) (2017). Bananas and plantains (*Musa* spp.). In Genetic Improvement of Tropical Crops. Springer International Publishing. Pp. 219-240.

Brown, L., Rosner, B., Willett, W.W. and Sacks, F.M. (1999). Cholesterol-lowering effects of dietary fibre: a meta-analysis. *The American Journal of Clinical Nutrition* 69, 30-42.

Byarugaba, W., Tumusiime, M. and Kimono, D.A. (2014). The technology of producing banana wine vinegar from starch of banana peels. *African Journal of Food Science and Technology* 5, 1–5.

Callejo, M.J., Bujeda, C., Rodriguez, G. and Chaya, C. (2009). Alveoconsistograph evaluation of rheological properties of rye dough. *Spanish Journal of Agricultural Research* 7, 638–644.

Castelo-Branco, V.N., Lago, M.G., Minuzzo, D.A., Moura-Nunes, N., Torres, A.G. and Nunes, J.C. (2016). Bread formulated with guava powder was enriched in phenolic and aroma compounds, and was highly acceptable by consumers. *Journal of Food Science and Technology* 53, 4168-4178.

Champ, M. and Guillon, F. (2000). Structural and physical properties of dietary fibres, and consequences of processing on human physiology. *Food Research International* 33, 233-245.

Chin, N.L. and Campbell, G.M. (2005). Dough aeration and rheology: part 2. Effects of flour type, mixing speed and total work input on aeration and rheology of bread dough. Scientific *Journal of Food and Agriculture* 85, 2194–2202.

Choe, E. and Min, D.B. (2015). Mechanisms of Antioxidants in the oxidation of foods. *Comprehensive Reviews in Food Science and Food Safety* 8, 345-358.

Chong, L.C. and Noor, A.A. (2010). Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. *Food Chemistry* 119, 34-40.

Crassina, A, Sheetal, G. and Venkateshwara, R.G. (2012). Effect of native and germinated finger millet flour on rheological and sensory characteristics of biscuits. *International Journal of Food Science and Technology* 47, 2413–2420.

Cummings, J.H., Beatty, E.R., Kingman, S.M., Bingham, S.A. and Englyst, H.N. (1996). Digestion and physiological properties of resistant starch in the human large bowel. *Brazilian Journal of Nutrition* 75, 733-747.

Dachana, K.B, Jyotsna, R., Indrani, D. and Prakash, J. (2010). Effect of dried Moringa (*Moringa oleifera* lam) leaves on rheological, microstructural, nutritional, textural and organoleptical characteristics of cookies. *Journal of Food Quality* 33, 660–677.

Danu, M., Rotaru, I., Ibănescu, C., Hurduc, N., Ibănescu, S. A., & Simionescu, B. C. (2012). Gluten content influence on rheological behavior of starch-gluten networks. Environmental Engineering.

Davidou, S., Le Meste, M., Debever, E. and Bekaert, D. (1996). A contribution to the study of staling of white bread: Effect of water and hydrocolloid. *Food Hydrocolloids* 10, 375–383.

Dervas, G., Doxastakis, G., Hadjisavva-Zinoviadi, S. and Triantafillakos, N. (1999). Lupine flour addition to wheat flour dough and effect on rheological properties. *Food Chemistry* 66, 67–73.

Dhaka, V., Gulia, N., and Khatkar, B.S. (2012). Application of Mixolab to Assess the Bread Making Quality of Wheat Varieties. 1: 183.

Dhingra, D., Mona, M., Rajput, H. and Patil, R.T. (2012). Dietary fibre in foods: a review. *Journal of Food Science and Technology* 49, 255-266.

Dobraszczyk, B. J., & Morgenstern, M. P. (2003). Rheology and the breadmaking process. Journal of cereal Science, 38(3), 229-245.

Dobraszczyk, B.J., and Salmanowicz, B.P. (2011). Comparison of predictions of baking volume using large deformation rheological properties. J Cereal Sci 47: 292-301.

Dotto, J., Matemu, A.O. and Ndakidemi, P.A. (2018). Potential of cooking bananas in addressing food security in East Africa. *International Journal of Biosciences* 13, 278–294.

Dotto, J., Matemu, A.O. and Ndakidemi, P.A. (2019). Nutrient composition and selected physicochemical properties of fifteen Mchare cooking bananas: A study conducted in northern Tanzania. *Scientific African* 6, 1-9.

Dowell, F.E., Maghirang, E.B., Pierce, R.O., Lookhart, G.L., Bean, S.R. and Xie, F. and Chung, O.K. (2008). Relationship of bread quality to kernel, flour, and dough properties. *Cereal Chemistry* 85, 82–91.

Doxastakis, G., Zafiriadis, I., Irakil, M., Marlani, H. and Tananaki, C. (2002). Lupin, soya and triticale addition to wheat flour dough and their effect on rheological properties. *Food* Chemistry 77, 219–227.

Dramola, B. and Osanyinlusi, S.A. (2006). Production, characterization and application of banana (*Musa* spp.) flour in whole maize. *African Journal of Biotechnology,* 5, 992-995.

Drzikova, B., Dongowsky, G., Gebhardt, E. and Habel, A. (2005). The composition of dietary fibre-rich extrudates from oat affects bile acid binding and fermentation in vitro. *Food Chemistry* 90, 181-192.

El-Dash, A.A., Tosello, A. and Roa, G. (1977). Pregelatinized Cara (water yam) flour: Effect on dough and bread quality. *Cereal Chemistry* 55, 799–808.

El-Soukkary, E.A.H. (2001). Evaluation of pumpkin seed products for bread fortification. *Plant Foods for Human Nutrition* 56, 365–384.

Englyst, H.N. and Cummings, J.H. (1986). Digestion of the carbohydrates of banana (*Musa paradisiaca* sapientum) in the human small intestine. *American Journal of Clinical Nutrition* 44, 42-50.

Faisant, N., Gallant, D.J., Bouchet, B., Champ, M. (1995). Banana starch breakdown in the human small intestine studied by electron microscopy. *European Journal of Clinical Nutrition* 49, 98-104.

FAO (1998). Food and Agriculture Organization of the United Nations. Carbohydrates in human nutrition. FAO Food and nutritional papers-66. Rome, Italy: Agriculture and consumer protection.

FAO (2019). Food and Agriculture Organization of the United Nations. Banana statistical compendium 2018. Rome, Italy.

Fasolin, L.H., Almeira, G.C., Castanho, P.S. and Netto-Oliveira, E.R. (2007). Chemical, physical, and sensorial evaluation of banana meal cookies. *Ciência e Tecnologia de Alimentos* 27, 787-792.

Figuerola, F., Hurtado, M.L., Estévez, A.M., Chiffelle, I. and Asenjo, F. (2005). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chemistry* 91, 395-401.

Fuentes-Zaragoza, E., Sánchez-Zapata, E., Sendra, E., Sayas, E., Navorro, C., Fernandez-López, J. and Pérez-Alvarez, J. (2011). Resistant starch as prebiotic: A review. *Starch* 63, 406-415.

Fustier, P., Csataigne, F., Turgeon, S.L. and Biladeris, C.G. (2008). Flour constituents' interactions and their influence on dough rheology and quality of semi- sweet biscuits: a mixture design approach with reconstituted blends of gluten, water solubles and starch fractions. *Journal of Cereal Science* 48, 144–158.

Gafuma, S. (2018). Influence of key chemical components on textural hardness of Ugandan indigenous cooking and juice banana cultivars. PhD Thesis. Kyambogo University.

Gallaher, D. and Schneeman, B.O. (2001). Dietary fibre. In: Bowman, B. and Russel, R. (Eds.), Present knowledge in nutrition. 8th ed. Washington DC. p. 805.

Garzón, M.A.G., Acosta, L.M.V., Cardona, L.J.M., Hurtado, M.A.A., Rodriquez, A.C.D., Taborda, N.C., Gutierrez, L.A.R. and Mejia, G.C.V. (2011). "Desarrollo de um product nutricional a partir de la harina obtenida del banana verde con cascara: una nueva opción para el aprovechamiento de residuos, de la industria de exportación". *Produción + Limpia* 6, 96-107.

Gerrard, J. A., Every, D., Sutton, K. H., & Gilpin, M. J. (1997). The role of maltodextrins in the staling of bread. Journal of Cereal Science, 26(2), 201-209.

Gomes, A.A.B., Ferreira, M.E. and Pimentel, T.C. (2016). Bread with flour obtained from green banana with its peel as partial substitute for wheat flour: Physical, chemical and microbiological characteristics and acceptance. International *Food Research Journal* 23, 2214-2222.

Gómez, A., Ferrero, C., Calvelo, A., Añón, M.C. and Puppo, M.C. (2011). Effect of mixing time on structural and rheological properties of wheat flour dough for bread making. *International Journal of Food Properties* 14, 583–598.

Goni, I., Garcia-Alonso, A. and Saura-Calixto, F. (1996). Analysis of resistant starch: a method for foods and food products. *Food Chemistry* 6, 445-449.

Greene, J.L. and Bovell-Benjamin, A.C. (2004). Macroscopic and sensory evaluation of bread supplemented with sweet potato flour. *Journal of Food Science* 69, 167–173.

Güemes-Vera, N., Arciniega-Ruiz Esperza, O. and Dávila-Ortiz, G. (2004). Structural analysis of the Lupinus Mutabilis seed, its flour, concentrate, and isolate as well as their behavior when mixed with wheat flour. *LWT – Food Science and Technology* 37, 283–290.

Gunathilake, K.D.P.P., Yalegama, C. and Kumara, A.A.N. (2009). Use of coconut flours as a source of protein and dietary fiber in wheat bread. *Asian Food Agro-Industrial Journal* 2, 382–391.

Hamit, K., Kevser, K., Turgay, S., Dilek, S. and Arnaud, D. (2014). Potential utilization of Mixolab for quality evaluation of bread wheat genotypes. *Cereal Chemistry* 86, 522–526.

Hapi, T., Herinavalona, R., Wathelet, B., Tchango, J. and Paquot, M. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chemistry* 103, 590-600.

Heslop-Harrison, J.S. (2011). Genomics, banana breeding and superdomestication. In Acta

Horticulturae. *International Society for Horticultural Science* 897, 55–62.

Ho, L.H., Abdul Aziz, N.A., and Azahari, B. (2013). Physico-chemical characteristics and sensory evaluation of wheat bread partially substituted with banana (Musa acuminata X balbisiana cv. Awak) pseudo-stem flour. Food Chem., 139, 532–539.

Hoseney, C.R. (1994). Principles of cereal science and technology. AACC Press, St. Paul, p. 87.

ICC (2006). Approved Standard 173. International Association for Cereal Science and Technology: Vienna.

Indrani, D. and Rao, G.V. (2007). Rheological characteristics of wheat flour dough as influenced by ingredients of parotta. *Journal of Food Engineering* 79, 100–105.

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

Janssen, A.M., van Vliet, T. and Vereijken. J.M. (1996). Fundamental and empirical rheological behaviour of wheat flour dough and comparison with bread making performance. *Journal of Cereal Science* 23, 43–54.

Jenkins D.J.A., Kendall, C.W.C. and Ransom, T.P.P. (1998). Dietary fibre, the evolution of the human diet and coronary heart disease. *Nutritional Research* 18, 633-652.

Jiménez-Escrig, A. and Sánchez-Muniz, F.J. (2000). Dietary fibre from edible seaweeds: Chemical structure, physicochemical properties and effects on cholesterol metabolism. *Nutritional Research* 20, 585-598.

Juarez-Garcia, E., Agama-Acevedo, E., Sáyago-Ayerdi, S.G., Rodriguez-Ambriz, S.L. and Bello-Perez, L.A. (2006). Composition, digestibility and application in breadmaking of banana flour. *Plant Foods for Human Nutrition* 61, 131–137.

Kabahenda, M. and Kapiriri, M.N. (2010). Analysing agricultural science and technology innovation systems: A case study of the banana sub-sector in Uganda. *Second RUFORUM Biennial Meeting* 20 - 24 September 2010, Entebbe, Uganda.

Karamura, E., Frison, E., Karamura, D.A. and Sharrock, S. (1998). Banana production systems in eastern and southern Africa. *Bananas and Food Security* 32, 401–412.

Kathleen, M.L. and Janice, R.L. (2017). Krause's Food and the Nutrition Care Process. Elsevier Inc.

Khatkar, B.S., Bell, A.E. and Schofield, J.D. (1995). The dynamic rheological properties of glutens and gluten sub-fractions from wheats of good and poor bread making quality. *Journal of Cereal Science* 22, 29–44.

Kisenyi, W.N. (2020). Relationship between physicochemical and sensory properties of selected local and hybrid cooking bananas in Uganda. Thesis. Kyambogo University.

Koksel, H., Kahraman, K., Sanal, T., Ozay, D.S., and Dubat, A. (2009). Potential Utilization of Mixolab for Quality Evaluation of Bread Wheat Genotypes. Cereal Chem. 86(5):522–526.

Komarek, A. (2010). The determinants of banana market commercialisation in Western Uganda. *African Journal of Agricultural Research* 5, 775–784.

Kurhade, A., Patil, S., Sonawane, S.K., Waghmare, J.S., Arya, S.S. (2016). Effect of banana peel powder on bioactive constituents and microstructural quality of chapatti: Unleavened Indian flat bread. J. Food Meas. Charact., 10, 32–41.

Lattimer, J.M. and Haub, M.D. (2010). Effects of dietary fiber and its components on metabolic health. *Nutrients* 12, 1266-1289.

Lee, K.A. and Brennand, C.P. (2005). Physico-chemical, textural and sensory properties of a fried cookie system containing soy protein isolate. *International Journal of Food Science and Technology* 40, 501–508.

Lehmann, U., Jacobasch, G. and Schmiedl, D. (2002). Characterization of resistant starch type III from banana (Musa acuminata). *Journal of Agricultural and Food Chemistry* 50, 5236–5240.

MacRitchie, F. (1973). Conversion of a weal flour to a strong one by increasing the proportion of its high molecular weight gluten protein. *Scientific Journal of Food and Agriculture* 24, 1325-1331.

Maforimbo, E., Skurray, G., Uthayakumaran, S. and Wringley, C. (2007). Incorporation of soy proteins into the wheat–gluten matrix during dough mixing. *Journal of Cereal Science* 47, 380–385.

Malomo, O., Jimoh, M.O., Adekoyeni, O.O., Soyebi, O.E. and Alamu. E.A. (2013). Effect of blanching and unblanching on rheological properties of sweet- potato bread. *Academic Research Journal* 1, 24–41.

Marco, C. and Rosell, C.M. (2008). Breadmaking performance of protein enriched, gluten-free breads. *European Food Research and Technology* 227, 1205–1213.

Mariera, L.N. (2018). Evaluation of wheat-sorghum-chickpea composite bread for physical, nutritional and sensory quality. MSc thesis submitted to Egerton University, Kenya. Pp. 1-64.

Martínez-Castaño, M., Lopera-Idarraga, J., Pazmiño-Arteaga, J., Gallardo-Cabrera, C. (2019). Evaluation of the behaviour of unripe banana flour with non-conventional flours in the production of gluten-free bread. Food Sci. Technol. Int.

Martínez-Castaño, M.; Lopera-Idarraga, J.; Pazmiño-Arteaga, J.; Gallardo-Cabrera, C. (2019). Evaluation of the behaviour of unripe banana flour with non-conventional flours in the production of gluten-free bread. Food Sci. Technol. Int. 2019, 0, 1082013219873246.

Meera, K. (2010). Falling number in wheat-how is it calculated and what does it mean to producers? USA: USDA, ARS, Soft wheat Quality Lab. Alpha amylase mkweon-FN-012810 pdf. (Accessed 19 Jan 2021).

Menezes, E.W., Tadini, C.C., Tribess, T.B., Zuleta, A., Binaghi, J., Pak, N., Vera, G., Dan, M.C.T., Bertolini, A.C., Cordenunsi, B.R. and Lajolo, F.M. (2011). Chemical composition and nutritional value of unripe banana flour (*Musa acuminata*, var. Nanicão). *Plant Foods for Human Nutrition*. DOI 10.1007/s11130-011-0238-0

Mepba, H.D., Eboh, L. and Nwaojigwa, S.U. (2007). Chemical composition, functional and baking properties of wheat-plantain composite flours. *African Journal of Food, Agriculture and Nutrition Development* 7, 1–22.

Michiyo, W., Tomoko, M., Kikuchi, T., Hiroshi, K. and Naofumi, M. (2004). Application of pregerminated brown rice for breadmaking. *Cereal Chemistry* 81, 450–455.

Mirsaeedghazi, H., Emam-Djomeh, Z. and Mousavi, S.M.A. (2008). Rheometric measurement of dough rheological characteristics and factors affecting it. *International Journal of Agriculture and Biology* 10, 112–119.

Mohamed, A., Xu, J., and Singh, M. (2010). Yeast leavened banana-bread: Formulation, processing, colour and texture analysis. Food Chem., 118, 620–626.

Muranga, F.I., Mutambuka, M., Nabugoomu, F. and 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, 223–230.

Muranga, F.I., Nabugoomu, F. and Katebarirwe, J.G. (2011). Effect of optimal incorporation of hybrid banana flours on acceptability of soy fortified banana flour-based products. *African Journal of Biotechnology* 10, 19788–19795.

Nakisozi, H (2017). Optimisation of bread quality from wheat, banana and cassava composite flour. Thesis. Kyambogo University.

Ndife, J., Abdulraheem, L.O. and Zakari, U.M. (2011). Evaluation of the nutritional and sensory quality of functional breads produced from whole wheat and soya bean flour blends. *African Journal of Food Science* 5, 466–472.

Nirmala, M., Jyotsna, R., Jeyarani, T. and Venkateshwara, R.G. (2011). Influence of debittered, defatted fenugreek seed powder and flax seed powder on the rheological characteristics of dough and quality of cookies. *International Journal of Food Science and Nutrition* 62, 336–344.

Noor, A.A., Ho, L.H., Shazliana, A.A. and Rajeev, B. (2012). Quality evaluation of steamed wheat bread substituted with green banana flour. *International Food Research Journal* 19, 869-876.

Noorfarahzilah, M., Lee, J.S., Sharifudin, M.S., Fadzelly, A.B. and Hasmadi, M. (2014). Applications of composite flour in development of food products. *International Food Research Journal* 21, 2061–2074.

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

Nyombi, K. (2013). Towards sustainable highland banana production in Uganda: opportunities and challenges. *African Journal of Food, Agriculture, Nutrition and Development* 13, 111-120

Ohizua, E.R., Adeola, A.A., Idowu, M.A., Sobukola, O.P., Afolabi, T.A., Ishola, R.O. and Falomo,

A. (2017). Nutrient composition, functional, and pasting properties of unripe cooking banana, pigeon pea, and sweetpotato flour blends. *Food Science and Nutrition* 5, 750–762.

Olatunji, O. and Akinrele, I.A. (1978). Comparative rheological properties and bread qualities of wheat flour diluted with tropical tuber and breadfruit flour. *Cereal Chemistry* 55, 1–6.

Ovando-Martinez, M., Sayago-Ayerdi, S., Agama-Acevedo, E., Goni, I. and Bello-Perez, L.A. (2009). Unripe banana flour as an ingredient to increase the undigestible carbohydrates of pasta. *Food Chemistry* 113, 121-126.

Oyeku, M.O., Kupoluyi, C.F., Osibanjo, H.A., Orji, C.U., Ajuebor, F.N. and Ajiboshin, I.O. (2008). An economic assessment of commercial production of 10% cassava- wheat composite flour bread. *Journal of Industrial Research Technology* 2, 13–20.

Ozturk, S., Kahraman, K., Tiftik, B. and Koksel, H. (2008). Predicting the cookie quality of flours by using Mixolab. *European Journal of Food Research and Technology* 227, 1549–1554.

Pacheco-Delahaye, E. and Testa, G. (2005). Evaluación nutritional fisica y sensorial de panes de trigo y plátano verde. *Interciencia* 30, 300-304.

Paraskevopoulou, A., Provatidou, E., Tsotsiou, D. and Kiosseoglou, V. (2010). Dough rheology and baking performance of wheat flour–lupin protein isolate blends. *Food Research International* 43, 1009–1016.

Pena, R. J., Cervantes-Espinoza, M. I., Ortiz-Monasterio, J. I., and Dubat, A. (2006). Gluten composition, gluten quality, and dough mixing properties (National-Mixograph; Chopin-Mixolab) of high yielding wheats derived from crosses between common (Triticum aestivum) and synthetic (T. dicoccon × Aegilops tauschii) wheats. In Proc. EUCARPIA: Hungary.

Pereira, A. and Maraschin, M. (2015). Banana (*Musa* spp.) from peel to pulp: Ethnopharmacology, source of bioactive compounds and its relevance for human health. *Journal of Ethnopharmacology* 160, 149-163.

Pyler, E.J. (1988). Baking science and technology, 3rd ed. 1 and II. Sosland Publishing Company, Reno, NV, USA. P. 345.

Ramli, S.B., Alkarkhi, A.F.M., Yong, Y.S. and Easa, A.M. (2010). Physicochemical properties of banana peel flour as influenced by variety and stage of ripeness: multivariate statistical analysis". *Journal of Agricultural Science and Technology* 4, 1250-1939.

Rieder, A., Holtekjølen, A.K., Sahlstrøm, S. and Moldestad, A. (2012). Effect of barley and oat flour types and sourdoughs on dough rheology and bread quality of composite wheat bread. *Journal of Cereal Science* 55, 44-52.

Roccia, P., Ribotta, P.D., Pérez, G.T. and León, A.E. (2009). Influence of soy protein on rheological properties and water retention capacity of wheat gluten. *LWT – Food Science and Technology* 42, 358–362.

Rosell, C. M. (2011). The science of doughs and bread quality. In Flour and breads and their fortification in health and disease prevention (pp. 3-14). Academic Press.

Sarawong, C., Gutierrez, Z.R., Berghofer, E. and Schoenlechner, R. (2014b). Effect of green plantain flour addition to gluten-free bread on functional bread properties and resistant starch content. *International Journal of Food Science and Technology* 49, 1825–1833.

Sarawong, C., Schoenlechner, R., Sekiguchi, K., Berghofer, E. and Perry, K.W.N. (2014a). Effect of extrusion cooking on the physicochemical properties, resistant starch, phenolic content and antioxidant capacities of green banana flour. *Food Chemistry* 143, 33-29.

Schiller, G.W. (1984). Bakery flour specifications. *CFW* 29, 647–651.

Schiraldi, A., & Fessas, D. (2012). The role of water in dough formation and bread quality. In Breadmaking (pp. 352-369). Woodhead Publishing.

Sharp, R. and Macfarlane, G.T. (2000). Chemostat enrichments of human feces with resistant starch are selective for adherent butyrate-producing clostridia at high dilution rates. *Applied Environmental Microbiology* 66, 4212-4221.

Shimelis, E., Meaza, M. and Raskshit, S. (2006). Physico-chemical properties, pasting behaviour and functional characteristics of flour and starches from improved Bean (*Phaseoulus vulgaris* L.) varieties grown in East Africa. *Agricultural Engineering International* 21, 5–15.

Shittu, T.A., Egwunyenga, R.I., Sanni, L.O. and Abayomi, L. (2014). Bread from composite plantain-wheat flour: Effect of plantain fruit maturity and flour mixture on dough rheology and fresh loaf qualities. *Journal of Food Processing and Preservation* 38, 1821–1829.

Shittu, T.A., Raji, A.O. and Sanni, L.O. (2007). Bread from composite cassava-wheat flour: Effect of baking time and temperature on some physical properties of bread loaf. *Food Research International* 40, 280–290.

Shuey, W. C. (1990). Interpretation of the farinogram. *Farinograph Manual* 1, 31–36.

Siddiq, M., Nasir, M., Ravi, R., Butt, M.S., Dolan, K.D. and Harte, J.B. (2009). Effect of defatted maize germ flour addition on the physical and sensory quality of wheat bread. L*WT- Food Science and Technology* 42, 464-470.

Simmonds, N.W. (2007). Notes on Banana Taxonomy. Kew Bulletin.

Soto-Maldonado, C., Concha-Olmos, J., Cáceres-Escobar, G. and Meneses-Gómez, P. (2018). Sensory evaluation and gycaemic index of a food developed with flour from whole (pulp and peel) overripe banana (*Musa cavendishii*) discards. *LWT Food Science and Technology* 92, 569-575.

Ssemwanga, J.K., Thompson, A.K. and Aked, J. (2000). Quality and acceptability of the new banana cultivar FHIA 3 compared to indigenous Uganda cultivars for matooke preparation. *Acta Horticulturae* 540, 61-70.

Subbaiah, K.V., Jagadeesh, S.L., Reddy, S. and Kanamadi, V.C. (2013). Effect of varieties and pre-treatments on physic-chemical and sensory quality of banana papads. Karnataka *Journal of Agricultural Science* 26, 115-118.

Tripathi, L., Nath, J. and Irie, T. (2007). Bananas and Plantains (*Musa* spp .): *Transgenic Plant Journal* 27, 186-201.

Tsamo, C., Herent, M.F., Tomekpe, K., Happi, T., Quetin-Leclercq, J., Rogez, H. and Andre, C. (2015). Phenolic profiling in the pulp and peel of nine plantain cultivars (*Musa* sp.). *Food Chemistry* 167, 197-204.

Tumuhimbise, R., Buregyeya, H., Barekye, A., Ssali, R.T., Kubiriba, J., Muhangi, S. and Karamura, E. (2016). Selection of cooking banana genotypes for yield and black Sigatoka resistance in different locations in Uganda. *Journal of Plant Breeding and Crop Science* 8, 60–71.

UBOS (2010). Uganda census of agriculture crop area and production report. www.ubos.org

Van Hall, M.V. (2000). Quality of sweet potato flour during processing and storage. *Food Research International* 16, 1–37.

van Vliet, T., Janssen, A.M., Bloksma, A.H. and Walstra, P. (1992). Strain hardening of dough as a requirement for gas retention. *Journal of Texture Studies* 23, 439–460.

Velazquez, O.C., Lederer, H.M. and Rombeau, J.L. (1996). Butyrate and the colonocyte, Implication for neoplasia. *Journal of Digestion Science* 41, 727-739.

Veluppillai, S., Nithyanantharajah, K., Vasantharuba, S., Balakumar, S. and Arasaratnam, V. (2010). Optimization of bread preparation from wheat flour and malted rice flour. *Rice Science* 17, 51-59.

Watson, C.A. (1984). An instrument for determining alpha – amylase activity. *CFW* 29, 507–509.

Wieser, H. (2007). Chemistry of gluten proteins. *Food Microbiology* 24, 115–119.

Wieser, H. (2007). Chemistry of gluten proteins. Food microbiology, 24(2), 115-119.

Wongsagonsup, R., Kittisuban, P., Yaowalak, A. and Suphantharika, M. (2015). Physical and sensory qualities of composite wheat-pumpkin flour bread with addition of hydrocolloids. *International Food Research Journal* 22, 745-752.

Zanoni, B. and Peri, C. (1993). A study of the bread-baking process: A phenomenological model. *Journal of Food Engineering* 19, 389-398.

Zeleznak, K. J., & Hoseney, R. C. (1986). The role of water in the retrogradation of wheat starch gels and bread crumb. Cereal chem, 63(5), 407-411.

Zhang, P., Whistler, R.L., BeMiller, J.N. and Hanaker, B.R. (2005). Banana starch: production, physicochemical properties and digestibility – a review. *Carbohydrate Polymers* 59, 443–458.

Zobel, H.F. and Kulp, K. (1996). The staling mechanism. In R. E. Hebeda & H. F. Zobel (Eds.), Baked goods freshness (pp. 1–64). New York: Marcel Dekker, Inc.

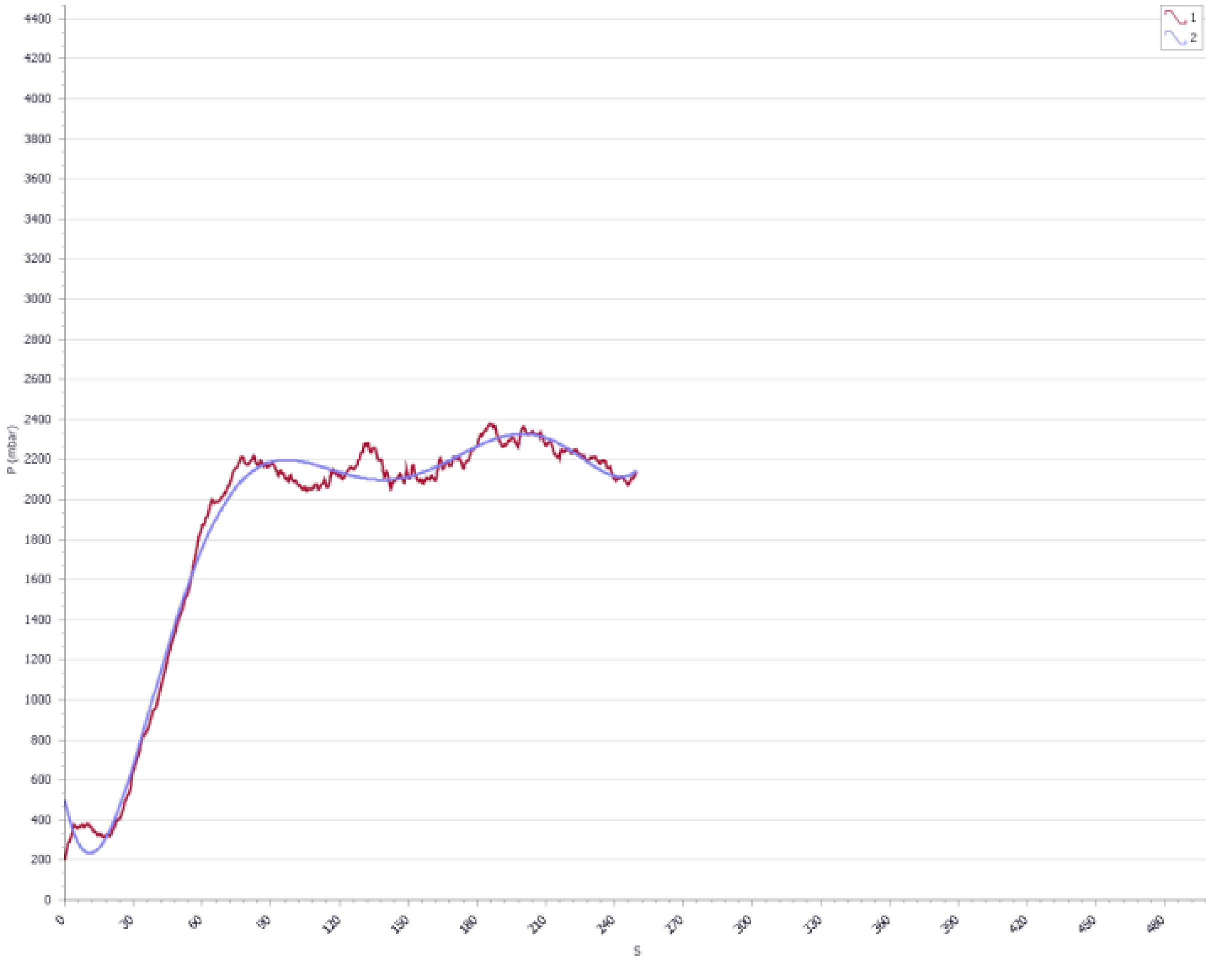
Zuleta, A., Binaghi, M.J., Greco, C.B., Aguirre., C., Dela Casa, L., Tadin, C. and Ferrer, P.A.R. (2012). Deseño de panes funcionales. *Revista Chilena de Nutrición* 39, 58-64.

Zuwariah, I. and Aziah, A.A.N. (2009). Physicochemical properties of wheat breads substituted with banana flour and modified banana flour. *Journal of Tropical Agriculture and Food Science* 37, 33–42.

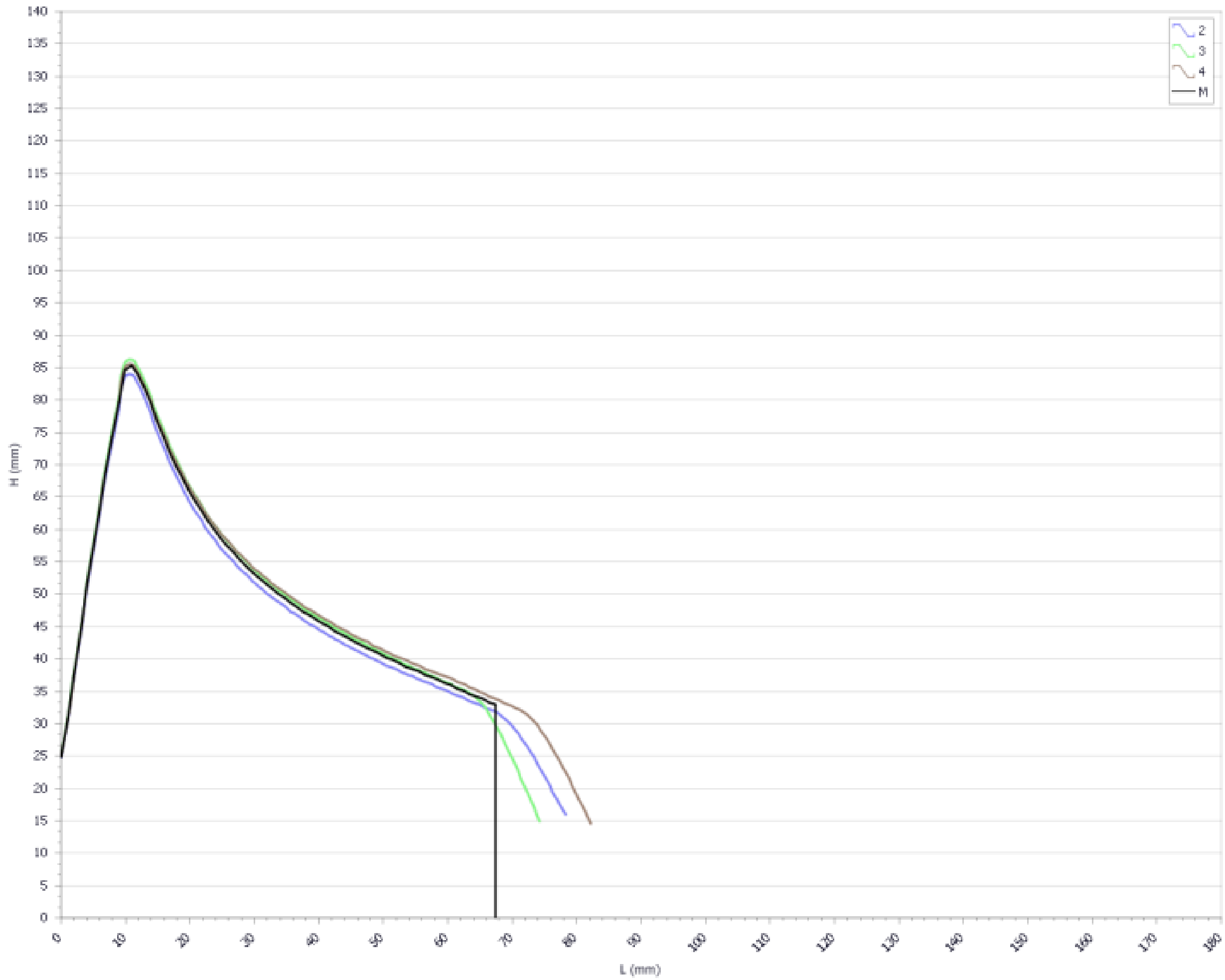
APPENDICES

Appendix I: Banana varieties used in the study. A, N23 hybrid; B, *Mpologoma*

Appendix II: Consistographic profile of high gluten wheat flour



Appendix III: Alveographic profile of dough obtained from high gluten wheat flour



Appendix IV. Ballot used for sensory evaluation of the banana – wheat composite bread

Panelist No.________________________

You are provided with samples of bread. Please observe and record your liking of the samples on the scale of 1 to 9 by placing your score in the box next to the sensory parameter under each sample in the table. Please evaluate the breads in the order in which they are presented. Use the water provided to refresh your palate before and between samples.

ANSWER ALL QUESTIONS. We would like to know what you think!!

Score the products using hedonic scale below	
Like extremely	**9**
Like very much	**8**
Like moderately	**7**
Like slightly	**6**
Neither like nor dislike	**5**
Dislike slightly	**4**
Dislike moderately	**3**
Dislike very much	**2**
Dislike extremely	**1**

Quality attributes	**Sample No.**											
Appearance												
Color												
Flavor												
Taste												
Mouth feel/ texture												
General acceptability												

Quality attributes	**Sample No.**											
Appearance												
Color												
Flavor												
Taste												
Mouth feel/ texture												
General acceptability												

Which sample (only one) would you prefer and why?

....………………………………………...

General comments (if any):

……………………………………………………………………………………………………

Thank you for participating in this exercise