DOUGH RHEOLOGY AND BAKING PROPERTIES OF BREAD FROM WHEAT/ HYBRID BANANA COMPOSITE FLOUR

BY

BAKER KIMERA

REG NO.: 20/U/GMFT/13324/PD

DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF SCIENCE IN FOOD TECHNOLOGY OF KYAMBOGO UNIVERSITY

FEBRUARY 2024

DECLARATION

I, Baker Kimera, declare that this dissertation is my original piece of work and has never been submitted to any university or higher institution of learning for any award of a degree and where other works have been included, it has been cited.

Baker Kimera,

Reg. No: 20/U/GMFT/13324/PD

Department of Food Science and Technology,

Faculty of Science, Kyambogo University

Signature...………………………………………Date………………………………………

SUPERVISORS

1. Dr. Musalima Hatoho Juliet

Lecturer

Department of Food Science and Technology

Faculty of Science, Kyambogo University

Signature...………………………………………Date………………………………………

2. Dr. Samuel Gafuma

Lecturer

Department of Food Science and Technology

Faculty of Science, Kyambogo University

Signature...………………………………………Date………………………………………

DEDICATION

This work is dedicated to my family for the support and encouragement offered to me in this academic pursuit.

ACKNOWLEDGEMENT

I wish to thank the Almighty Allah for the provision, favour, grace, guidance and strength that he has given me all throughout this academic journey and also for enabling me carry out this research successfully.

I am deeply grateful to my supervisors, Dr. Juliet Musalima and Dr. Samuel Gafuma for the guidance, encouragement and patience that they accorded me in the course of this research.

Special thanks go to the administration and management of Kyambogo University Business Incubation Centre (KYU BIC), for the partial research grant which offered me an opportunity to carry out my research in an effective and timely manner.

I am equally indebted to all my lecturers; Assoc. Prof. Ediriisa Mugampoza, Assoc. Prof. G.W. Bazirake, Dr. Martin Mutambuka, Ms. Phionah Nakatete, Dr. Phoebe Kaddumukasa, Dr. Matia Mukama, Dr. Michael Bamuwamye, Mr. Tony Kiyimba and Mr. Jacob Tengi for all the knowledge and skills they imparted in me during my study.

With gratitude, I acknowledge my wife, Mrs. Lydia Bwamiki Kimera. Her support made this academic journey a lot easier.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In spite of high productivity and good agronomic adoptability of hybrid cooking bananas, they have undesirable sensory characteristics hence low consumer acceptability. This study aimed at evaluating the effect of partial substitution of wheat with hybrid cooking banana flour on the dough rheology and baking properties of composite bread. Five hybrid banana varieties; M30, M9, N15, N21 and N23 were used in this study. Bananas at green maturity were processed into flour and blended with wheat to make various composite flours (10/90, 20/80, 30/70 and 40/60%). Unblended wheat flour (100%) was used as a control. The different blends were then used to make the wheat composite bread using the straight-dough method. Rheological properties of the composite dough were analyzed using a consistograph (water absorption capacity and maximum pressure), alveograph (peak height, extensibility and baking strength) and farinograph (mixing tolerance index and development time). Textural properties (hardness, springiness, cohesiveness) were determined using the texture analyzer while sensory attributes were investigated using the 9-point hedonic scale. The dough rheology values reported in this study ranged from; water absorption capacity (47.25% to 54.45%), maximum pressure (1315.50 mbar to 2911.50 mbar), peak height (82.50 mm to 151.50 mm), extensibility (19.50 mm to 113.50 mm), baking strength (67.50 J to 244.50 J), development time (1.10 min to 5.40 min) and mixing tolerance index (86.00 BU to 175.50 BU).

Hardness increased with increasing banana flour percentage inclusions, ranging from 2.09 N to 4.39 N. Springiness had no specific trend across the hybrids, but ranged from 0.35 to 0.80. Cohesiveness decreased with an increase in banana flour inclusion levels, ranging from 0.05 to 0.56. Sensory evaluation results showed a decrease in panel acceptability of the composite bread as the percentage inclusion of hybrid banana flour increased. The best scores for the sensory parameters evaluated were recorded at 10% inclusions of M30. Inclusion of hybrid banana flour up to 10% for all varieties studied as well as 20% inclusions for M30, N21 and N15 was comparable to 100% wheat flour. It is therefore recommended to use up to 20% inclusion levels of hybrid cooking banana flour from M30, N21 and N15 in preparation of hybrid banana / wheat composite bread.

Key Words: Composite flour, hybrid cooking bananas, wheat, dough rheology, textural properties, sensory attributes, Uganda.

CHAPTER ONE: INTRODUCTION

1.1 Background

Bread is one of the most widely consumed staple foods worldwide, providing essential nutrients and dietary energy to populations globally (Richard, 2020). Wheat flour has been the traditional main ingredient for bread production due to its gluten content, which imparts desirable viscoelastic properties to the dough and contributes to the structure and texture of the final product (Igrejas et al., 2020). Most of the wheat used in bread processing in Uganda is imported from other countries increasing the cost of bread production (Amone, 2014). The increasing demand for alternative and nutritious food sources has led to the exploration of novel composite flours (Mikus et al., 2021).

Bananas are a member of the Musaceae family, genus, Musa, and are a fruit that easily spoils. Equatorial regions of the world are the largest growers of bananas (Voora et al., 2023). Bananas are categorized as non-cooking and cooking varieties and are mainly grown for household consumption (Marimo et al., 2019). A number of indigenous and hybrid cooking banana varieties are native to Uganda. Uganda and Tanzania produce most of the bananas harvested in the East African region with a combined annual output of 20.4 million tonnes (FAOSTAT 2018). Hybrid bananas have gained attention as a potential ingredient in composite flours due to their unique nutritional profile and desirable functional properties. Hybrid banana flour has shown promise in various food applications, including bakery products, due to its high resistant starch content, dietary fiber, and natural sweetness. Incorporating hybrid banana flour into wheat flour has the potential to enhance the nutritional value of bread while maintaining acceptable sensory qualities (Ayo-Omogie & Odekunle, 2017). *Nakitembe*, *Mpologoma*, and *Kibuzi* are examples of indigenous cooking bananas having high consumer acceptability, mainly because their soft texture and good flavour (Marimo et al., 2019). In Uganda, hybrid varieties such as; FHIA 17, FHIA 23, N21, N7 (M9), NABIO 808 (M30), NAROBan 1, and NAROBan 2 have low adoption and consumption due to poor sensory properties (Gafuma, 2019) and therefore underutilized.

Dough rheology refers to the study of the flow and deformation behavior of dough, which is a complex system consisting of flour, water, yeast, and other ingredients (Shongwe et al., 2022). It involves the understanding of how the dough responds to mechanical forces during mixing, kneading, and fermentation (Nie et al., 2019). Substituting hybrid banana cooking flour for wheat flour at different percentage inclusions might impact the dough rheology in a number of aspects such as; viscosity changes, where banana flour may absorb moisture differently than wheat flour, affecting the overall viscosity of the dough, with higher percentages of banana flour leading to a stickier and less elastic dough (Osundahunsi, et al., 2016). Gluten Interaction is another factor, where higher inclusions of banana flour will weaken gluten development, affecting dough structure (Amjid et al., 2013).

Baking Properties encompass various factors related to the transformation of dough into the final baked product (Ayo-Omogie & Odekunle, 2017) and include rising and leavening, which are related to the expansion of dough due to the production of gases, primarily carbon dioxide, by yeast or chemical leavening agents (Chen et al., 2009). Maillard browning, which is the reaction between amino acids and reducing sugars, contributing to the crust color and flavor development (Bakare et al., 2016). Crumb structure, related to the internal structure of the bread, influenced by factors like gas retention, gluten development, and fermentation (Osella et al., 2008). Texture, which represents the overall feel of the bread, including crust crispiness and crumb softness and color, the visual appearance of the crust and crumb (Atudorei et al., 2021).

Substituting hybrid banana cooking flour for wheat flour at different percentage inclusions will impact baking properties in the following ways; the sugar content in banana flour can influence yeast activity, with higher percentages affecting the rate of fermentation and gas production (Kaya & Sahin, 2015). The banana flavor will become more pronounced with higher inclusions, impacting the overall taste and aroma of the bread. Higher percentages of banana flour inclusions might lead to a denser crumb, since gluten development will be reduced (Zghal et al., 2001). Higher banana flour content may impart a more yellowish hue to both the crust and crumb. Banana flour can add nutritional value, including potassium and dietary fiber. Sensory evaluations can provide valuable feedback on the acceptability of the bread at different inclusion levels.

This study investigated the effect of the selected banana varieties on the dough rheology properties and quality characteristics of wheat composite bread.

1.2 Problem Statement

Hybrid cooking bananas, renowned for their nutritional content, versatility, and resilience to diseases (Kikulwe et al., 2018), are often criticized for having a flavor profile that falls short of consumer expectations (Nowakunda & Tushemereirwe, 2004). The taste is frequently described as bland, starchy, or lacking the desirable sweetness associated with traditional / local bananas (Marimo et al., 2019). Poor flavor perception translates into reduced market demand for hybrid cooking bananas as well as utilization (Wilberforce et al., 2014). As a result, farmers face challenges in selling their produce, leading to surplus bananas in the market (Biosci et al., 2018). This surplus coupled with decreased demand, contributes to post-harvest losses, with farmers struggling to sell their entire harvest, leading to wastage and inefficiencies in the supply chain (Akankwasa et al., 2021). Finding alternative uses for these hybrid cooking bananas such as use in the baking industry particularly bread making can address this challenge.

Utilization of hybrid banana flour as a partial substitute for wheat flour in bread production may as well introduce complexities with regard to dough rheology and baking properties (Ewunetu et al., 2023). These complexities are related to the reduction in levels of the functional protein gluten that provides for elasticity, gas retention and extensibility of baked products and ultimately affecting the baking outcome (Huang et al., 2019).

Consuming the same type of bread made solely from wheat flour over an extended period can result in a loss of interest and enjoyment in the food (taste fatigue) (Cappelli & Cini, 2021). By using composite flours, which combine wheat flour with other ingredients like hybrid banana flour, the flavor profile of the bread can be diversified.

1.3 Objectives

1.3.1. Main Objective

To investigate the effect of selected varieties of hybrid cooking bananas on dough rheology and baking properties of wheat composite bread.

1.3.2 Specific Objectives

1. To assess the rheological behaviour of dough formulated from wheat/hybrid banana composite flour.
2. To evaluate textural properties of bread from the wheat/hybrid banana composite flour.
3. To evaluate sensory properties of bread from the wheat/hybrid banana composite flour.

1.4 Hypotheses

1. There is no difference in the rheological properties of the wheat / hybrid banana composite doughs prepared from different hybrid banana varieties and ratios of the composite flour.
2. There is no difference in the textural properties of the bread prepared from the wheat / hybrid banana composite flour.
3. There is no difference in the sensory properties of the bread prepared from the wheat / hybrid banana composite flour.

1.5 Significance of the Study

This study could enhance the understanding of the dough rheology and baking properties of bread made from wheat/hybrid cooking banana composite flour. Findings could contribute to the development of optimized processes and formulations hence facilitating the production of high-quality bread with improved textural properties and consumer acceptance. Ultimately, this research will provide valuable insights for the baking industry and contribute to the utilization of hybrid banana flour as a sustainable and nutritious ingredient in bread production. The data will also inform bread producers in Uganda about the most suitable hybrid cooking bananas and percentage inclusions for production of wheat composite bread.

CHAPTER TWO: LITERATURE REVIEW

2.1 Description of Wheat / Hybrid Banana Composite Flour and Bread

Wheat/hybrid cooking banana composite flour is a blend of wheat flour and flour derived from hybrid cooking bananas. The composite flour is created by combining the two flours in varying proportions to achieve the desired characteristics for bread making. When used in bread production, the composite flour offers unique properties and benefits (Shittu et al., 2014). The hybrid cooking bananas used in the composite flour are a crossbreed between indigenous cooking bananas and other banana varieties. These hybrids are specifically developed to possess desirable traits such as improved disease resistance, higher yield, and enhanced nutritional content. They are selected for their suitability as cooking bananas due to their texture, flavor, and cooking properties (Nyakabau et al., 2013).

To create the composite flour, the hybrid cooking bananas are harvested at their optimal maturity (12 months) from planting and 3 months from flowering (Kuchi, 2021) and processed into flour. The bananas are peeled, sliced, and dehydrated using methods like sun drying or low-temperature drying. Once fully dried, the banana slices are milled into a fine powder, resulting in hybrid cooking banana flour (Jirukkakul et al., 2011).

The wheat flour used in the composite is typically refined wheat flour, which is commonly used in bread making. It provides structure, gluten formation, and contributes to the overall texture of the bread (Dooshima et al., 2014). When these two flours are combined, they create a composite flour that offers a unique blend of characteristics.

In bread production, the composite flour is mixed with water, yeast, salt, and other necessary ingredients to form a dough. The dough is then kneaded to develop gluten and improve its elasticity. As water is added to the flour, it interacts with the proteins glutenin and gliadin, which are initially separate entities in the dry flour (Preichardt & Gularte, 2013). Glutenin and gliadin form glutenin-gliadin complexes when they come into contact with water (Yang et al., 2022). These complexes are initially weak and disorganized. The kneading process involves the repeated folding, pressing, and stretching of the dough. This physical manipulation aligns and strengthens the glutenin-gliadin complexes (Ooms & Delcour, 2019).

The mechanical action of kneading provides energy to the proteins. This energy contributes to the formation of a stable and elastic gluten network. As the dough is kneaded, the glutenin molecules form cross-links with each other (Lagrain et al., 2008). These cross-links create a three-dimensional network that traps gas produced during fermentation, allowing the dough to rise. The gluten network gives the dough its elasticity and structure (Shewry et al., 2000). This allows the dough to stretch and expand as gas is produced by yeast during fermentation. It also contributes to the final texture of the baked bread.

The rheological properties of the dough, such as its viscosity and stability are influenced by the presence of hybrid cooking banana flour (Kouassi-Koffi, 2016). The resulting bread from wheat/hybrid cooking banana composite flour offers a combination of wheat familiar taste and structure with the added flavors and nutritional benefits of hybrid cooking bananas. It presents a visually appealing product with a moist crumb, pleasing aroma, and a subtle sweetness. The bread may have a slightly different texture compared to traditional wheat bread, providing a unique sensory experience to consumers. Overall, bread made from wheat/hybrid cooking banana composite flour offers an opportunity to incorporate locally available ingredients, diversify bread options, and enhance nutritional value. It allows for the utilization of hybrid cooking bananas, reduces food waste, and promotes sustainable and nutritious baking practices (Da Mota et al., 2000).

Composite flours are blends of different grains, including gluten-containing grains and gluten-free grains or starches. These flours are formulated to provide a balance of texture, structure, and taste while reducing the overall gluten content (Hasmadi et al., 2020).

Composite flours can aid in gluten dilution, and this is done by combining gluten-containing grains with gluten-free grains or starches, hence reducing the overall gluten content in the flour. This can be beneficial for individuals with gluten-related disorders or those following a gluten-free diet (Litwinek et al., 2014). Composite flours are equally useful for texture modification, where the inclusion of gluten-free grains or starches can help modify the texture of the final product. These ingredients may provide favourable characteristics, such as increased tenderness or moisture, which can enhance the quality of gluten-free bread. Composite flours often incorporate a variety of grains, which can provide a broader range of nutrients compared to using a single grain. By combining different grains, composite flours can offer a more balanced nutritional profile, including a diverse array of vitamins, minerals, and dietary fiber (Olaoye & Ade-Omowaye, 2011).

2.2 Description of Bananas

Bananas are tropical fruits that belong to the *Musa* genus and are part of the family *Musaceae* (Tushemereirwe et al., 2001). They are widely cultivated and known for their distinctive elongated shape and yellow color when ripe. Bananas grow in clusters on large herbaceous plants that are not actually trees but are often referred to as banana trees due to their size and appearance (Spreen, 2010). Bananas have a soft, creamy flesh and a mildly sweet flavor, making them a popular and versatile fruit. Bananas are a widely consumed fruit in Africa, and they are known by various names across different regions and languages. For example; English - Banana (common name used in many African countries), Swahili - *Ndizi* (commonly used in

East Africa), Yoruba - *Ogede* (Nigeria), Igbo - *Ogede* (Nigeria), Hausa - *Kwai* (Nigeria), Amharic - *Mato* (Ethiopia), Somali - *Muz* (Somalia), Malagasy - *Akondro* (Madagascar)
Zulu - *Umkhomo* (South Africa), Xhosa - *iBhanana* (South Africa), Shona - *Murenje* (Zimbabwe), Chewa - *Umunthu* (Malawi), Tigrinya - *Mes* (Eritrea, Ethiopia) (Ploetz et al., 2007).

The banana fruit is botanically classified as a berry due to its fleshy pulp and the presence of seeds, although the seeds are typically small and under developed in cultivated varieties (Gorst, 2008). Bananas are harvested when they are still green and firm, and they ripen over time, gradually turning yellow and becoming softer.

2.3 Global Production of Bananas

Bananas are grown in tropical and subtropical regions worldwide, with major producers including countries in Latin America, Asia, and Africa. They are one of the most economically important fruit crops globally and contribute significantly to the agricultural sector and international trade (Bagamba et al., 2010). According to the FAO, regarding the production in 2021, Angola is ahead of Rwanda (3.5 million), Tanzania (2.1 million), Kenya (1.9 million), Egypt (1.2 million), Burundi (1.2 million), Cameroon (1.1 million), Sudan (934,000), and Ethiopia (849,000) (Olumba & Onunka, 2020).

Table 1: Top banana producers globally between 2010 and 2017

S.no.	Country	Average production (MT) per year
1	India	29
2	China	11
3	Philippines	7.5
4	Ecuador	7
5	Brazil	7

Source: FAOSTAT (2018)

2.4 Banana Production and Consumption in Uganda

Uganda has a rich tradition of banana cultivation and is known as the "Banana Republic" due to its significant banana production and consumption (Ronner et al., 2023). The country boasts a diverse range of banana varieties, including both indigenous and hybrid cultivars.

Uganda is home to numerous indigenous banana varieties that have been cultivated for generations by local communities. The most prominent indigenous banana variety in Uganda is the East African Highland banana, also known as the "*matooke*" (*Musa* spp., EA-AAA) (Albertson, 2016), that takes up over 85% of all bananas in Uganda (Wairegi, 2010). *Matooke* are the staple food crop in many parts of Uganda, particularly in the central and south-western regions (Akankwasa et al., 2021). These bananas are typically cooked before consumption and play a central role in traditional dishes like *matooke* (steamed banana mash) and *luwombo* (banana leaf-wrapped stew) (Marimo et al., 2019).

In recent years, hybrid banana varieties have gained popularity in Uganda due to their improved characteristics, disease resistance, and higher yields (Sanya et al., 2020). Hybrid banana varieties, such as ; Fundación Hondureña de Investigación Agrícola (FHIA) hybrids and the

National Agricultural Research Organization - International Institute of Tropical Agriculture (NARITA) hybrids, are commonly cultivated in the country (Tumuhimbise et al., 2018). These hybrids are developed by crossing indigenous banana varieties with other banana types to incorporate desired traits such as disease resistance, higher productivity, and improved marketability.

Indigenous bananas are mainly cultivated by smallholder farmers in Uganda. The cultivation of indigenous banana varieties follows traditional farming practices and is often integrated into mixed cropping systems (Nowakunda et al., 2015). Hybrid bananas, on the other hand, are cultivated by both small holder farmers and larger commercial plantations. Hybrid banana cultivation is supported by agricultural research institutions, which provide farmers with improved planting materials, technical guidance, and disease management practices (Wilberforce et al., 2014).

Banana production, including both indigenous and hybrid varieties, contributes significantly to Uganda's economy (Kalyebara et al., 2007). Bananas are a major source of income for smallholder farmers, providing livelihood opportunities and contributing to rural development. The commercial cultivation of hybrid banana varieties has the potential to enhance export opportunities, generate foreign exchange, and promote economic growth in the country (Ollen, 2009).

The promotion of hybrid banana varieties, combined with good agricultural practices, disease management, and value addition, holds promise for improving productivity, income generation, and food security in Uganda (Ssennoga et al., 2019). Both indigenous and hybrid banana varieties play a crucial role in Uganda's agriculture and food systems. Indigenous bananas are deeply rooted in the country's cultural heritage and provide staple food for many households. Hybrid bananas offer improved traits and productivity, contributing to economic growth and diversifying market opportunities. Sustainable management of diseases, increased value addition, and market access are key factors for the continued development of Uganda's banana sector (Akankwasa et al., 2021).

Banana yellowing, also known as ripening, is a crucial stage in the banana production process. However, it can pose challenges for producers such as; in timing and logistics, where coordinating the timing of banana yellowing is crucial for producers. If bananas ripen too early or too late, it can affect the overall supply chain, from harvesting to transportation and distribution (Viljoen et al., 2017). Transportation Issues: Bananas are often grown in tropical regions and then transported to various parts of the world. If they yellow too quickly during transportation, it might result in a shorter shelf life by the time they reach consumers (Wairegi, 2010). Uniformity: Consumers expect a certain level of uniformity in terms of ripeness when buying bananas. If there's inconsistency in yellowing among a batch, it may lead to consumer dissatisfaction and impact sales (Batte et al., 2019). Wastage: Bananas have a limited shelf life once they start yellowing. If there are delays in distribution or if bananas ripen too quickly, it can result in wastage as overripe bananas are less desirable to consumers (Cheok et al., 2018). To address these challenges, producers often employ various techniques, such as controlled atmosphere storage, ethylene management, and temperature control, to regulate the ripening process and ensure that bananas reach consumers in optimal condition.

2.4.1 Consumption

Both indigenous and hybrid bananas are widely consumed in Uganda. Indigenous bananas, particularly *matooke* are a staple food in many households. Hybrid bananas, with their improved characteristics and market appeal, are also gaining popularity. They are consumed both as fresh fruit and used in processed forms such as banana chips and flour (Gafuma et al., 2018). Bananas are a staple food in Uganda, particularly in the central (e.g. in districts of

Kampala, Wakiso, Mukono, Butambala and others) and Western regions (e.g. Isingiro, Kabale, Kabarole, Ibanda etc.). They are consumed by a large portion of the population, providing essential nutrients and calories. Consumption of bananas per capita tends to be highest in countries where they are grown locally, such as Ecuador, the Philippines, and Uganda (Vazhacharickal et al., 2021). According to FAOSTAT (2018), the banana consumption per capita in Uganda reached 12.3 kg in 2018. Ugandans use bananas in various forms, including boiling, steaming, roasting, or mashing, depending on the variety and desired preparation method. Bananas are often eaten as a main meal, commonly known as *"matooke,"* and *"katogo"* and are frequently served with traditional dishes, stews, or sauces (Biosci et al., 2018). In many developing countries, bananas are an essential part of the diet, providing a significant source of calories, vitamins, and minerals (Fahrasmane et al., 2014). Bananas are also used in various processed forms, such as banana puree, dried bananas, banana chips, and banana-based beverages. There is an increasing trend towards value-added banana products, including frozen banana pulp, baby food, and banana flour for baking and culinary applications (Vazhacharickal et al., 2021, Muranga et al., 2010). Bananas play a crucial role in food security, nutrition, and livelihoods for millions of people worldwide (Jagwe & Owuor, 2004)

2.5 Types of Bananas

As shown in Table 2 below, bananas are categorised into 5 groups depending on the usage (Albertson, 2016).

Table 2: Categorization of bananas

Variety	**Characteristics**	**Common uses**
Non-cooking bananas	Cavendish; most popular and widely cultivated, known for its sweet taste and creamy texture	Used in desserts, smoothies, and eaten as a snack
	Lady Finger (also known as "Sucrier" or "Baby"); are smaller in size and have a sweet flavor and a delicate texture.	Eaten fresh, added to fruit salads, or used in baking and desserts (Wikandari, 2022)
	Williams (also known as "Gros Michel") are sweet and aromatic (Mallick et al., 2020).	Used in smoothies, fruit salads, and as a topping for breakfast cereals
	Gold finger; new cultivar, is disease resistant with extended shelf life, has a sweet flavor with hints of apple and strawberry	Consumed fresh and are also used in baking and cooking
	Red Dacca (also known as "Red Banana") have a distinctive red or maroon peel and a sweet taste. They are less starchy	Often eaten fresh or used in salads and desserts (Sachter-smith & Sardos, 2019)
Cooking bananas	Comprise all the varieties with AAA genome, about 84 varieties grown in Uganda	cooked in the unripe form (Akankwasa et al., 2021)
	Bluggoe, (ABB) and locally known as '*Kivuvu*' or *'Kidhozi'*	cooked, especially when it is ripe
	Matooke is the most common and widely consumed cooking banana in Uganda (Muranga et al., 2010).	Key ingredient in various traditional dishes, often boiled or steamed
	Gonja, it is similar to plantains but is typically smaller in size and has a slightly sweeter taste	Often sliced, fried, and served as a snack or side dish
	Kibuzi, characterized by its large size and starchy flesh	Typically peeled, boiled, and mashed
	Kisansa, is popular in eastern Uganda and has a distinct flavor and a softer texture compared to other cooking bananas	Boiled or steamed and used in stews, soups, and porridges
	Ndizi, as cooking bananas, it is larger in size, starchy, and less sweet compared to dessert bananas (Tumuhimbise et al., 2018)	Used in stews, roasts, and fried snacks
Juice or Beer bananas	Sisters to the matooke with the only difference being that their fruits have an astringency taste. Locally known as *'Mbidde'* Other varieties include Pisang awak (ABB) locally known as *'Kayinja'* or *'Musa'* (Omulo, 2015).	Used for juice extraction from ripened fruits
Roasting banana	This group is a plantain, locally known as *'Gonja'* (AAB) (FAO, 2007)	The ripened fruits are entirely eaten when roasted, cooked or diced and fried into crisps
Dessert bananas	Include Gros Michel locally known as *'Bogoya'*, Cavendish, *Sukali ndizi* and FHIA 17 (Mugisha et al., 2009).	Eaten fresh when ripened

2.5.1. The Banana Breeding Programme in Uganda

Breeding program in Uganda plays a crucial role in improving banana varieties, enhancing their resistance to diseases, increasing yields, and addressing the specific needs of farmers and consumers (Kikulwe et al., 2008). The banana industry faces significant challenges, including diseases such as Banana Xanthomonas Wilt (BXW) and Fusarium Wilt (TR4), which can devastate banana plantations (Nyombi, 2013).

The National Agricultural Research Organization (NARO) in Uganda is responsible for leading the banana breeding program. NARO collaborates with international research institutions and partners to access germplasm, expertise, and funding for banana breeding activities (Tumuhimbise et al., 2018). The banana breeding program involves cross-breeding different banana varieties to create hybrids with desirable traits (Batte et al., 2019). Parental lines are selected based on their resistance to diseases, yield potential, and other desirable characteristics. Through controlled pollination, hybrid seeds are obtained, which are then grown and evaluated for various traits, including disease resistance, yield, and agronomic performance (Rica et al., 2002). Disease resistance is a primary focus of the banana breeding program in Uganda. Screening methods, such as artificial inoculation and field trials, are employed to identify disease resistant varieties. Resistant hybrids are then further evaluated and selected for their agronomic performance and quality attributes (Batte et al., 2019).

The banana breeding program in Uganda involves close collaboration with farmers and other stakeholders through participatory plant breeding approaches. Farmers' preferences and needs such as disease resistance and high yield are taken into consideration in selecting and evaluating new banana varieties. On-farm trials and farmer feedback are essential in identifying promising varieties that align with farmers' requirements and consumer preferences (*Banana, Breeding, and Biotechnology Commodity*, 1998). The breeding program also considers market demands and consumer preferences in developing new banana varieties. Traits such as improved taste, texture, shelf life, and processing qualities are taken into account to ensure market acceptability and value addition (Tumuhimbise et al., 2018). Promising banana varieties that undergo rigorous evaluation and selection are released for commercial cultivation. Released varieties are distributed to farmers, and extension services are provided to promote their adoption and proper management practices. Continuous monitoring and evaluation of released varieties are carried out to assess their performance and address any challenges (Kikulwe et al., 2007).

The banana breeding program in Uganda is essential for sustaining the banana industry and improving the livelihoods of smallholder farmers. By developing disease-resistant and high-yielding banana varieties, the program contributes to food security, income generation, and the overall development of the agricultural sector.

2.5.2 Composition of Bananas

Bananas are a nutrient-rich fruit that offers several essential nutrients including; potassium, vitamin B6, dietary fiber, and antioxidants (such as; vitamin C, catechins, dopamine, carotenoids and superoxide dismutase)

Carbohydrates

Bananas are primarily composed of carbohydrates, making them a good source of energy. The quantity of carbohydrates in bananas can vary based on their size and ripeness. On average, a medium-sized banana (about 7 to 8 inches in length) contains approximately 24 g of carbohydrates. The main carbohydrates in bananas are starch (which accounts for the firmness of unripe bananas) and pectin, whose content decreases as the bananas ripen, which is why ripe bananas are softer and sweeter than unripe ones. As bananas ripen, starch is converted into sugars, primarily glucose, fructose, and sucrose, giving ripe bananas their sweet taste (Hasanah et al., 2017).

Dietary Fiber

A medium-sized banana (about 7 to 8 inches in length) contains approximately 3 g of dietary fiber. Dietary fiber refers to a group of carbohydrates that resist digestion in the small intestine by human digestive enzymes. The fiber in bananas includes soluble and insoluble fiber, such as pectins and cellulose (Phillips et al., 2021). The dietary fiber in bananas aids in digestion and promotes bowel regularity (Fahrasmane et al., 2014).

Resistant starch is a type of dietary fiber that resists digestion in the small intestine and reaches the large intestine mostly intact. In the large intestine, it becomes a source of nutrients for beneficial gut bacteria, serving as a prebiotic and promoting gut health (Prema et al., 2013). Resistant starch (RS) is classified into different types, and one of them, known as RS2, is found green and under-ripe bananas (Leszczynski & Technology, 2004). The RS content in bananas varies depending on their ripeness, i.e. as bananas ripen, the starch is converted into natural sugars and the resistant starch content decreases. Green or under-ripe bananas tend to have a higher amount of resistant starch compared to ripe bananas (Toe et al., 2018).

Vitamins

Bananas contain vitamins C, B6, and B9 (folate). Vitamin C is an antioxidant that supports the immune system, collagen production, and iron absorption. Vitamin B6 is essential for brain development, hormone regulation, and the production of red blood cells. Folate is crucial for proper cell division, Deoxyribonucleic Acid (DNA) synthesis, (Kumar et al., 2012) and the prevention of certain birth defects, especially during early pregnancy that are primarily related to the development of the neural tube in the foetus such as; spina bifida, anencephaly, encephalocele and cleft lip and palate (Chitayat et al., 2016).

Minerals

Bananas contain potassium, magnesium, and manganese. Bananas are known for their high potassium content (358 mg), which is important for maintaining proper heart and muscle function, as well as regulating blood pressure. Magnesium plays a role in enzyme function, nerve function, and the maintenance of bone health. Manganese is involved in bone formation, metabolism, and antioxidant defences (Hardisson et al., 2001).

Antioxidants and phytochemicals

Bananas antioxidants and phytochemicals. Antioxidants help protect the body's cells from damage caused by harmful free radicals. Bananas also contain phenolic compounds, such as dopamine and catechins, which are associated with improved heart health and antioxidant activity (Sad et al., 2018).

Water

The water content of bananas can vary depending on factors such as the ripeness and size of the fruit. On average, bananas typically have a water content of approximately 74 to 78%. This high water content makes bananas a hydrating and refreshing fruit to consume, especially during hot weather or after physical activities. Additionally, the water content, along with the presence of dietary fiber and natural sugars, contributes to the overall texture and taste of the fruit (Burdon et al., 1994). The nutritional composition of bananas can vary with variety and ripeness of the fruit. Ripe bananas are generally sweeter and have a higher sugar content compared to unripe ones, which are higher in starch (Hapsari & Lestari, 2016).

2.5.3 Utilization of Bananas in Uganda

Utilization of bananas in Uganda is multifaceted, encompassing food security, income generation, value-added products, livestock feed, traditional medicine, and cultural practices. Bananas contribute to the livelihoods of farmers, support rural economies, and provide essential nutrition for the population. The diverse uses of bananas showcase their importance and versatility in Ugandan society (Calkins, 2021).

Bananas play a vital role in the local economy, providing income opportunities for farmers and other stakeholders. Smallholder farmers in Uganda cultivate bananas as a cash crop, selling them in local markets or to larger traders and processors. Banana production and trade create employment opportunities, supporting the livelihoods of many individuals involved in farming, transportation, marketing, and processing (FAO, 2007).

Bananas are processed into various value-added products, expanding their utilization and market potential. For instance, banana flour is made by drying and milling bananas into a fine powder. Banana flour can be used as a gluten-free alternative in baking or as a thickening agent in soups and sauces (Vazhacharickal et al., 2021). Banana juice and puree are also produced and consumed locally or exported to other countries. These products can be used as ingredients in beverages, desserts, and baby food. Additionally, banana chips and crisps are common snacks made from sliced and fried or dried bananas (National Planning Authority report, 2013). Banana by products such as peels and stems are used as feed ingredients for cattle, pigs, and poultry. Utilization of banana by-products as livestock feed contributes to reducing waste and enhancing the economic value of banana plants (Kramer, 2014).

In traditional medicine practices, various parts of the banana plant are used for their potential healing properties. Banana leaves are commonly used for wrapping and cooking food, but they are also used in traditional remedies for wound healing, skin conditions, and as poultices for relieving pain. Banana sap and extracts from different parts of the plant are also believed to have medicinal properties and are used in traditional herbal preparations (Calkins, 2021).

Bananas hold cultural and social significance in Uganda, often being part of traditional ceremonies, rituals, and celebrations. They are used as offerings during cultural events and as gifts to signify hospitality and goodwill. Bananas are also used in traditional dances, where dancers often carry or wear banana leaves or use them as props (Wibowo et al., 2021).

2.6 Maturity Indices of Bananas

The maturity indices of cooking bananas are indicators used to assess the readiness of the fruit for harvesting and consumption (Cantwell, 2009). The time it takes for cooking bananas to mature and be ready for harvesting can vary depending on various factors, including the banana variety, growing conditions, and climate. However, on average, cooking bananas typically take around 9 to 12 months from planting to reach maturity or 90 – 120 days after appearance of the first fruit depending on the season and cultivar (Kuchi, 2021). Typical maturity indices include the following;

Color of banana peel

This is a visible and easily recognizable indicator of maturity. Bananas progress from green to yellow as they ripen. The desired color may vary depending on the banana variety and consumer preferences. For example, some varieties are consumed when still green, while others are preferred when fully yellow or even with some specks of brown (Kuchi, 2021).

Peel Firmness

Firmness of the banana peel changes as the fruit ripens. Immature bananas have a firm and green peel, while ripe bananas have a softer and more pliable peel. The degree of firmness can affect the texture and mouthfeel of the fruit, and the desired level of firmness may vary depending on consumer preferences and the intended use of the bananas (Ma et al., 2022).

Starch Content

Starch content of bananas decreases as they ripen, while the sugar content increases. The conversion of starch into sugars contributes to the sweet flavor of ripe bananas. The starch content can be assessed by performing a starch iodine test, where a ripe banana will show a blue-black color, indicating a lower starch content compared to unripe bananas (Blankenship et al., 2018).

Total Soluble Solids (TSS) and Sugar Content

The total soluble solids (TSS) content, often measured in degrees brix, indicates the sugar content of the banana. A higher Brix reading suggests a higher sugar content and a more mature banana (Subedi & Walsh, 2011).

Flavor and aroma

Flavor and aroma of bananas develop and intensify as they mature. Immature bananas tend to have a starchy taste (perceived as bland, with a subtle sweetness), while ripe bananas are sweeter and more aromatic. The desired flavor profile may depend on personal preference and the intended use of the bananas, such as fresh consumption or processing into various products (Surahman et al., 2022).

2.7 Production and Consumption of Wheat

In Asia, China and India are the largest wheat producers, contributing 44% of the total world production. In Europe, Russia, France, Germany, and Ukraine are major wheat producers and in North America, the United States and Canada are significant wheat producers, while Australia is a major wheat producer in the Southern hemisphere (Halecki & Bedla, 2022). Wheat production in Africa is generally lower (around 3.5%) compared to other continents, as the crop is primarily grown in regions with suitable climatic conditions (moderate temperatures between 15°C to 25°C, longer day light hours, frost free periods, well distributed rainfall throughout the growth stage) and adequate irrigation facilities (Ahmed et al., 2011). The countries in Africa with the highest volumes of production in 2021 were Egypt, Ethiopia and Algeria, with a combined 68% share of total production. Morocco, South Africa, Tunisia and Sudan lagged somewhat behind, together comprising a further 27%. These countries have favourable agro-climatic conditions, irrigation infrastructure, and advanced agricultural practices that support wheat cultivation (Shiferaw et al., 2013).

The production of wheat in Uganda is relatively limited compared to other major staple crops in the country. However, there has been a gradual increase in wheat cultivation over the years (Table 3), driven by changing dietary preferences and increasing demand for wheat-based products (Kagorora & Kansiime, 2021). The main wheat-growing areas include the highland districts of the Eastern (Kapchorwa, Zombo) and South Western (Kabale, Kisoro, Kaborole, Kasese, Buhweju, Isingiro) Uganda (USAID, 2010). These areas have cooler temperatures, moderate rainfall, and well-drained soils, which are favourable for wheat production. Consumption of wheat in Uganda stands at an average of 631,634 metric tonnes and local production only provides about 4% of this demand (Kagorora & Kansiime, 2021).

Different wheat varieties are grown in Uganda, including both hard and soft wheat types. Hard wheat has a higher protein content, typically ranging from 10% to 15%. The protein in hard wheat is high in gluten, which gives it a strong and elastic structure. Soft wheat has a lower protein content, usually below 10%. The gluten in soft wheat is weaker and less elastic compared to hard wheat. The choice of variety depends on factors such as climate, disease resistance, and market demand. Common wheat varieties cultivated in Uganda include; Star, *Konya*, *Nganda,* and Superior (Mottaleb et al., 2021).

Table 3: Wheat production and consumption in Uganda

	2014	2015	2016	2017	2018
Area planted (ha)	13,797	13,799	13,812	13,813	14,504
Production (MT)	22,076	22,078	22,100	22,100	23,206
Add imports (MT)	520,237	461,630	561,911	665,870	631,634
Less exports/re-exports (MT)	189	1,638	433	141	55
Domestic consumption (MT)	542,124	482,070	583,578	687,829	654,785
Domestic consumption met by local production (%)	4.1	4.6	3.8	3.2	3.5

UBOS, (2019)

Asia stands out as the main aggregate consumer, with 53% of global wheat consumption followed by Europe (26%) and around 10% each in the Americas and Africa (FAOSTAT, 2020). Per capita consumption of wheat in Uganda was 23 kg/year and the corresponding national consumption of 939,000 MT (FAOSTAT 2021).

Consumption has been affected in different ways by the current flux in prices of wheat partly due to the Russia-Ukraine war which are major producers and exporters of wheat. Wheat prices can also be influenced by factors such as global supply and demand, weather events affecting production, trade policies, currency exchange rates, and market speculation (Ding & Kinnucan, 2011). In Uganda, domestic production of wheat is not sufficient to meet the country's demand, leading to significant imports from countries like Argentina ($37M), Australia ($32.9M), Russia ($19.8M), Lithuania ($4.16M), Ukraine ($3.07M), Kenya and Tanzania (Vitale et al., 2013). The demand for wheat-based products in Uganda has been steadily increasing, driven by changing consumer preferences and urbanization (Blecha, 2019).

2.7.1 Utilization of Wheat

Food applications

Wheat is a staple food for a large part of the world's population. World over it is primarily used for human consumption in various forms, including bread, pasta, pastries, cakes, cookies, and breakfast cereals. Wheat flour, obtained by milling wheat grains, is a key ingredient in many culinary preparations (Onipe et al., 2015).

Industrial applications

Wheat is a crucial ingredient in the brewing and distilling industries. It is used in the production of beer, as well as in the production of certain types of spirits, such as whiskey and vodka. Wheat contributes to the flavor, body, and texture of the final products (Lynch et al., 2016).

By products

Wheat starch is extracted from wheat flour and is utilized in various industrial applications, such as in the production of adhesives, paper, textiles, and food products. Gluten, a protein component of wheat, is extracted and used in the baking industry to improve dough elasticity and structure (Shevkani et al., 2017). Wheat bran is a valuable by product that results from the milling process of wheat to produce refined flour. The extraction of bran provides an additional product with various applications and benefits like its use as a component in animal feed, providing a cost-effective source of nutrition for livestock. Its fiber content is beneficial for the digestive health of animals, and the nutrient profile contributes to overall animal well-being (Stevenson et al., 2012).

Bio fuel

Wheat can be used as a feedstock for biofuel production, specifically in the form of ethanol. The process involves fermenting sugars derived from wheat to produce ethanol, which can be used as a renewable and cleaner alternative to traditional fossil fuels. Wheat's high carbohydrate content makes it a suitable source for biofuel production. However, the use of wheat for biofuel has raised concerns about potential impacts on food prices and availability, leading to ongoing debates regarding the balance between using crops for fuel versus food production. (Shevkani et al., 2017).

Pharmaceuticals

Wheat-based ingredients, such as wheat germ oil and wheat proteins, are used in the pharmaceutical and cosmetic industries. They are incorporated into various products, including skincare formulations, hair care products, and vitamin supplements (Johnson, 2014).

Wheat straw, the leftover stalks after harvest, has industrial applications. It can be used for animal bedding, paper production, building materials, and biofuel production.

Additionally, wheat straw can be converted into biodegradable materials, such as packaging and disposable products (Al-Saleh & Brennan, 2012).

2.8 Dough Rheology Properties and their Characterisation

Dough is a viscoelastic material composed of flour, water, and other ingredients. (Khoozani et al., 2020). Dough rheology (flow and deformation behaviour) is crucial in various aspects of baking, as it directly influences dough handling, fermentation, and the final quality of baked products (Korus et al., 2023). Key properties related to dough rheology are;

2.8.1 Elasticity:

The ability of dough to recover its original shape after deformation. It is responsible for the dough's ability to retain gas bubbles during fermentation and baking, contributing to volume and texture in the final product. Elasticity is characterized by measuring parameters such as elasticity modulus (G) and elasticity index (Boita et al., 2016).

2.8.2 Extensibility:

The dough's ability to stretch without breaking or tearing. It is essential for shaping and molding dough during processing. Extensibility can be quantified by measuring parameters like extensibility modulus (G") and extensibility index (Chen et al., 2009).

Dough exhibits both viscous and elastic behavior (viscoelasticity). The viscoelastic nature of dough is characterized by measuring parameters such as storage modulus (G'), loss modulus (G"), and complex viscosity (Angioloni & Collar, 2012).

2.8.3 Dough mixing properties:

These determine the dough resistance to deformation during mixing and its ability to develop gluten structure. Mixing properties are often evaluated using mixing curves obtained from a farinograph or a mixograph. These curves provide information about dough development time, mixing tolerance, stability, and mixing energy requirements (Muchová & Žitný, 2010).

2.8.4 Dough relaxation:

The reduction in stress or tension within the dough after mixing or deformation. It occurs during resting periods / bulk fermentation / first rise (usually between 1 – 2 h) in the baking process and affects dough handling and shaping. Dough relaxation can be evaluated by measuring relaxation time, relaxation modulus, and extent of stress reduction over time (Li et al., 2003).

2.8.5 Dough fermentation properties:

Relates to the changes that occur during yeast fermentation. These properties include dough gas retention capacity, gas production rate, and dough expansion behavior. Gas retention is essential for achieving desired bread volume and texture (Munteanu et al., 2019).

2.8.6 Dough proofing:

Refers to the final fermentation stage before baking, where the dough rises and undergoes further structural development. The proofing behavior of dough includes parameters such as proofing time, proofing volume, and gas retention capacity. These parameters affect the final volume, texture, and crumb structure of baked products (Osella et al., 2008).

There instruments that can be used to determine the rheology of the dough. The alveograph evaluates the extensibility and strength of dough and provides valuable information about the behavior of dough during expansion and gas retention (Hrušková & Šmejda, 2003). The consistograph assesses the mixing and kneading characteristics of dough and provides information about the consistency, development, and gluten quality of the dough (Callejo et al., 2009). The farinograph evaluates the mixing and hydration properties of dough by providing information about the dough's water absorption capacity, mixing characteristics, and gluten development (Diósi et al., 2015).

Characterization of dough rheology properties involves various testing methods and instruments. Common techniques include:

Farinograph, which measures the dough mixing properties, including water absorption, development time, stability, and mixing tolerance index (Voicu et al., 2017).

Extensograph, it measures dough extensibility and resistance to extension, providing information about the dough's strength and elasticity (Fu et al., 2017).

Alveograph, which evaluates dough strength, extensibility, and gas retention capacity by measuring the resistance to extension and the ability to retain gas bubbles (Hrušková & Šmejda, 2003).

Rheometer, this measures the rheological properties of dough, such as storage modulus, loss modulus, and complex viscosity, under controlled shear or oscillatory conditions (Mirsaeedghazi et al., 2008).

These characterization methods provide valuable data for optimizing dough formulations, adjusting processing parameters, and ensuring consistent dough quality for bakery applications (Shittu et al., 2014).

2.9 Description of Bread

Bread is a baked product made from a dough composed primarily of flour, water, yeast, and salt (Giannou et al., 2003). Bread can vary in shape, size, texture, and flavor, depending on the ingredients used, the baking technique, and regional preferences.

Each ingredient used in bread making serves a specific purpose, and their proportions and interactions with other ingredients greatly influence the quality and characteristics of the bread. Balancing the ingredients and understanding their functions is crucial for achieving desired outcomes in terms of flavor, texture, and overall appeal of the bread (Yadav et al., 2009).

2.9.1 Ingredients used in the Bread Making Process

Flour:

This is the main ingredient in bread making, typically derived from wheat. It provides the structure and bulk of the bread. The proteins in flour, mainly gluten, form a network that traps gases produced by yeast, giving bread its structure and elasticity (Hughes et al., 2020).

Water:

Hydrates the flour, allowing gluten development and activating the yeast. It also contributes to the overall moisture content of the dough (Petkova & Verkhivker, 2022).

Yeast:

Responsible for fermentation, a process in which yeast consumes sugars and produces carbon dioxide gas. This gas gets trapped in the gluten network, causing the dough to rise and creating air pockets that result in a light and airy texture in the final bread (Ali et al., 2012).

Salt:

Enhances the flavor of bread and also regulates fermentation. It helps control yeast activity, preventing excessive fermentation and maintaining a balanced flavor profile. Salt also strengthens the gluten structure, providing better dough handling and improving bread texture (Tuhumury, 2020).

Sugar:

Acts as a food source for yeast, helping to stimulate fermentation. It provides the necessary energy for yeast growth and enhances yeast activity, resulting in a faster and more robust fermentation process. Sugar can also contribute to the brown colour of the crust and impart a slight sweetness to the bread (Trinh et al., 2015).

Fats:

Oil, butter, or shortening, contribute to the texture and flavor of bread. They tenderize the crumb, giving it a softer and more tender mouthfeel. Fats also help to retain moisture in the dough, resulting in a longer shelf life for the bread (Renzyaeva, 2013).

Eggs:

Adds richness and flavor to bread. They contribute to the overall structure and help bind the ingredients together. Eggs can also add moisture, tenderness, and a desirable golden color to the crust (Van Steertegem et al., 2013).

Milk or dairy products:

Milk powder, yogurt, or buttermilk, contribute to the flavor, texture, and nutritional value of bread. They add moisture, tenderness, and a subtle tanginess to the bread (Trinh et al., 2015).

Flavorings and additives:

Various flavorings and additives, such as herbs, spices, seeds, nuts, dried fruits, and commercial dough conditioners, can be added to enhance the taste, texture, and appearance of bread. These ingredients provide additional flavors, aromas, and visual appeal to the final product (Sirbu et al., 2015).

The bread making process begins by mixing the ingredients to form a dough. Flour, water, yeast, and salt are combined and kneaded either by hand or using a dough mixer. After kneading, the dough undergoes a fermentation period, allowing the yeast to consume sugars in the dough and produce carbon dioxide gas. This gas gets trapped within the gluten network, causing the dough to rise and increase in volume. Fermentation also develops flavors in the dough (Canja et al., 2014). Once the dough has risen, it is shaped into the desired form, such as a loaf, rolls, or specialty shapes. Shaping involves gently deflating the dough, forming it into the desired shape, and allowing it to rest briefly to relax the gluten (Valle Guy et al., 2014). After shaping, the dough undergoes a final rise called proofing or proving. During this stage, the dough is placed in a warm, humid environment to allow further fermentation. The dough continues to rise, and the gluten structure strengthens, resulting in increased volume and improved texture (Jha et al., 2017).

The proofed dough is then baked in an oven at a high temperature (200°C). Baking causes the dough to expand further as the gas trapped within expands with heating. The heat also triggers various chemical reactions, resulting in the browning of the crust and the development of desirable flavors and aromas. The exact baking time and temperature varies depending on the type and size of bread (Al-Saleh & Brennan, 2012). Once baked, the bread is removed from the oven and allowed to cool on a wire rack. Cooling helps to set the structure and prevent excessive moisture retention. Once completely cooled, the bread can be stored in airtight containers or bags to maintain freshness (Kouassi-Koffi, 2016).

Bread is versatile and can be enjoyed in numerous ways. It can be sliced, toasted, or used as a base for sandwiches, to accompany soups or stews, or to make breadcrumbs for coatings or fillings. The characteristics of bread, such as crust color, crumb texture, and flavor, can vary based on the recipe, ingredients, and baking technique employed. With its widespread availability and diverse variations, bread remains a fundamental and beloved food worldwide (Muranga et al., 2010).

As presented in Table 4, bread can be classified in various ways considering factors such as ingredients, production methods, and regional variations (Prates et al., 2020).

Table 4: Categorization of bread

By ingredients	*White bread*: made primarily from refined wheat flour, with the bran and germ removed. *Whole wheat bread*: made from whole grain flour, which includes the bran, germ, and endosperm of the wheat kernel. *Multigrain bread*: which contains a mixture of different grains such as wheat, rye, oats, or barley. *Gluten-free bread*, made without gluten-containing ingredients, suitable for individuals with gluten intolerance or celiac disease (Sabanci et al., 2017; Cocchi et al., 2005)
By leavening agents	*Yeast bread*: rises through the action of yeast, which ferments the dough and produces carbon dioxide bubbles. *Quick bread*: is leavened with baking powder or baking soda, which reacts with acidic ingredients like buttermilk or yogurt (Neeharika, 2020)
By shape or type	*Loaf bread*: which is rectangular-shaped bread baked in a loaf pan. *Baguette*: which is a long, thin French bread with a crisp crust. *Rolls*: which are small individual-sized bread portions, often served with meals or used for sandwiches. *Flatbread*: it is thin, unleavened bread that can be rolled, folded, or topped with ingredients (Kouassi-Koffi, 2016).
By regional or cultural variations	*Sourdough bread*: which is made using a natural fermentation process with a sourdough starter, resulting in a distinct tangy flavor. *Naan*: a traditional Indian bread made from wheat flour, typically cooked in a tandoor oven. *Pita bread*: a middle Eastern bread known for its round, hollow shape that can be filled with various ingredients (Demirtaş et al., 2018).

2.9.2 Health Benefits of Bread

Consuming bread can provide several health benefits including the following;

- Bread is a source of various nutrients and dietary fiber. Bread made from whole grains, such as whole wheat bread, is a good source of protein , vitamins (B vitamins, vitamin E) and minerals (iron, magnesium, zinc) (Zain et al., 2022).
- Whole grain bread, particularly, is rich in dietary fiber which promotes digestive health, helps maintain regular bowel movements, and can contribute to a feeling of fullness, which may aid in weight management (Jarosław Wyrwisz, 2015; Thielecke & Jonnalagadda, 2014) . Whole grain bread has been associated with a lower risk of heart disease. The fiber and other beneficial compounds in whole grains can help lower cholesterol levels, reduce blood pressure, and improve overall heart health (Marquart, 2008).
- Bread with a lower glycemic index (GI) can help regulate blood sugar levels. Whole grain bread, which is digested more slowly than refined white bread, has a lower GI and can help prevent spikes in blood sugar (Nazari et al., 2021). Bread is a source of carbohydrates, which are the body's primary source of energy.

It is important to note that the health benefits of bread can vary depending on the type of bread, ingredients used, and individual dietary needs. Some individuals may need to choose gluten-free options or limit their bread intake due to specific dietary restrictions or health conditions.

2.9.3 The Role of Gluten in Bread Making

Gluten is a protein found in certain grains, most notably wheat. It is formed when two proteins, glutenin and gliadin, combine upon hydration and kneading of dough (Shewry, 2019). Gluten plays a crucial role in the bread making process as it provides structure, elasticity, and texture to the dough (Dahina, 2014).

In structure formation, when flour is combined with water and kneaded, the glutenin and gliadin proteins in wheat flour interact to form gluten. Gluten forms a network of interconnected strands, creating a framework that traps gases produced by yeast or leavening agents. This network provides structural characteristics of the dough, allowing it to rise and maintain its shape during baking (Moore et al., 2006). In gas retention, as yeast ferments the sugars in the dough, carbon dioxide gas is produced. The gluten network acts as a barrier, trapping the gas and causing the dough to rise. This process, known as leavening, results in a light and airy texture in the final bread (Mietton et al., 2022). Furthermore, gluten provides dough with its characteristic elasticity and stretchiness. This allows the dough to expand and rise as the gas is produced, as well as to be shaped into different forms, such as rolls or loaves (Shewry et al., 2002).

Gluten has the ability to absorb water, contributing to the hydration of the dough. This hydration helps develop the gluten network and provides moisture to the bread, enhancing its texture and keeping it moist (Unbehend et al., 2006)

Gluten can be problematic for individuals with gluten-related disorders, such as celiac disease, non-celiac gluten sensitivity, or wheat allergy. In these conditions, the immune system reacts negatively to gluten, leading to various symptoms and health issues (Žilic, 2013).

2.9.4 Effect of Non-Wheat Ingredients on the Quality of Composite Bread

When formulating composite bread using non-wheat ingredients, the choice and proportion of these ingredients can significantly affect the quality of the final product (Shittu et al., 2007). It is essential to carefully select the non-wheat ingredients, considering their functional properties, nutritional composition, and sensory attributes, to achieve the desired quality and acceptability of composite bread. Recipe formulations and processing techniques may need to be adjusted to optimize the interaction between wheat and non-wheat ingredients and to ensure a well-balanced, nutritious, and palatable final product.

- Non-wheat ingredients, such as alternative flours or grains, can influence the texture and structure of composite bread. These ingredients may have different protein content, gluten-forming properties, or starch characteristics compared to wheat flour. This influences crumb structure, loaf volume, and overall texture of the bread (Kulushtayeva et al., 2023).
- Rheological properties of the dough, including; viscoelasticity, extensibility, and dough handling characteristics are also affected. Ingredients with different water absorption capacities, viscosity, or gelatinization properties can alter the dough's flow behavior, affecting its workability, fermentation, and baking performance (Liu et al., 2019).
- Non-wheat ingredients can contribute distinct flavors and aromas to composite bread. For example, the use of ingredients like rye flour, cornmeal, or oats can impart their characteristic flavors and aromas. This can enhance the sensory profile and add complexity to the taste of the bread (Stępniewska et al., 2018).
- Non-wheat ingredients can enrich the nutritional composition of composite bread by adding dietary fiber, vitamins, minerals, and phytochemicals. Ingredients like whole grains, seeds, legume flours, or fruit and vegetable purees can enhance the nutritional profile and contribute to the overall health benefits of the bread (Atudorei et al., 2023).
- The inclusion of non-wheat ingredients can impact the shelf life and staling characteristics of composite bread. Some ingredients, such as certain whole grains or high-fiber ingredients, may retain moisture and contribute to increased bread moisture content, thus affecting its shelf life. Additionally, the presence of different starches,

fibers, or enzymes in non-wheat ingredients can influence the retrogradation of starch and the rate of bread staling (Collar, 2016).

- Non-wheat ingredients may introduce allergenic components, such as gluten in other cereal grains like rye, barley, or oats. In cases where the aim is to produce gluten-free composite bread, the choice of non-wheat ingredients becomes critical to ensure the absence of gluten or to use gluten-free alternatives (Jothi et al., 2014).

2.9.5 Bread Making Techniques

There are various bread making techniques, each with its own unique process and characteristics. Each technique offers unique characteristics and flavors (Baasandorj et al., 2020).

Straight Dough Method

This is the simplest and most common bread making technique. It involves combining all the ingredients, including flour, yeast, water, salt, and sometimes sugar or fat, in a single mixing bowl. The dough is then kneaded, allowed to rise (ferment), shaped, proofed, and finally baked. The entire process is completed in one continuous sequence (Luiz & Vanin, 2022).

Sponge or Pre-Ferment Method

In this technique, a portion of the dough ingredients, typically the flour, yeast, and water, are mixed together to form a pre-ferment or sponge. This pre-ferment is then left to ferment for a specific period, ranging from a few hours to overnight. After fermentation, the pre-ferment is incorporated into the main dough along with the remaining ingredients. This technique enhances flavor development, texture, and shelf life of the bread (Amr & Ajo, 2005).

Sourdough Method

Sourdough bread is made using a natural leavening agent called sourdough starter, which is a mixture of flour and water that has been fermented by wild yeasts and lactobacilli bacteria. The process involves creating and maintaining a sourdough starter, which takes several days to develop. The starter is then mixed with flour, water, and salt to create the dough. Sourdough breads have a distinct tangy flavor, longer shelf life, and unique texture (Chawla & Nagal, 2015).

No-Knead Method

This technique gained popularity through artisan bread baker Jim Lahey in 2006. It involves minimal kneading or no kneading at all, relying on long fermentation periods for gluten development. The ingredients are mixed together, usually with a higher hydration level, and left to ferment for an extended period, typically 12-18 hours. The dough is then shaped and baked. The long fermentation enhances flavor and texture, resulting in a rustic, crusty bread (Pao et al., 2011).

Artisan Bread Technique

This technique focuses on traditional methods including intense kneading (hands-on methods) and slower fermentation. It involves using high-quality ingredients, longer fermentation times, and shaping the dough by hand. The dough is usually wet and sticky, requiring gentle handling. The bread is often baked on a hot stone or in a Dutch oven to create a crusty exterior and a soft, chewy crumb (Landi et al., 2016).

Enriched Dough Method

Enriched breads include ingredients like eggs, butter, milk, or sweeteners, which add richness, flavor, and tenderness to the bread. The technique involves mixing the ingredients, kneading, fermentation, shaping, proofing, and baking. Enriched breads include brioche, challah, and cinnamon rolls (Devani et al., 2016).

2.9.6 Quality Aspects of Bread and Their Measurement

The quality of bread can be assessed based on several aspects that contribute to its overall desirability and consumer satisfaction (Adebayo-Oyetoro et al., 2016).

Appearance

The visual appearance of bread plays a crucial role in consumer perception. It includes characteristics such as crust color, crumb color, shape, and uniformity. Appearance is typically evaluated by visual inspection and comparison to standard criteria or scoring systems (Nwosu, et al., 2014).

Texture

It is an important quality attribute that encompasses various characteristics like crumb softness, crumb elasticity, crust crispness, and crumb grain. Texture analysis methods such as texture profile analysis (TPA) are commonly used (Gull et al., 2015).

Flavor

Evaluation of flavour involves the assessment of taste, aroma, and overall sensory perception. Trained sensory panelists or consumer panels are often used to evaluate the flavor attributes, and descriptive sensory analysis methods are employed to quantify specific flavor characteristics (Heenan et al., 2008).

Moisture Content

The moisture content of bread affects its freshness, texture, and shelf life. Moisture content is typically measured using methods like moisture analyzers or drying ovens (Matos & Rosell, 2012).

Crust and Crumb Characteristics

The crust thickness, crust-to-crumb ratio, and crumb structure contribute to the eating experience. These characteristics can be evaluated by visual observation, measuring the crust thickness using callipers, and assessing crumb structure using image analysis techniques or subjective scoring systems (Gallagher et al., 2003).

Nutritional Composition

Commonly assed components include; protein, fat, and carbohydrate content as well as dietary fiber, vitamins, and minerals. (Gull et al., 2015).

Shelf Life

The ability of bread to maintain its quality over time is an important aspect. Shelf life can be evaluated by monitoring changes in characteristics like moisture content, firmness, mould growth, and sensory attributes over a specified storage period (Phimolsiripol, 2009).

Bread manufacturers and researchers often employ a combination of subjective sensory evaluation, instrumental analysis and laboratory tests to comprehensively assess the quality of bread and ensure consistency and consumer satisfaction.

2.9.7 Subjective Sensory Evaluation

Subjective sensory evaluation is a method used to assess the sensory attributes of a product, such as the taste, aroma, texture, and appearance, through the perceptions and judgments of human senses (Savlak et al., 2016). It involves trained panelists who evaluate and describe the sensory characteristics of the product based on their personal sensory experiences (Gull et al., 2015). In subjective sensory evaluation, panelists are selected and trained to develop their sensory abilities and use a standardized sensory evaluation protocol. They are provided with a set of attributes and a sensory evaluation form or scoring system to record their observations and ratings. The panelists evaluate the product using their senses of sight, smell, taste, touch, and sometimes sound. Examples include; descriptive analysis, hedonic evaluation,
ranking, difference or discrimination testing; (Birwal, 2015).

2.9.8 Instrumental Analysis

Instrumental analysis of bread involves using various scientific instruments to objectively measure specific properties and characteristics of the bread (Balarabe et al., 2017). Examples are;

Texture Analysis:

Texture analyzers are used to measure the mechanical properties of bread, such as hardness, springiness, chewiness, and elasticity. These instruments apply controlled forces to the bread sample and measure its response, providing quantitative data on its textural attributes (Chikwendu et al., 2015).

Color Measurement:

Spectrophotometers or colorimeters are used to objectively measure the color of bread crust and crumb. These instruments quantify parameters such as Lab* values, which represent lightness, red-greenness, and yellow-blueness, providing an objective assessment of bread color (Biller & Ekielski, 2007).

Moisture Analysis:

Moisture content is an important parameter in bread quality. Moisture analyzers or drying ovens with precise temperature control can be used to determine the moisture content of bread samples through moisture loss measurement (Mello et al., 2014).

Gas Chromatography (GC):

GC analysis can be employed to analyze volatile compounds in bread, such as aroma compounds. It allows for the identification and quantification of specific volatile compounds contributing to the bread's flavor and aroma profile (Kolberg et al., 2010).

Fourier Transform Infrared Spectroscopy (FTIR):

FTIR spectroscopy is used to analyze the molecular composition of bread samples. It provides information about functional groups present in the bread's macromolecules, such as proteins, lipids, and carbohydrates (Ikram et al., 2021).

Scanning Electron Microscopy (SEM):

SEM can be used to examine the microstructure of bread, including the distribution of air cells, starch granules, and gluten network. It provides high-resolution images that help in understanding the bread's structure and its impact on quality (Indrani et al., 2003).

These instrumental analysis techniques provide objective and quantitative data, which complement subjective sensory evaluation and help in understanding the physical, chemical, and structural properties of bread. The combination of subjective sensory evaluation and instrumental analysis provides a comprehensive assessment of bread quality and aids in quality control and product development (Momchilova & Zsivanovits, 2016).

Laboratory Tests

Laboratory tests are used to analyze bread, which help assess its quality, composition, and nutritional content (World et al., 2017). Examples of such tests are; moisture, protein, fat, ash, carbohydrate, pH, Microbial and gluten measurement.

CHAPTER THREE: MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Sample Collection

Five (5) hybrid varieties of cooking bananas (M30, M9, N15, N21 and N23) developed by National Agricultural Research Organization (NARO), Kawanda were used in the study. They were harvested at green maturity stage (14 months from the time of planting). Criteria for selection was based on high yield and low consumer acceptability as cooking bananas. Wheat flour (AZAM brand, home baking flour, Bakhresa Grain Milling, (U) Ltd. Bweyogerere, Kampala), sugar, shortening, salt, and baker’s yeast were purchased from new Mutungo supermarket in Nakawa Division, Kampala.

3.2 Methods

3.2.1 Study Design

Hybrid banana varieties were processed into banana flour which was then mixed in different proportions with wheat flour, which proportions were adopted from Manano et al. (2021). These combinations were then used to prepare the composite dough and bread. For the composite doughs, the rheological properties were determined and for the composite breads, the textural properties and sensory attributes were determined.

3.2.2 Sample Preparation

3.2.2.1. Banana Flour Preparation

Flours for each of the hybrid cooking banana varieties were prepared in triplicate according to the procedure of Kumari et al. (2017). Banana fruits were sorted and washed with clean potable water to remove unwanted impurities. The banana fingers were peeled using a stainless steel knife after which they were cut into uniform sizes of 2 inches. Banana slices were blanched in hot water (95°C for 5 min) to prevent browning. Blanched slices were then put on a tray and dried in an oven (M120, Macadams, South Africa) at 60°C for 24 h. The dried slices were then ground in a blender (4696, Yutai, China) at a high speed of 20,000 rpm to obtain a powder that was sieved using a flour sifter (40µm mesh size) to remove any lumps. The flour was put in stomacher bags and sealed using an impulse sealer (IS400, Packer, China). The stomacher bags were then put in a black polythene bag and kept at room temperature (25°C) until analysis.

3.2.2.2. Preparation of the Composite Flours

The different ratios of the wheat / hybrid cooking banana flour that were used in this study were adopted from Manano et al. (2021).

The ratios of the wheat: hybrid banana composite flour that were prepared included; 100:0 (the control), 90:10, 80:20, 70:30 and 60:40. The composite flours were prepared by weighing the different ratios of wheat and banana flour using a weighing balance (ATY224R, Shimadzu, Japan). The wheat and banana flour was thoroughly mixed in a mixing bowl using a spoon ensuring homogeneity by visual inspection, which involved looking for consistent color and texture throughout the mixture, ensuring that there no visible clumps or streaks of one flour type in another. The composite flour was then sieved through a flour sifter (40 µm mesh size) to remove any lumps and ensure a smooth texture. The composite flours were then put in stomacher bags and sealed using an impulse sealer (IS400, Packer, China). The stomacher bags were then put in a black polythene bag and kept at room temperature (25°C) until analysis.

3.2.3. Dough Preparation and Baking of Composite Bread

The composite bread was baked using the straight dough method as described by Manano et al. (2021) and Kumari et al. (2017).

The dough was prepared by mixing 250 g composite flour, 45 g margarine, 25 g sugar, 1.5 g salt, 2.5 g dried instant baker's yeast, 137 ml of water and 50 ppm ascorbic acid as a dough improver. Bread baked with 100% wheat flour was used as a control. All of the ingredients were measured using a weighing scale (ATY224R, Shimadzu, Japan). The ingredients were put in a mixing bowl and mixed by hand for approximately 15 min. The dough was then manually kneaded on a flat surface for approximately 5 min until a uniform dough was obtained. The kneaded dough was shaped into loaves and put in baking pans that had been greased with margarine to avoid sticking. Proofing of the dough was done in the baking pans by covering the dough with plastic wrap to create a warm and humid environment and leaving it at 25°C for 30 min. Part of the dough was reserved for determining the dough rheology properties and the rest was baked in an oven (M120, Macadams, South Africa) at 200 °C for 30 min. After baking, the bread was removed from the oven and cooled to 25°C, sealed in white polythene bags and stored at 25°C ready for analysis. The bread was analyzed within 48 h after baking. By waiting for 48 h, the staling process (process by which bread undergoes changes in texture and flavor over time after it has been baked) is more complete, and the textural properties are relatively stable, allowing for consistent and meaningful analysis of the bread's texture.

3.3 Rheological Characterization of Composite Dough

Rheological characterization of composite dough involves studying the flow and deformation properties of the dough to understand its structural and textural properties. This was done through alveograph, consistograph and farinograph measurements (Manano et al., 2021).

3.3.1 Consistograph Properties

Dough consistency behaviour of the wheat- banana-composite dough was studied using the ICC (International Association for Cereal Science and Technology) method. ICC method NO. 173 (2006) was used using a consistograph (AlveoLAB, Chopin Technologies, Villeneuve-la-Garenne, France). The mixing process started by the mixer hook being inserted into the mixing bowel of the consistograph followed by addition of 250 g of flour. The water was gradually incorporated into the flour sample as mixing progressed, while monitoring the changes in dough consistency. The water was added incrementally until the desired consistency was achieved. Mixing was done for 10 min. The consistograph started recording and generating the torque-time curve as the mixing progressed, providing valuable data about the dough's consistency and development. The water absorption capacity (WAC) and maximum pressure (PrMax) were determined. Two independent determinations were recorded.

3.3.2 Alveograph Properties

The AACC (2010) method using the alveograph (AlveoLAB, Chopin Technologies, Villeneuve-la-Garenne, France) was used to measure the characteristics that provide insight in to the fermentation tolerance of the dough as may be exhibited during proofing stage of bread making. Characteristics measured included the average resistance to expansion indicated by the peak height (mm), extensibility indicated by length (L) of the alveograph curve, energy input required for the mechanical deformation of the dough and the baking strength (W).

The process was started by inserting the kneader hook into the mixing bowl of the alveograph followed by addition of the dough sample that was obtained from the consistograph. Water was automatically added and the dough was kneaded for 8 min. The dough was then laminated (laminated dough was created by repeatedly folding and rolling the dough) to uniform thickness and cut into 5 uniform pellets with dimensions (5x5 cm). The pellets were placed in the resting chamber for 15 min (to allow the dough to relax and stabilize before performing the actual alveograph test. The resting period helped ensure that the dough is in an optimal condition for testing to provide accurate and representative results) and thereafter subjected to alveographic analysis as follows, the standard Chopin+ protocol at 80 rpm mixing speed was followed: initial equilibrium at 30°C, 8 min, heating to 90°C (at a rate of 4°C/min), holding at 90°C for 7 min, cooling to 50°C, (at a rate of 4°C/min), and holding at 50°C for 5 min. The alveograph collected data throughout the test, which was displayed in real-time and stored for analysis later. Two independent determinations were recorded.

3.3.3 Farinograph Properties

The Brabender farinograph (Model T 150 E, Ohgduisburg, Germany) was used to measure dough properties (development time and mixing tolerance index) in the mixing phase according to standard AACC method 54-21. The moisture content of the wheat-banana composite flours was determined according to AOAC method 925.10 (1997): [Solids (Total) and moisture in flour]. Three hundred grams (300 g) of flour was placed in the farinograph bowl and water was added from a burette to the flour and mixed to form a dough. The bowl was kept at a constant temperature of (30±0.2°C) during mixing by a thermostatically controlled circulating water bath. The midpoint of the farinograph bandwidth (i.e. at the maximum resistance) was always centred on the 500-FU line by adjusting the amount of flour and water used, to ensure that farinograms from different samples could be compared. As the dough was mixed, the dough resistance against constant mechanical shear was recorded for 30 min on a chart in the form of a torque-time curve. Two independent determinations were recorded.

3.4 Determination of Textural and Sensory Properties of the Composite Bread

3.4.1. Textural Properties of the Composite Bread

The texture characteristics of the composite bread were analysed on a TA-XT2 Texture Analyser (Stable Microsystems, UK) according to AACC method no. 74-09. Perforation and compression tests were performed. To obtain more reliable and representative results, the analyses was carried out after 24 h of baking but not more than 48 h to allow the bread to undergo moisture equilibration and structural stabilization, that happens as the bread cools leading to a more consistent and representative texture.

For the perforation test, a 2 mm diameter drilling probe was used. In this test, whole loaves were used, with 12 perforations distributed over the upper and lower bread crumb. The test conditions were: pre-test speed of 2 mm/s; post-test speeds of 1 mm/s; perforation distance 20 mm; trigger force of 0.1 N. The properties measured with this test were: Crust hardness and adhesiveness. For the compression test, four slices were cut per sample, then a cube with approximately 40 mm on each side was removed from each slice. The analysis of the texture profile consisted of two compression cycles using a cylindrical probe with a 75 mm base diameter (the probe being larger than the sample), spaced by an interval of 5 seconds between cycles. A 30 kg load cell was used and the test and post-test speeds were 1 mm/s. The compression distance was 4 mm, the trigger force was 0.5 N and the acquisition rate was 50 readings per second. The texture attributes: springiness and cohesiveness were determined. Three independent determinations were recorded.

3.4.2. Sensory Evaluation

Bread loaves were allowed to cool for 12 h and cut into slices of uniform thickness and transferred onto white-coloured plates. A panel of 30 semi-trained volunteer students of Food Science and Technology department of Kyambogo University were recruited to participate in bread affective sensory evaluation. Inclusion criteria for the panellists included: good health, non-smoker, non-allergic to wheat gluten, willingness to participate and who very much like bread - passion. Each panellist was requested to evaluate the bread samples for colour, aroma, flavor, taste and general acceptability using a 9-point hedonic scale where 1 = dislike very much and 9 = like very much (Appendix I). The bread samples were evaluated simultaneously and served randomly and individually to the panellists along with water to cleanse/rinse their palate between tasting.

Statistical Analysis

All data were analyzed for statistical significance using Statistical Package for Social Sciences (SPSS), v. 20 to generate means ±standard deviations. Two-way analysis of variance (ANOVA) was used to test for the relationship between the 2 independent variables (variety and percentage inclusion) and the dependent variables. Means were analysed for significant difference using the Tukey's test and differences were considered significant at $p<0.05$. The relationship between proportion of banana flour addition (%), dough rheology and bread physical and sensory properties was evaluated using principal component analysis (PCA) using XLSTAT (v.2.2, 2019).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Consistograph Properties of the Wheat- Hybrid Banana Composite Dough

4.1.1. Water Absorption Capacity

Water absorption capacity (WAC) of wheat–hybrid banana composite doughs with banana inclusions of 10, 20, 30 and 40% ranged from 47.25 to 52.95%, 49.45 to 53.65%, 51.55 to 53.15%, 48.75 to 53.15% and 49.50 to 54.45% for M30, M9, N15, N21 and N23, respectively, (Table 5). N23 (10%) had the highest WAC and 40% M30 had the lowest WAC. The control (100% wheat flour) had a value of 54.50%. Increasing the % inclusion of banana flour significantly ($p<0.05$) decreased the WAC of the composite dough. The findings of this study are consistent with those of Bamidele et al. (1990) who showed that the higher the % inclusion of blanched plantain flour, the lower the WAC of the composite flour. The findings of this study, however disagree with those of Mepba et al. (2007) who reported that the water absorption capacities of composite flours increased with increasing percent inclusions of matured green plantain (*Musa paradisiaca*). Differences could be attributed to the variety used.

Table 5: Water absorption capacity (%) of wheat - hybrid banana doughs

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	47.25±0.07	49.95±0.07	52.75±0.07	52.95±0.07	54.50±0.71
M9	49.55±0.64	49.45±0.07	52.65±0.07	53.65±0.07	54.50±0.71
N15	52.50±0.71	51.55±0.07	52.85±0.07	53.15±0.07	54.50±0.71
N21	48.75±0.07	52.25±0.07	52.55±0.07	53.15±0.07	54.50±0.71
N23	49.50±0.71	49.85±0.07	52.25±0.07	54.45±0.07	54.50±0.71

Values are means of two independent replicates ± standard errors of means.

According to Bamidele et al. (1990), blanching causes partial cooking of starch granules hence lowering their water absorption capacity. This could explain the decrease in water absorption capacity with increasing hybrid cooking banana flour % inclusions in this study as the hybrid cooking bananas used in this study were first blanched before being processed into banana flour. Water absorption capacity represents the dough's ability to absorb and retain water. The reduction in water absorption capacity is primarily attributed to the unique properties and characteristics of banana flour (Buckley, 2011). According to Kakar et al. (2022), wheat flour has a higher water absorption capacity compared to banana flour owing to the gluten that has the ability to absorb and retain water, forming a cohesive dough structure. This implies that as the % banana flour increases, the overall proportion of wheat flour decreases, resulting in a reduction in the absorbent components available in the dough.

4.1.2. Maximum Pressure

In the current study, maximum pressure (PrMax) ranged from 1315.50 to 2590.50 mbar, 1740.50 to 2741.50 mbar, 2268.50 to 2623.50 mbar, 1642.50 to 2623.50 mbar and 1701.50 to 2911.50 mbar for M30, M9, N15, N21 and N23 dough, respectively, (Table 6). N23 (10%) had the highest PrMax and 40% M30 had the lowest. The control had a PrMax of 2840.50 mbar.

Table 6: Maximum pressure (mbar) of wheat - hybrid banana doughs

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	1315.50±0.71	1913.50±0.71	2531.50±0.69	2590.50±0.71	2840.50±0.68
M9	1740.50±0.69	1802.50±0.70	2525.50±0.71	2741.50±0.68	2840.50±0.58
N15	2379.50±0.71	2268.50±0.71	2553.50±0.73	2623.50±0.68	2840.50±0.71
N21	1642.50±0.61	2426.50±0.72	2489.50±0.70	2623.50±0.64	2840.50±0.70
N23	1701.50±0.70	1979.50±0.69	2420.50±0.71	2911.50±0.59	2840.50±0.63

Values are means of two independent replicates ± standard errors of means.

Upon addition of banana flour to wheat flour to create a composite dough, it was observed that the maximum pressure exerted by the dough decreased as the percentage of banana flour inclusion increased. Results of this study are in line with findings of Manano et al., (2021), who reported a significant ($p<0.05$) decrease in the maximum pressure with the addition of cassava flour to wheat flour.

Maximum pressure is attained when the gluten network is sufficiently developed, and the dough has achieved its desired strength and elasticity (Chin & Campbell, 2005). It is associated with the dough's ability to retain gas during fermentation, which contributes to the final volume and texture of baked products. The high content of resistant starch and dietary fiber in the banana flour causes the flour to have a strong capacity to absorb and hold water molecules limiting the formation of a strong gluten network in the dough. As a result, the dough ability to trap and retain air during mixing is reduced, leading to a lower maximum pressure development (Guadalupe-Moyano et al., 2022). This could explain why the PrMax in this study decreased with increasing percentage inclusion of banana flour. Gluten proteins present in wheat flour have the ability to form a network that traps gas bubbles during fermentation, resulting in increased dough volume and higher maximum pressure. However, the presence of banana flour, which lacks gluten-forming proteins, hinders gluten formation and hence reduces the dough's ability to generate high maximum pressure (Marchetti et al., 2012).

4.2 Alveograph Properties of the Wheat- Hybrid Banana Composite Dough

4.2.1. Peak Height

The peak height ranged from 95.50 to 124.50 mm, 93.50 to 151.50 mm, 94.50 to 113.50 mm, 97.50 to 130.50 mm and 82.50 to 148.50 mm, for M30, M9, N15, N21 and N23 dough, respectively, (Table 7). M9 (10%) had the highest peak height whereas 40% N23 had the lowest. The control had a peak height of 112.50 mm. Significant differences ($p<0.05$) were observed with increasing inclusion of banana flour which resulted in a decrease in the peak height of the composite dough.

Table 7: Peak height (mm) of wheat - hybrid banana doughs

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	95.50±0.65	124.50±0.85	119.50±0.69	117.50±0.86	112.50±0.71
M9	93.50±0.66	114.50±0.89	151.50±0.78	128.50±0.90	112.50±0.71
N15	94.50±0.65	113.50±0.86	108.50±0.64	112.50±0.71	112.50±0.71
N21	97.50±0.71	126.50±0.89	130.50±0.73	112.50±0.71	112.50±0.71
N23	82.50±0.69	107.50±0.70	148.50±0.73	125.50±0.69	112.50±0.71

Values are means of two independent replicates ± standard errors of means.

In this study, increasing the percentage inclusion of banana flour up to 40% significantly ($p<0.05$) decreased the peak height of the composite dough. The findings of this study are in agreement with Ogunbowale, et al., 2016 who reported an increase in the peak height of the wheat flour / blanched banana flour with increasing inclusion of the blanched banana flour. These differences could possibly be attributed to the varieties that were used.

Peak height gives an indication of the dough's ability to trap gas produced by yeast fermentation (Uthayakumaran et al., 2000). A relatively high and well-defined peak height indicates that the gluten network has developed sufficiently, providing the dough with strength, elasticity, and the ability to trap and retain gas during fermentation (Ayo-Omogie & Odekunle, 2017). Due to lack of gluten-forming proteins in banana flour, dough will have reduced gluten formation and a weaker gluten network, which can lead to a lower dough peak height compared to dough made solely with wheat flour (Marchetti et al., 2012). The decrease in the peak height that was observed in this study could equally be attributed to the reduced gluten formation as explained by Marchetti et al. (2012).

4.2.2. Extensibility

Extensibility ranged from 21.50 to 64.50 mm, 22.50 to 84.50 mm, 19.50 to 106.50 mm, 21.50 to 113.50 mm and 22.50 to 106.50 mm for M30, M9, N15, N21 and N23 dough, respectively (Table 8). The control had an extensibility of 61.50 mm. N21 (20%) had the highest extensibility whereas 40% N15 had the lowest.

Table 8: Extensibility (mm) of wheat - hybrid banana doughs

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	21.50±0.71	34.50±0.74	64.50±0.71	46.50±0.71	61.50±0.71
M9	22.50±0.71	22.50±0.71	84.50±0.71	46.50±0.69	61.50±0.71
N15	19.50±0.65	22.50±0.71	106.50±0.89	41.50±0.71	61.50±0.71
N21	21.50±0.66	109.50±0.86	113.50±0.92	56.50±0.59	61.50±0.71
N23	22.50±0.71	95.50±0.81	106.50±0.71	48.50±0.71	61.50±0.71

Values are means of two independent replicates ± standard errors of means.

The values for extensibility obtained in this study do not show any specific trend or relationship and can be classified as random values. Mepba et al. (2017) observed that dough extensibility remained unchanged at 5% levels of substitution of wheat flour with plantain flour, but decreased with further increase in substitution level. Chauhan et al. (1992), also reported reduced extensibilities of dough with increased substitution levels of non-wheat flour protein. Extensibility is important during shaping and molding of the dough (Munteanu et al., 2019). The decrease in extensibility of the composite doughs could be attributed primarily to the gluten network in the dough (Anderssen et al., 2004). Accoding to Zaidel et al. (2008), the weak gluten network formed by inclusion of banana flour can lead to decreased dough extensibility as the gluten network provides the structure and elasticity required for stretching without tearing. The findings of this study are in agreement with these findings where by 40% inclusions of banana flour showed a lower extensibility value as compared to the 10% inclusions.

4.2.3. Baking Strength

The baking strength (W) ranged from 108.50 to 221.50 x10^{-4} J, 106.50 to 242.50 x10^{-4} J, 94.00 to 242.50 x10^{-4} J, 104.50 to 242.50 x10^{-4} J and 67.50 to 244.50 x10^{-4} J for M30, M9, N15, N21 and N23 dough, respectively, (Table 9). The control has a baking strength of 281.50 x10^{-4}J. The highest baking strength was observed in 10% N23 and the lowest in 40% N23.

Table 9: Baking strength (J) of wheat – hybrid banana doughs.

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	108.50±0.71	129.50±0.71	171.50±0.71	221.50±0.69	281.50±0.71
M9	106.50±0.73	133.50±0.73	119.50±0.59	242.50±0.70	281.50±0.71
N15	94.00±0.054	170.50±0.82	177.50±0.71	242.50±0.68	281.50±0.71
N21	104.50±0.72	148.50±0.69	210.50±0.93	242.50±0.68	281.50±0.71
N23	67.50±0.58	128.50±0.67	212.50±0.94	244.50±0.69	281.50±0.71

Values are means of two independent replicates ± standard errors of means.

It was observed that increasing the % inclusion of hybrid banana flour decreased the baking strength of the composite dough. The results of this study are comparable to a report by Mepba et al. (2017) who observed that the baking strength of the wheat / plantain flour composite flour decreased with increasing levels of plantain flour addition. Moradi et al. (2016) also reported a reduction in the baking strength with increasing fibre content of flour.

Baking strength refers to the ability of the dough to expand and hold its shape during baking and is an indicator of deformation energy (Gómez et al., 2008). It depends on the quantity and quality of gluten formed during the mixing and fermentation processes.

The decrease in baking strength observed in this study could be attributed to the fact that banana flour has no gluten which is the protein responsible for the structure and elasticity in wheat-based dough, resulting in a weak dough. This phenomenon was equally explained by Osella et al. (2008). Gluten in wheat flour acts as a natural binder, contributing to the cohesiveness of the dough. Banana flour may lack the same binding properties as wheat flour hence the formation of dough that is less elastic and more prone to breaking or crumbling (Al-Sahlany & Al-musafer, 2020). For most standard bread recipes, a flour with high baking strength is generally preferred to achieve optimal results in terms of volume, structure, and texture (Zghal et al., 2001).

4.3 Farinograph Properties of the Wheat- Hybrid Banana Composite Dough

4.3.1. Development Time

Results for dough development time are as indicated in Table 10. The development time ranged from 2.15 to 5.15 min, 3.75 to 5.40 min, 1.60 to 2.35 min, 1.70 to 2.35 min and 1.10 to 4.75 min for M30, M9, N15, N21 and N23 dough, respectively, (Table 10). The control had a development time of 5.30 min. The longest development time was from 10% M9 and the shortest was from 40% N23.

Table 10: Development time (min) of wheat – hybrid banana doughs.

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	2.15±0.35	3.55±0.92	3.55±0.49	5.15±0.35	5.30±0.28
M9	4.25±0.21	3.75±0.21	4.40±0.14	5.40±0.00	5.30±0.28
N15	1.70±0.00	1.60±0.00	1.80±0.00	2.35±0.64	5.30±0.28
N21	2.25±0.07	2.55±1.20	1.70±0.00	2.35±0.64	5.30±0.28
N23	1.10±0.14	1.20±0.00	2.00±0.57	4.75±0.64	5.30±0.28

Values are means of two independent replicates ± standard errors of means.

In this study, increasing the % inclusion of banana flour significantly ($p<0.05$) decreased the development time. The results of this study were comparable to what was reported by Bamidele et al., (1990), who observed that with increasing levels of supplementation with plantain flour, the dough development time of the composite flour decreased.

Development time is an important parameter because it affects the dough strength and extensibility (Verheyen & Jekle, 2014). The decrease in development time with increasing banana flour % inclusion levels could be attributed to the absence of gluten in banana flour, implying that there are fewer gluten-forming proteins available to create a robust gluten structure, leading to a decrease in dough development time (Verheyen & Jekle, 2014). This is evident in this study, where by increasing the percentage inclusions of banana flour led to a decrease in the dough's strength (4.1.2.3) and extensibility (4.1.2.2) which ultimately resulted in a decrease in the development time of the dough. The overall starch content in the dough as well increases with increasing banana flour inclusions, which can dilute the gluten network because starch has a weakening effect on gluten, and this will further contribute to a decrease in dough development time (Muchová & Žitný, 2010).

4.3.2. Mixing Tolerance Index

The mixing tolerance index (MTI) ranged from 87.50 to 152.50, 102.50 to 175.50, 86.00 to 149.00, 86.00 to 149.00 and 116.50 to 165.00 for M30, M9, N15, N21 and N23 dough, respectively, (Table 11). The control had an MTI value of 54.50 BU. The highest MTI of the composite dough was from 40% M9 and the lowest from 10% N15 and N21.

Table 11: Mixing tolerance index (Brabender Units) of wheat – hybrid banana doughs

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	152.50±19.09	137.50±0.71	117.50±17.68	87.50±19.09	54.50±2.12
M9	175.50±9.19	150.50±7.78	135.50±2.12	102.50±0.71	54.50±2.12
N15	149.00±1.41	134.00±0.00	109.00±1.41	86.00±1.41	54.50±2.12
N21	149.00±4.24	136.00±4.24	127.50±0.71	86.00±1.41	54.50±2.12
N23	165.00±9.89	159.00±11.31	140.50±4.95	116.50±2.12	54.50±2.12

Values are means of two independent replicates ± standard errors of means.

The MTI in this study increased with increasing % banana flour inclusions. The results from this study were comparable to what was reported by Bamidele et al. (1990) who observed that with increasing levels of plantain supplementation of wheat flour, the mixing tolerance increased.

Mixing Tolerance Index provides valuable insights into the dough's behavior during industrial processing (Muchová & Žitný, 2010). A low MTI value (≤30 BU) indicates that the dough has an excellent mixing tolerance. Such dough can withstand mixing processes without significant changes in consistency or breakdown. Conversely, MTI value >50 BU, suggest that the dough may present more challenges during mechanical handling and makeup stages (Kassomeh, n.d.). A higher MTI implies a sticky, less elastic, and more extensible dough, which can make it harder to handle and shape into desired forms. It may require more effort and skill to shape the dough properly without losing its structure (Abera & Geremew, 2017). In this study, even inclusions of up to 10% resulted in MTI values above 50 BU. A high mixing tolerance as obtained in this study indicated a strong dough. This phenomenon could lead to a dough that is difficult to handle and shape during the baking process. A high MTI may also suggest reduced extensibility as observed from the extensibility results in table 8, where inclusions of 40% had the lowest extensibility values, meaning the dough may not stretch and expand well, resulting in a dense and less aerated final product, affecting the texture of the baked goods.

4.4 Textural Properties of Wheat – Hybrid Banana Composite Bread

4.4.1. Hardness

The hardness of the composite bread produced ranged from 2.33 to 4.26 N, 2.09 to 4.23 N, 2.42 to 3.37 N, 2.42 to 4.15 N and 2.22 to 4.39 N for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 12). The control had a hardness of 2.17 N. The highest hardness was from 40% M30 and the lowest from 10% M9.

Table 12: Hardness (N) of wheat – hybrid banana composite bread.

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	4.26±0.11	3.18±0.97	2.33±0.22	2.35±0.24	2.17±0.11
M9	4.23±0.71	3.38±0.23	2.72±0.35	2.09±0.21	2.17±0.11
N15	3.37±0.13	4.09±0.48	2.42±0.31	3.33±0.31	2.17±0.11
N21	4.15±0.56	4.27±0.43	2.42±0.31	3.33±0.31	2.17±0.11
N23	4.39±0.54	3.32±0.39	3.66±0.20	2.22±0.11	2.17±0.11

Values are means of two independent replicates ± standard errors of means.

In this study, increasing the percentage inclusion of banana flour increased the hardness of the composite bread. Hardness directly relates to the perceived firmness or softness of the bread. Consumers often associate a softer, more tender crumb with higher quality bread. The increase in hardness could be attributed to factors such as; lack of gluten-forming proteins in the banana flour, which potentially leads to a less developed gluten network, resulting in a harder and denser bread texture (Dooshima et al., 2014). Another factor could be the high starch and dietary fiber of banana flour that can result in increased water absorption, leading to a firmer texture. Additionally, dietary fiber can have a binding effect, reducing moisture availability and contributing to a drier and harder bread (Ho et al., 2017). A higher hardness value suggests that the bread is likely to have a denser crumb texture. It may be less airy or have smaller, tighter air pockets within the crumb. The bread may feel more compact and solid when bitten or chewed. A harder bread texture can result in increased chewiness, where the bread may require more effort to chew and break down in the mouth compared to a softer loaf (Crowley et al., 2002).

4.4.2. Springiness

The springiness of the composite bread ranged from 0.56 to 0.65, 0.56 to 0.80, 0.35 to 0.65, 0.53 to 0.65 and 0.53 to 0.67 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 13). The control had a springiness of 0.75m. The highest springiness of the composite bread was from 30% M9 and the lowest, 40% N15.

Table 13: Springiness (m) of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	0.59±0.98	0.56±0.06	0.65±0.02	0.56±0.03	0.75±0.09
M9	0.57±0.01	0.80±0.02	0.59±0.01	0.56±0.03	0.75±0.09
N15	0.35±0.03	0.45±0.01	0.53±0.01	0.65±0.06	0.75±0.09
N21	0.59±0.03	0.59±0.06	0.53±0.01	0.65±0.06	0.75±0.09
N23	0.59±0.03	0.62±0.01	0.53±0.02	0.67±0.07	0.75±0.09

Values are means of two independent replicates ± standard errors of means.

In this study, increasing the % inclusion of banana flour significantly ($p<0.05$) decreased the springiness of the composite bread. The variation in springiness for the different banana varieties could be attributed to differences in the chemical composition and starch properties of the bananas (Sankararao et al., 2016). Springiness indicates the bread ability to bounce back after being compressed or stretched.

Different banana varieties may have variations in their starch composition, including the ratio of amylose to amylopectin, with starches having higher amylose content tending to retrograde more during storage, leading to a firmer and less springy bread crumb (Adeyeye et al., 2019). On the other hand, higher amylopectin content can contribute to a more elastic and springy crumb. The fiber content could also be a cause of the variation in springiness of the composite breads. Higher fiber content can affect water absorption and dough rheology, influencing the dough's elasticity and the final bread springiness (Abu-Alruz, 2023). In this study, increasing the fibre content by increasing percentage inclusion of banana flour decreased the elasticity of the dough which equally led to a decrease in the springiness of the bread. Higher sugar content can result in increased fermentation and gas production, contributing to a more open and springy crumb.

4.4.3. Cohesiveness

The cohesiveness of the composite bread ranged from 0.33 to 0.37, 0.31 to 0.56, 0.05 to 0.40, 0.33 to 0.43 and 0.27 to 0.46 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 14). The control had a cohesiveness of 0.50. The strongest cohesiveness was from 30% M9 and the weakest from 40% N15.

Table 14: Cohesiveness of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	0.33±0.07	0.33±0.01	0.37±0.01	0.37±0.02	0.50±0.09
M9	0.36±0.02	0.56±0.02	0.38±0.01	0.31±0.02	0.50±0.09
N15	0.05±0.04	0.26±0.02	0.33±0.03	0.40±0.01	0.50±0.09
N21	0.43±0.02	0.33±0.04	0.33±0.03	0.40±0.01	0.50±0.09
N23	0.27±0.03	0.30±0.05	0.32±0.01	0.46±0.04	0.50±0.09

Values are means of two independent replicates ± standard errors of means.

Results showed that increasing the % inclusion of banana flour significantly ($p<0.05$) decreased the cohesiveness of the composite bread. Cohesiveness measures how well the bread crumb sticks together after being chewed or broken. Cohesiveness is crucial for a positive sensory perception of the bread's texture, as it ensures a smooth mouthfeel (Matos & Rosell, 2012). The variation in cohesiveness for the different banana varieties could be due to different starch properties and the chemical composition of the bananas such as the moisture content (Sankararao et al., 2016). A higher cohesiveness value is generally desirable as it indicates that the bread holds together well, maintaining its structural integrity and resisting crumbling or falling apart, and offers a more pleasant eating experience, easier handling, and better sliceability. The cohesiveness values of the bread in this study were higher at lower percent inclusions which ultimately resulted in a higher general acceptability score (4.3.5).

4.5 Sensory Evaluation of the Wheat – Hybrid Banana Composite Bread

4.5.1. Colour

The colour scores ranged from 5.53 to 7.34, 4.48 to 6.81, 5.41 to 6.18, 5.14 to 6.90 and 5.35 to 7.29 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 15). The control had a colour of 8.14. The percentage inclusion that had the best score was 10% M30 with a value of 7.34. The worst was presented by 40% M9 (4.48).

Table 15: Colour scores of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	5.67 ± 1.93	5.53 ± 1.95	6.16 ± 1.30	7.34 ± 1.73	8.14 ± 1.21
M9	4.48 ± 1.85	4.68 ± 1.82	4.74 ± 2.32	6.81 ± 1.27	8.14 ± 1.21
N15	5.41 ± 1.90	5.76 ± 1.62	6.36 ± 1.42	6.18 ± 1.67	8.14 ± 1.21
N21	5.14 ± 2.14	5.87 ± 1.24	5.87 ± 1.85	6.90 ± 1.27	8.14 ± 1.21
N23	5.55 ± 1.25	5.35 ± 1.64	5.74 ± 1.87	7.29 ± 1.30	8.14 ± 1.21

Values are means of thirty independent replicates ± standard errors of means.

The visual appearance of bread, including its crust and crumb color, is the first sensory attribute that consumers perceive. Banana flour is naturally yellowish in color, and this can affect the final color of the bread. Increasing the proportion of banana flour in the dough may result in a bread with a slightly darker or more yellow hue compared to bread made solely with wheat flour. The intensity of the colour change depends on the amount of banana flour used and the original color of the wheat flour (Ayo-omogie, 2019).

4.5.2. Aroma

The aroma scores ranged from 5.32 to 6.95, 3.42 to 6.49, 4.81 to 5.97, 4.21 to 6.33 and 4.13 to 6.55 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 16). The control had an aroma score of 7.22. The percentage inclusion that had the best score was 10% M30 with a value of 6.95. The worst was from 40% M9 (3.42).

Table 16: Aroma of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	5.32 ± 1.65	5.34 ± 1.99	6.00 ± 1.32	6.95 ± 1.67	7.22 ± 1.31
M9	3.42 ±2.25	3.93 ± 1.77	3.97 ± 1.85	6.49 ± 1.48	7.22 ± 1.31
N15	4.81 ± 1.90	5.06 ± 1.41	5.64 ± 1.99	5.97 ± 1.95	7.22 ± 1.31
N21	4.21 ± 1.81	5.19 ± 1.39	5.63 ± 1.89	6.33 ± 1.20	7.22 ± 1.31
N23	4.13 ± 1.57	4.93 ± 1.53	4.97 ± 1.78	6.55 ± 1.27	7.22 ± 1.31

Values are means of thirty independent replicates ± standard errors of means

The aroma is a result of various volatile compounds released during baking, and its presence significantly influences the overall perception of bread quality. Higher proportions of banana flour result in a more pronounced banana aroma (Rahman et al., 2021), which may affect consumer acceptability of the composite bread.

4.5.3. Flavour

The flavour scores ranged from 5.19 to 6.85, 3.45 to 5.94, 4.68 to 5.73, 4.45 to 6.44 and 4.07 to 6.52 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 17). The control had a flavour score of 7.12. The percentage inclusion that had the best score was 10% M30 with a value of 6.85. The worst was from 40% M9 (3.45).

Table 17: Flavour of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	5.19 ± 2.16	5.59 ± 2.06	6.03 ± 1.25	6.85 ± 1.61	7.12 ± 1.50
M9	3.45 ± 2.23	3.84 ± 1.58	4.03 ± 1.71	5.94 ± 1.50	7.12 ± 1.50
N15	4.68 ± 0.60	5.42 ± 1.50	5.61 ± 1.71	5.73 ± 1.45	7.12 ± 1.50
N21	4.45 ± 1.63	5.03 ± 1.54	5.57 ± 1.86	6.44 ± 1.39	7.12 ± 1.50
N23	4.07 ± 1.85	4.93 ± 1.43	4.99 ± 1.83	6.52 ± 1.62	7.12 ± 1.50

Values are means of thirty independent replicates ± standard errors of means

Flavour encompasses a combination of taste and aroma. Banana flour has a naturally sweet and slightly tangy flavor, which added a subtle (not strong or overpowering) banana taste to the bread. The flavor of the composite bread combines that of the wheat and banana (Dooshima et al., 2014) which will either be liked or dislike depending on consumer perception. In this study, the flavour score declined as the % inclusion of hybrid banana flour increased.

4.5.4. Taste

The taste scores ranged from 5.27 to 6.98, 3.58 to 6.03, 4.72 to 5.79, 4.04 to 6.47 and 4.26 to 6.45 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 18). The control had a taste score of 7.29. The percentage inclusion that had the best score was 10% M30 with a value of 6.98. The worst was from 40% M9 (3.58).

Table 18: Taste of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	5.27 ± 2.07	5.34 ± 2.09	6.13 ± 1.73	6.98 ± 1.51	7.29 ± 1.50
M9	3.58 ± 2.22	3.64 ± 1.81	3.84 ± 1.77	6.03 ± 1.77	7.29 ± 1.50
N15	4.72 ± 1.90	5.42 ± 1.77	5.42 ± 2.21	5.79 ± 1.62	7.29 ± 1.50
N21	4.04 ± 1.85	4.83 ± 1.41	5.97 ± 1.76	6.47 ± 1.41	7.29 ± 1.50
N23	4.26 ± 1.93	4.84 ± 1.91	4.93 ± 1.73	6.45 ± 1.37	7.29 ± 1.50

Values are means of thirty independent replicates ± standard errors of means

According to Ewunetu & Tessema, (2023), the taste may have a slightly sweeter or fruitier note due to the natural sugars present in bananas. In this study, it was observed that increasing the % inclusion of banana flour reduced the taste score, implying that the panel preferred the traditional wheat taste of the bread more than the fruitier note introduced by the banana flour.

4.5.5. General Acceptability

The general acceptability scores ranged from of 5.52 to 7.31, 3.83 to 6.29, 4.91 to 6.06, 4.80 to 6.67 and 4.36 to 6.88 for M30, M9, N15, N21 and N23 composite bread, respectively, (Table 19). The control had a general acceptability score of 7.70. M30 had the best general acceptability score up to 40% inclusions compared to the other varieties. M9 had the worst score even at 20% inclusions, below the mark of 5

Table 19: General acceptability of wheat – hybrid banana composite bread

	% inclusion of hybrid banana flour				
Variety	40%	30%	20%	10%	0%
M30	5.52 ± 1.67	5.62 ± 1.69	6.13 ± 1.63	7.31 ± 1.51	7.70 ± 1.07
M9	3.83 ± 2.21	3.96 ± 1.75	3.96 ± 1.67	6.29 ± 1.94	7.70 ± 1.07
N15	4.91 ± 1.70	5.51 ± 1.63	5.85 ± 1.95	6.06 ± 1.59	7.70 ± 1.07
N21	4.80 ± 1.64	4.93 ± 1.19	5.87 ± 1.85	6.67 ± 1.26	7.70 ± 1.07
N23	4.36 ± 1.50	5.11 ± 1.46	5.74 ± 1.87	6.88 ± 1.24	7.70 ± 1.07

Values are means of thirty independent replicates ± standard errors of means

From the results, it was observed that inclusions of up to 20% with the exception of M9, had general acceptability scores above 5, which is neither like nor dislike.

The results of this study indicated a decrease in general acceptability of the composite bread with increasing % inclusion levels of banana flour. This was in agreement with Mepba et al. (2017) who observed that as the level of plantain incorporation increased beyond 5% in fortified wheat flour, there was a significant decrease in the sensory attributes of bread samples. Bamidele et al. (1990) similarly observed that the sensory attributes decreased with corresponding increase in the proportion of plantain flour. Mepba et al. (2007) also had similar observations, noting that the level of acceptability of the composite bread was observed to decrease with an increase in plantain flour supplementation.

General acceptability represented an overall assessment of all sensory attributes combined and reflected how well the bread met consumers' expectations and preferences. Even if individual sensory parameters (color, aroma, flavor, taste) are acceptable, the bread general acceptability ultimately determines whether consumers will purchase and enjoy the product (Adebayo-oyetoro et al., 2016).

From the results obtained from the sensory evaluation carried out, bread made from 100% wheat flour (control) was superior in all the quality attributes. However, increasing the percentage inclusion of banana flour decreased the quality attributes of the composite bread.

4.6 Correlation between Dough Rheology, Sensory and Textural Properties of the Composite Bread

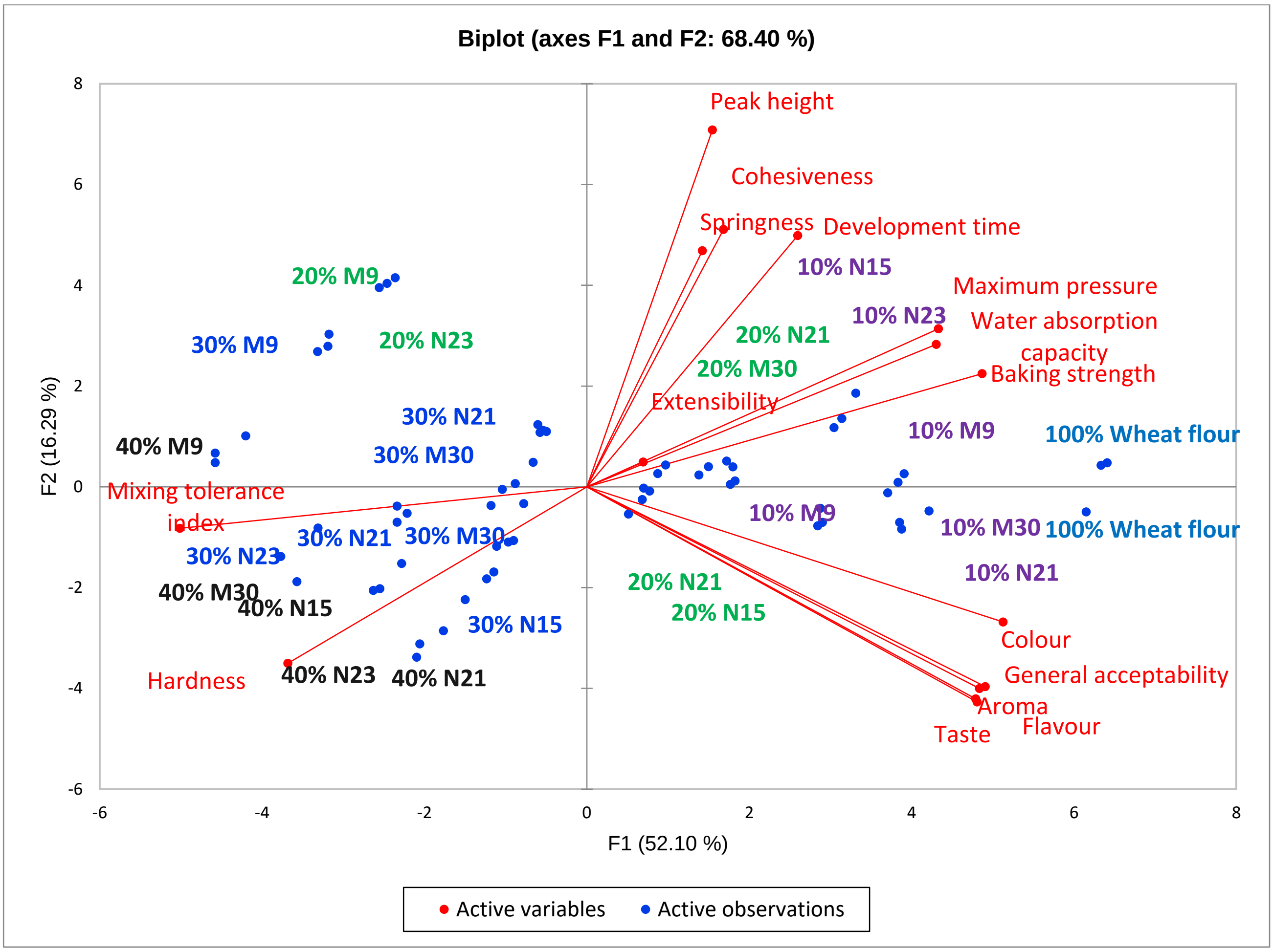


Figure 1: Principal component analysis (PCA) of the various rheological parameters of the dough and sensory attributes and textural properties of the composite bread

Correlations were determined between consistograph, alveograph, farinograph parameters, textural properties and bread sensory attributes (Fig 1). The first two principal components PC1 and PC2 explained 68.40 % of the variability, with the first and second principle component accounting for 52.10% and 16.29% of the variance respectively.

Any positive correlation would guide millers in producing the right composite flour, and bakers, in making bread of acceptable quality.

According to the PCA data, general acceptability of bread was positively correlated with the bread sensory characteristics of colour (r = 0.962), aroma (r = 0.983), flavour (r = 0.982) and taste (r = 0.991). General acceptability was also positively related to bread textural properties of cohesiveness (r = 0.156) and springiness (r = 0.118) but negatively correlated to hardness (r = -0.446). General acceptability was positively related with farinograph parameters, dough development time (r = 0.255), but negatively correlated to mixing tolerance index (r = -0.766) General acceptability was equally positively correlated to the alveograph parameters of; extensibility (r = 0.085) and baking strength (r = 0.690), but negatively correlated to the peak height (r = -0.038). The general acceptability was also positively correlated to the consistograph parameters of water absorption capacity (r = 0.507) and maximum pressure (r = 0.502).

From the correlation data (r), it was observed that in order to produce wheat – hybrid banana composite bread that is acceptable to the consumers, the dough rheology properties of extensibility, baking strength, maximum pressure, water absorption capacity, development time and bread textural properties of springiness and cohesiveness should be prioritized and carefully controlled. Dough rheology properties of peak height and mixing tolerance index as well as the textural attribute of hardness do not affect the general acceptability of the composite bread developed.

From the PCA bi-plot, it can also be observed that the hybrid cooking banana flour from 10% (M3, M9, N15, N21 and N23) and 20% (M30, N21 and N15) are in the same positive quadrant as 100% wheat flour, implying that these inclusions gave composite breads that were similar to 100% wheat bread. The varieties and % inclusions of 10% (M9, M30 and N21) as well as 20% (N15 and N21) were in the same positive quadrant as general acceptability, implying that inclusions of these varieties at those percentages mentioned gave rise to wheat – hybrid banana composite bread that was generally accepted by the consumers. All varieties at 30% and 40%

inclusions as well as 20% (M9 and N23) were in the negative quadrant implying that they were negatively correlated to 100% wheat flour bread and were not acceptable sensory wise by the consumers.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Hybrid banana- wheat composite flours generated acceptable doughs particularly with 10% hybrid banana inclusion. Based on findings, the rheological (consistograph, alveograph and farinograph) properties of the composite dough decreased with increasing % inclusion of hybrid banana flour and hence affecting the final composite bread quality.

The textural properties of the composite bread were negatively affected as the percentage inclusions kept increasing. Increasing the percentage inclusion of banana flour increased the hardness and decreased the springiness and cohesiveness of the composite bread. These results suggested a decrease in baking quality of the composite bread with increasing % banana flour inclusions.

Regarding sensory properties, bread with 10% inclusion of hybrid banana was the best preferred. Although, 20% hybrid banana inclusion for M30, N21 and N15 hybrid banana varieties equally gave rise to acceptable composite bread similar to 100% wheat flour bread.

Results suggest that hybrid banana can complement wheat in bread making at a level of 10% inclusion. Varieties M30, N21, and N15 have potential for use at higher percentage inclusions.

5.2 Recommendations

Based on findings of this study, the following are recommended,

1. Manufacturers can substitute hybrid banana flour inclusion at a level of 10% for all varieties studied and 20% for M30, N21 and N15 is appropriate for making bread with acceptable rheological, textural and sensory properties.
2. Varieties M30, N21 and N15 should be studied further regarding nutrient analysis of the composite bread as well as their use in other bakery products.

3. Market testing of the composite breads should be done to ascertain the marketability of this novel product.
4. Use of hybrid bananas in production of bakery products could address challenges of dietary restrictions.

REFERENCES

AOAC method 925.10 (1997): [Solids (Total) and moisture in flour]

Abu-Alruz, K. (2023). Effects of using composite flour containing wheat flour with different levels of green banana pulp flour on the quality of saj flatbread. *Potravinarstvo Slovak Journal of Food Sciences*, *17*, 419–432. https://doi.org/10.5219/1879

Adebayo-Oyetoro, A. O., Ogundipe, O. O., & Adeeko, K. N. (2016). Quality assessment and consumer acceptability of bread from wheat and fermented banana flour. *Food Science and Nutrition*, *4*(3), 364–369. https://doi.org/10.1002/fsn3.298

Adebayo-oyetoro, A. O., Ogundipe, O. O., & Nojeemdeen, K. (2016). Quality assessment and consumer acceptability of bread from wheat and fermented banana flour Quality assessment and consumer acceptability of bread from wheat and fermented banana flour. May. https://doi.org/10.1002/fsn3.298

Adeyeye, S. A. O., Bolaji, O. T., Abegunde, T. A., Adebayo-Oyetoro, A. O., Tiamiyu, H. K., & Idowu-Adebayo, F. (2019). Quality characteristics and consumer acceptance of bread from wheat and rice composite flour. *Current Research in Nutrition and Food Science*, *7*(2), 488–495. https://doi.org/10.12944/CRNFSJ.7.2.18

Aini, K., & Retno Wikandari, P. (2022). The Use of Lady Finger Banana Fruit (Musa acuminata Colla) As Probiotic Ice Cream With The Addition Of Starter Cultures Of Lactobacillus plantarum B1765. *International Journal of Research in Engineering and Science (IJRES) ISSN*, *10*(6), 1121–1126. www.ijres.org

Akankwasa, K., Marimo, P., Tumuhimbise, R., Asasira, M., Khakasa, E., Mpirirwe, I., Kleih, U., Forsythe, L., Fliedel, G., Dufour, D., & Nowakunda, K. (2021). The East African highland cooking bananas 'Matooke' preferences of farmers and traders: Implications for variety development. *International Journal of Food Science and Technology*, *56*(3), 1124–1134. https://doi.org/10.1111/ijfs.14813

Al-Sahlany, S. T. G., & Al-musafer, A. M. S. (2020). Effect of substitution percentage of banana peels flour in chemical composition, rheological characteristics of wheat flour and the viability of yeast during dough time. *Journal of the Saudi Society of Agricultural Sciences*, *19*(1), 87–91. https://doi.org/10.1016/j.jssas.2018.06.005

Al-Saleh, A., & Brennan, C. S. (2012). Bread wheat quality: Some physical, chemical and rheological characteristics of syrian and english bread wheat samples. *Foods*, *1*(1), 3–17. https://doi.org/10.3390/foods1010003

Albertson, E. (2016). Adopting new banana varieties in Uganda : the role of gender and head of household status. *International Development, Community and Environment (IDCE)*, *27*, 1–44. https://commons.clarku.edu/idce_masters_papers/27

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 Review. *Pakistan Journal of Food Sciences*, *22*(3s), 171–179.

Amini Khoozani, A., Kebede, B., & El-Din Ahmed Bekhit, A. (2020). Rheological, textural and structural changes in dough and bread partially substituted with whole green banana flour. *Lwt*, *126*, 109252. https://doi.org/10.1016/j.lwt.2020.109252

Amjid, M. R., Shehzad, A., Hussain, S., Shabbir, M. A., Rafiq Khan, M., & Shoaib, M. (2013). A comprehensive review on wheat flour dough rheology. *Pakistan Journal of Food Sciences*, *23*(2), 2226–5899.

Amone, C. (2014). We are strong because of our millet bread: Staple foods and the growth of ethnic identities in Uganda. *Trames*, *18*(2), 159–172. https://doi.org/10.3176/tr.2014.2.04

Amr, A., & Ajo, R. (2005). Production of two types of pocket-forming flat bread by the sponge and dough method. *Cereal Chemistry*, *82*(5), 499–503. https://doi.org/10.1094/CC-82-0499

Anderssen, R. S., Bekes, F., Gras, P. W., Nikolov, A., & Wood, J. T. (2004). Wheat-flour dough extensibility as a discriminator for wheat varieties. *Journal of Cereal Science*, *39*(2), 195–203. https://doi.org/10.1016/j.jcs.2003.10.002

Angioloni, A., & Collar, C. (2012). Promoting dough viscoelastic structure in composite cereal matrices by high hydrostatic pressure. *Journal of Food Engineering*, *111*(4), 598–605. https://doi.org/10.1016/j.jfoodeng.2012.03.010

Atudorei, D., Atudorei, O., & Codină, G. G. (2021). Dough rheological properties, microstructure and bread quality of wheat-germinated bean composite flour. *Foods*, *10*(7). https://doi.org/10.3390/foods10071542

Atudorei, D., Mironeasa, S., & Gabriela, G. (2023). *Dough Rheological Behavior and Bread Quality as Affected by Addition of Soybean Flour in a Germinated Form*.

Ayo-Omogie, H. N., & Odekunle, O. Y. (2017). Substituting Wheat Flour with Banana Flour : Effects on the Quality Attributes of Doughnut and Cookies. *Applied Tropical Aggriculture*, *22*(2), 134–142.

Baasandorj, T., Ohm, J. B., & Simsek, S. (2020). Comparison of different experimental breadmaking methods and their associations with flour quality parameters in hard red spring wheat. *Cereal Chemistry*, *97*(2), 515–526. https://doi.org/10.1002/cche.10266

Bakare, A. H., Osundahunsi, O. F., & 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*(4), 573–587. https://doi.org/10.1002/fsn3.321

Balarabe, *, Mohammed, M. M., & Orukotan, S. S. D. (2017). Physico-Chemical Analysis and Sensory Evaluation of Bread Produced Using Different Indigenous Yeast Isolates. *Science World Journal*, *12*(1), 33–37. www.scienceworldjournal.org

Bamidele, E. A., Cardoso, A. O., & Olaofe, O. (1990). Rheology and baking potential of wheat/plantain composite flour. *Journal of the Science of Food and Agriculture*, *51*(3), 421–424. https://doi.org/10.1002/jsfa.2740510315

Banana , Breeding , and Biotechnology Commodity. (1998).

Batte, M., Swennen, R., Uwimana, B., Akech, V., Brown, A., Tumuhimbise, R., Hovmalm, H. P., Geleta, M., & Ortiz, R. (2019a). Crossbreeding east African highland bananas: Lessons learnt relevant to the botany of the crop after 21 years of genetic enhancement. *Frontiers in Plant Science*, *10*(February), 1–9. https://doi.org/10.3389/fpls.2019.00081

Batte, M., Swennen, R., Uwimana, B., Akech, V., Brown, A., Tumuhimbise, R., Hovmalm, H. P., Geleta, M., & Ortiz, R. (2019b). Crossbreeding east African highland bananas: Lessons learnt relevant to the botany of the crop after 21 years of genetic enhancement. *Frontiers in Plant Science*, *10*(February). https://doi.org/10.3389/fpls.2019.00081

Biller, E., & Ekielski, A. (2007). Application of Instrumental Colour Measurement As an Indicator of Changes Occuring in Wheat Bakery Products During Production Process. *Polish Journal of Food and Nutrition Sciences*, *57*(2), 29–34. www.pan.olsztyn.pl/

Biosci, I. J., Dotto, J., Matemu, A. O., & Ndakidemi, P. A. (2018). Potential of cooking bananas in addressing food security in East Africa Department of Food Biotechnology and Nutritional Sciences , The Nelson Mandela African The Nelson Mandela African Institution of Science and Technology , Arusha , Tanzania. *Int. J. Biosci*, *6655*(December), 278–294. https://doi.org/10.12692/ijb/13.4.278-294

Birwal P, S. P., & BK, Y. (2015). Importance of Objective and Subjective Measurement of Food Quality and their Inter-relationship. *Journal of Food Processing & Technology*, *06*(09). https://doi.org/10.4172/2157-7110.1000488

Blankenship, S. M., Ellsworth, D. D., & Powell, R. L. (2018). A Ripening Index for Banana Fruit Based on Starch Content. *HortTechnology*, *3*(3), 338–339. https://doi.org/10.21273/horttech.3.3.338

Boita, E. R. F., Oro, T., Bressiani, J., Santetti, G. S., Bertolin, T. E., & Gutkoski, L. C. (2016). Rheological properties of wheat flour dough and pan bread with wheat bran. *Journal of Cereal Science*, *71*, 177–182. https://doi.org/10.1016/j.jcs.2016.08.015

Buckley, E. (2011). Factors in hard winter wheat affecting water absorption tolerance. *_5.3 _Thesis*, 51.

Burdon, J. N., Dori, S., Lomaniec, E., Marinansky, R., & Pesis, E. (1994). The post-harvest ripening of water stressed banana fruits. *Journal of Horticultural Science*, *69*(5), 799–804. https://doi.org/10.1080/14620316.1994.11516515

Calkins, S. (2021). Food as medicine: Making ‘better bananas’ in Uganda. *Sociological Review*, *69*(3), 560–579. https://doi.org/10.1177/00380261211009059

Canja, C. M., Lupu, M., & Tăulea, G. (2014). The influence of kneading time on bread dough quality. *Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering*, *7*(1), 79–84.

Cantwell, M. (2009). Maturation and Maturity Indices. *Maturation and Maturity Indices Quality*, 55–62. http://ucce.ucdavis.edu/files/datastore/234-1338.pdf

Cappelli, A., & Cini, E. (2021). Challenges and opportunities in wheat flour, pasta, bread, and bakery product production chains: A systematic review of innovations and improvement strategies to increase sustainability, productivity, and product quality. *Sustainability (Switzerland)*, *13*(5), 1–16. https://doi.org/10.3390/su13052608

Chawla, S., & Nagal, S. (2015). Sourdough in Bread-Making: An Ancient Technology to

Solve Modern Issues. *JIBB International Journal of Industrial Biotechnology and Biomaterials, 1*(1), 1–10. www.journalspub.com

Chen, R. Y., Seabourn, B. W., Xie, F., & Herald, T. J. (2009). A Modified extensigraph method for evaluating dough properties of hard wheat breeding lines. *Cereal Chemistry, 86*(5), 582–589. https://doi.org/10.1094/CCHEM-86-5-0582

Cheok, C. Y., Sulaiman, R., Manan, N. A., Zakora, A. J., Chin, N. L., & Hussain, N. (2018). Pasting and physical properties of green banana flours and pastas. *International Food Research Journal*, *25*(6), 2585–2592.

Chin, N. L., & 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. *Journal of the Science of Food and Agriculture*, *85*(13), 2194–2202. https://doi.org/10.1002/jsfa.2237

Chitayat, D., Matsui, D., Amitai, Y., Kennedy, D., Vohra, S., Rieder, M., & Koren, G. (2016). Folic acid supplementation for pregnant women and those planning pregnancy: 2015 update. *Journal of Clinical Pharmacology*, *56*(2), 170–175. https://doi.org/10.1002/jcph.616

Collar, C. (2016). Impact of visco-metric profile of composite dough matrices on starch digestibility and firming and retrogradation kinetics of breads thereof: Additive and interactive effects of non-wheat flours. *Journal of Cereal Science*, *69*, 32–39. https://doi.org/10.1016/j.jcs.2016.02.006

Crowley, P., Schober, T. J., Clarke, C. I., & Arendt, E. K. (2002). *The effect of storage time on textural and crumb grain characteristics of sourdough wheat bread*. 489–496. https://doi.org/10.1007/s00217-002-0500-7

Da Mota, R. V., Lajolo, F. M., Ciacco, C., & Cordenunsi, B. R. (2000). Composition and

Functional Properties of Banana Flour from Different Varieties. *Starch/Staerke*, *52*(2–3), 63–68. https://doi.org/10.1002/(sici)1521-379x(200004)52:2/3<63::aid-star63>3.0.co;2-v

Dahina, B. (2014). *Volume 5 Issue 3 [Year - 2014] ISSN 2319 – 9202 Role of Gluten protein in the food products of living beings and its effect on their body both physicochemical and metabolically reactions Praveen Kumar CASIRJ Volume 5 Issue 3 [Year - 2014] ISSN 2319 – . 5*(3), 65–83.

Devani, B. M., Jani, B. L., Kapopara, M. B., Vyas, D. M., & Ningthoujam, M. D. (2016). Study on quality of white bread enriched with finger millet flour. *International Journal of Agriculture, Environment and Biotechnology*, *9*(5), 903. https://doi.org/10.5958/2230-732x.2016.00116.9

Dooshima, I. B., Julius, A., & Abah, O. (2014). *Quality evaluation of composite bread produced from wheat , defatted soy and banana flours*. *3*(5), 471–476. https://doi.org/10.11648/j.ijnfs.20140305.26

Ewunetu, M. G., Atnafu, A. Y., & Fikadu, W. (2023). Nutritional Enhancement of Bread Produced from Wheat, Banana, and Carrot Composite Flour. *Journal of Food Quality*, *2023*, 1–7. https://doi.org/10.1155/2023/1917972

Ewunetu, M. G., & Tessema, A. (2023). *Development and characterization of bread from wheat , banana (Musa spp), and orange-fleshed sweet potato (Ipomoea batatas L .) composite flour*. *June*. https://doi.org/10.1080/23311932.2023.2219114

Food and Agriculture Organization of the United Nations (FAO). (2007). *Economic Significance of Banana Varieties Other Than Cavendish - Uganda Case Study*. *May*, 3–5. https://www.fao.org/3/ma801E/ma801E.pdf

Fu, B. X., Wang, K., Dupuis, B., & Cuthbert, R. D. (2017). A rapid extensigraph protocol for measuring dough viscoelasticity and mixing requirement. *Journal of Cereal Science*, *76*, 99–107. https://doi.org/10.1016/j.jcs.2017.05.012

GAFUMA, S. (2019). *INFLUENCE OF KEY CHEMICAL COMPONENTS ON HARDNESS OF INDIGENOUS COOKING AND JUICE BANANA CULTIVARS FROM UGANDA Samuel GAFUMA REG NO . 14 / U / 14225 / GDFT / PE Thesis Submitted to Graduate School in Partial Fulfillment of the Requirements for the Award of*. *14*.

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

Gallagher, E., Gormley, T. R., & Arendt, E. K. (2003). Crust and crumb characteristics of gluten free breads. *Journal of Food Engineering*, *56*(2–3), 153–161. https://doi.org/10.1016/S0260-8774(02)00244-3

Giannou, V., Kessoglou, V., & Tzia, C. (2003). Quality and safety characteristics of bread made from frozen dough. *Trends in Food Science and Technology*, *14*(3), 99–108. https://doi.org/10.1016/S0924-2244(02)00278-9

Gorst, J. (2008). *The Biology of Musa L . (banana)*. *January*.

Guadalupe-Moyano, V., Palacios-Ponce, A. S., Rosell, C. M., & Cornejo, F. (2022). Impact of drying methods on banana flour in the gluten-free bread quality. *Lwt*, *168*(June). https://doi.org/10.1016/j.lwt.2022.113904

Gull, A., Bhat, J., Afzal, S., Haq, R.-U., & Safapuri, T. A. (2015). Amir Gull, Raees-ul Haq, Tariq Ahmad Safapuri. Textural and Sensory Characteristics of Bread Made from Wheat Flour Supplemented with Water Chestnut. *American Journal of Food Science and Nutrition Research*, *2*(3), 94–97. http://www.openscienceonline.com/journal/fsnr

Hapsari, L., & Lestari, D. A. (2016). Fruit characteristic and nutrient values of four

Indonesian banana cultivars (Musa spp.) at different genomic groups. *Agrivita*, *38*(3), 303–311. https://doi.org/10.17503/agrivita.v38i3.696

Hardisson, A., Rubio, C., Baez, A., Martin, M., Alvarez, R., & Diaz, E. (2001). Mineral composition of the banana (Musa acuminata) from the island of Tenerife. *Food Chemistry*, *73*(2), 153–161. https://doi.org/10.1016/S0308-8146(00)00252-1

HASANAH, R., DANINGSIH, E., & TITIN, T. (2017). The analysis of nutrient and fiber content of banana (Musa paradisiaca) sold in Pontianak, Indonesia. *Biofarmasi Journal of Natural Product Biochemistry*, *15*(1), 21–25. https://doi.org/10.13057/biofar/f150104

Hasmadi, M., Noorfarahzilah, M., Noraidah, H., Zainol, M. K., & Jahurul, M. H. A. (2020). Functional properties of composite flour: A review. *Food Research*, *4*(6), 1820–1831. https://doi.org/10.26656/fr.2017.4(6).419

Heenan, S. P., Dufour, J. P., Hamid, N., Harvey, W., & Delahunty, C. M. (2008). The sensory quality of fresh bread: Descriptive attributes and consumer perceptions. *Food Research International*, *41*(10), 989–997. https://doi.org/10.1016/j.foodres.2008.08.002

Ho, L., Tan, T.-C., Abdul Aziz, N. A., & Muhamad, N. (2017). Physical and functional properties of banana pseudostem flour and its effect on the quality (texture and microstructure) of formulated bread. *J. Agrobiotech*, *8*, 1–12.

Hrušková, M., & Šmejda, P. (2003). Wheat flour dough alveograph characteristics predicted by NIRSystems 6500. *Czech Journal of Food Sciences*, *21*(1), 28–33. https://doi.org/10.17221/3474-cjfs

Huang, S., Martinez, M. M., & Bohrer, B. M. (2019). The compositional and functional attributes of commercial flours from tropical fruits (breadfruit and banana). *Foods*, *8*(11). https://doi.org/10.3390/foods8110586

Hughes, J., Vaiciurgis, V., & Grafenauer, S. (2020). Flour for home baking: A cross-sectional analysis of supermarket products emphasising the whole grain opportunity. *Nutrients*, *12*(7), 1–14. https://doi.org/10.3390/nu12072058

Igrejas, G., Ikeda, T. M., & Guzmán, C. (2020). Wheat quality for improving processing and human health. In *Wheat Quality For Improving Processing And Human Health*. https://doi.org/10.1007/978-3-030-34163-3

Ikram, A., Saeed, F., Arshad, M. U., Afzaal, M., & Anjum, F. M. (2021). Structural and nutritional portrayal of rye-supplemented bread using fourier transform infrared spectroscopy and scanning electron microscopy. *Food Science and Nutrition*, *9*(11), 6314–6321. https://doi.org/10.1002/fsn3.2592

Indrani, D., Prabhasankar, P., Rajiv, J., & Venkateswara Rao, G. (2003). Scanning Electron Microscopy, Rheological Characteristics, and Bread-Baking Performance of Wheat-Flour Dough as Affected by Enzymes. *Journal of Food Science*, *68*(9), 2804–2809. https://doi.org/10.1111/j.1365-2621.2003.tb05809.x

Jarosław Wyrwisz, M. K. (2015). The Application of Dietary Fiber in Bread Products. *Journal of Food Processing & Technology, 06*(05). https://doi.org/10.4172/2157-7110.1000447

Jha, P. K., Chevallier, S., Cheio, J., Rawson, A., & Le-Bail, A. (2017). Impact of resting time between mixing and shaping on the dough porosity and final cell distribution in sandwich bread. *Journal of Food Engineering*, *194*, 15–23. https://doi.org/10.1016/j.jfoodeng.2016.07.016

Jirukkakul, N., Rakshit, S. K., Khai, K., Aa, M., Hom, K., Aaa, M., Khai, K., Aa, M., Hom, K., & Aaa, M. (2011). *Processing and Functional Properties of Banana Flour The aim of this study was to observe banana ripening of Kluai Namwa , to produce banana flour from Kluai Namwa (Musa The color of the banana flour was measured by a The* *inhibitor*. *January*, 41–46.

Johnson Wilbur Jnr. (2014). *Safety Assessment of Camellia Sinensis-Derived Ingredients as Used in Cosmetics Status : Release Date : Panel Meeting Date : Draft Tentative Report for Panel Review*. 2.

Jose Vazhacharickal, P., Augustine, A., Sajeshkumar, N. K., JohnMathew, J., Sreejith, P. E., & Sabu, M. (2021). International Journal of Current Research and Academic Review By-Products and Value Addition of Banana: An Overview. *Int.J.Curr.Res.Aca.Rev*, *9*(02), 2.

Jothi, J. S., Hashem, S., Rana, M. R., Rahman, M. R. T., & Shams-Ud-Din, M. (2014). Effect of Gluten-free Composite Flour on Physico-chemical and Sensory Properties of Cracker Biscuits. *Journal of Scientific Research*, *6*(3), 521–530. https://doi.org/10.3329/jsr.v6i3.16531

Kakar, A., Miano, T. F., Soomro, A. H., Yar, A., Memon, S. A., Khan, B., & Miano, F. (2022). Oil and Water Absorption Capacity of Wheat, Rice and Gram Flour Powders. *International Journal of Ecosystems and Ecology Science (IJEES*, *12*(2), 585–594. https://doi.org/10.31407/ijeesISSN:2224-4980https://doi.org/10.31407/ijees12.2

Kalyebara, M. R., Ragama, P. E., Kikulwe, E., Bagamba, F., Nankinga, K. C., & Tushemereirwe, W. K. (2007). Economic importance of the banana bacterial wilt in Uganda. *African Crop Science Journal*, *14*(2). https://doi.org/10.4314/acsj.v14i2.27915

Kassomeh, M. (n.d.). *Farinograph Language*.

Kaya, Y., & Sahin, M. (2015). Non-parametric stability analyses of dough properties in wheat. *Food Science and Technology (Brazil)*, *35*(3), 509–515. https://doi.org/10.1590/1678-457X.6642

Kikulwe, E. M., Nowakunda, K., Byabachwezi, M. S. R., Nkuba, J. M., Namaganda, J., Talengera, D., Katungi, E., & Tushemereirwe, W. K. (2007). Development and dissemination of improved Banana cultivars and management practices in Uganda and Tanzania. *Research Report of the International Food Policy Research Institute*, *155*, 37–48.

Kikulwe, E., Wesseler, J., & Falck-Zepeda, J. (2008). Introducing a Genetically Modified Banana in Uganda. *International Food Policy Research Institute*, *May*.

Kolberg, D. I., Prestes, O. D., Adaime, M. B., & Zanella, R. (2010). A new gas chromatography/mass spectrometry (GC-MS) method for the multiresidue analysis of pesticides in bread. *Journal of the Brazilian Chemical Society*, *21*(6), 1065–1070. https://doi.org/10.1590/S0103-50532010000600016

Korus, A., Witczak, M., Korus, J., & Juszczak, L. (2023). Dough Rheological Properties and Characteristics of Wheat Bread with the Addition of Lyophilized Kale (Brassica oleracea L. var. sabellica) Powder. *Applied Sciences (Switzerland)*, *13*(1). https://doi.org/10.3390/app13010029

KOUASSI-KOFFI, J. D. (2016). Essential Steps of Bread making Process Due to Relevant Rheological Parameters of the Raw Material. *International Journal of Pure & Applied Bioscience*, *4*(2), 58–70. https://doi.org/10.18782/2320-7051.2265

Kramer, K. (2014). Banana Foliage and Rejected Banana Fruits as Feed for Livestock in Hawai ‘ i. *Animal Science 321*, *12*, 17–20.

Kuchi, V. S. (2021a). *Judging Maturity Indices of Banana*. *May*.

Kuchi, V. S. (2021b). *Judging Maturity Indices of Banana*. *May 2019*.

Kulushtayeva, B., Nurymkhan, G., Tumenova, G., Bayazitova, K., & Imanbayev, A. (2023). Composite flour production and assessment of the safety quality of gluten-free bread. *Food Science and Technology (Brazil)*, *43*, 1–7. https://doi.org/10.1590/fst.56522

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

Kumari, V., C. Sindhu, S., & Singh, J. (2017). Nutritional Evaluation of Indigenously Developed Weaning Food from Malted Sorghum Incorporated with Soybean and Raw Banana Flour. *International Journal of Current Microbiology and Applied Sciences*, *6*(6), 1264–1271. https://doi.org/10.20546/ijcmas.2017.606.148

Lagrain, B., Thewissen, B. G., Brijs, K., & Delcour, J. A. (2008). Mechanism of gliadin-glutenin cross-linking during hydrothermal treatment. *Food Chemistry*, *107*(2), 753–760. https://doi.org/10.1016/j.foodchem.2007.08.082

Landi, M., Lo Piccolo, E., Ricciardi, R., Rossi, A., Massai, R., Guidi, L., & Remorini, D. (2016). Contrasting the cracking phenomena in sweet cherries: Positive effect of microelements addition (B, Fe, and Zn) to pre-harvest Caand Si-based spray treatments. *Agrochimica*, *60*(2), 114–125. https://doi.org/10.12871/0021857201625

Leszczynski, W. (Wroclaw A. U. (Poland) D. of F. S., & Technology). (2004). Resistant starch – classification, structure, production. *Polish Journal of Food and Nutrition Sciences (Poland)*, *13*, 37–50. http://agris.fao.org/agris-search/search.do?recordID=PL2005000378

Li, W., Dobraszczyk, B. J., & Schofield, J. D. (2003). Stress relaxation behavior of wheat dough, gluten, and gluten protein fractions. *Cereal Chemistry*, *80*(3), 333–338. https://doi.org/10.1094/CCHEM.2003.80.3.333

Litwinek, D., Ziobro, R., Gambuś, H., & Sikora, M. (2014). Gluten free bread in a diet of celiacs. *International Journal of Celiac Disease*, *2*(1), 11–16. https://doi.org/10.12691/ijcd-2-1-4

Liu, X., Mu, T., Sun, H., Zhang, M., Chen, J., & Fauconnier, M. L. (2019). Effect of ingredients on the quality of gluten-free steamed bread based on potato flour. *Journal of Food Science and Technology*, *56*(6), 2863–2873. https://doi.org/10.1007/s13197-019-03730-9

Luiz, R. O., & Vanin, F. M. (2022). Effect of straight dough X pre-fermented dough method on composite wheat breads characteristics. *Food Science and Technology (Brazil)*, *42*(June). https://doi.org/10.1590/fst.64420

Lynch, K. M., Steffen, E. J., & Arendt, E. K. (2016). Brewers' spent grain: a review with an emphasis on food and health. *Journal of the Institute of Brewing*, *122*(4), 553–568. https://doi.org/10.1002/jib.363

Ma, L., Liang, C., Cui, Y., Du, H., Liu, H., Zhu, L., Yu, Y., Lu, C., Benjakul, S., Brennan, C., & Brennan, M. A. (2022). Prediction of banana maturity based on the sweetness and color values of different segments during ripening. *Current Research in Food Science*, *5*(501), 1808–1817. https://doi.org/10.1016/j.crfs.2022.08.024

Mallick, J., Das, N., Roy, K., & Mazumder, S. (2020). an Overview of Various Types of Banana Production and Its Market Value in India. *International Research Journal of Engineering and Technology*, 1195–1204. www.irjet.net

Manano, J., Ogwok, P., Byarugaba-Bazirake, G. W., & Mugampoza, E. (2021). Rheological, Baking and Sensory Characteristics of Bread from Wheat-Cassava Composite Dough. *Journal of Food Research*, *10*(5), 18. https://doi.org/10.5539/jfr.v10n5p18

Marchetti, L., Cardós, M., Campaña, L., & Ferrero, C. (2012). Effect of glutens of different quality on dough characteristics and breadmaking performance. *Lwt*, *46*(1), 224–231. https://doi.org/10.1016/j.lwt.2011.10.002

Marimo, P., Karamura, D., Tumuhimbise, R., Shimwela, M. M., Bergh, I. Van Den, Batte, M., Massawe, C. R., Okurut, A. W., Mbongo, D. B., & Rhiannon, C. (2019). *Post-*

harvest Use of Banana in Uganda and Tanzania : Product Characteristics and Cultivar Preferences of Male and Female Farmers. 51. https://doi.org/10.4160/23096586RTBWP20193

Marquart, L. (2008). Whole Grains and Health. *Nutrition & Food Science*, *38*(3), 296–296. https://doi.org/10.1108/nfs.2008.38.3.296.1

Matos, M. E., & Rosell, C. M. (2012). *Relationship between instrumental parameters and sensory characteristics in gluten-free breads Relationship between instrumental parameters and sensory characteristics in gluten-free breads*. *July*. https://doi.org/10.1007/s00217-012-1736-5

Mello, P., Ishida, G., & Steel, C. J. (2014). Pan Brasileño. *Physicochemical and Sensory Characteristics of Pan Bread Samples Available in the Brazilian Market*, *2014*(006453), 746–754.

Mietton, L., Samson, M. F., Marlin, T., Godet, T., Nolleau, V., Guezenec, S., Segond, D., Nidelet, T., Desclaux, D., & Sicard, D. (2022). Impact of Leavening Agent and Wheat Variety on Bread Organoleptic and Nutritional Quality. *Microorganisms*, *10*(7), 1–21. https://doi.org/10.3390/microorganisms10071416

Mikus, M., Galus, S., Ciurzyńska, A., & Janowicz, M. (2021). Development and characterization of novel composite films based on soy protein isolate and oilseed flours. *Molecules*, *26*(12). https://doi.org/10.3390/molecules26123738

Mirsaeedghazi, H., Emam-Djomeh, Z., & Mousavi, S. M. A. (2008). Rheometric measurement of dough rheological characteristics and factors affecting it. *International Journal of Agriculture and Biology*, *10*(1), 112–119.

Momchilova, M., & Zsivanovits, G. (2016). Instrumental texture characterization of bread. *Bulgarian Chemical Communications*, *48*, 435–441.

http://www.bcc.bas.bg/BCC_Volumes/Volume_48_Special_E_2016/Special Issue E/Statii/Pages435-441.pdf

Moore, M. M., Heinbockel, M., Dockery, P., Ulmer, H. M., & Arendt, E. K. (2006). Network formation in gluten-free bread with application of transglutaminase. *Cereal Chemistry, 83*(1), 28–36. https://doi.org/10.1094/CC-83-0028

Muchová, Z., & Žitný, B. (2010a). New approach to the study of dough mixing processes. *Czech Journal of Food Sciences, 28*(2), 94–107. https://doi.org/10.17221/91/2009-cjfs

Muchová, Z., & Žitný, B. (2010b). New Approach to the Study of Dough Mixing Processes. *Czech Journal of Food Sciences, 28*(2), 94–107. https://doi.org/10.17221/91/2009-CJFS

Mugisha, J., Akankwasa, K., Tushemereirwe, W., & Ragama, P. (2009). *URBAN CONSUMER WILLINGNESS TO PAY FOR INTRODUCED DESSERT BANANAS IN UGANDA Dessert bananas form one of the world ' s most important fruits . Over 85 % of the total world banana production is made up of bananas and plantain varieties grown by small holder . 16*(4), 251–258.

Munteanu, G. M., Voicu, G., Ferdeș, M., Ștefan, E. M., Constantin, G. A., & Tudor, P. (2019). Dynamics of fermentation process of bread dough prepared with different types of yeast. *Scientific Study and Research: Chemistry and Chemical Engineering, Biotechnology, Food Industry, 20*(4), 575–584.

Munteanu, M. G., Voicu, G., Ştefan, E. M., & Constantin, G. A. (2019). Determination of extensibility for certain types of pretzels dough. *E3S Web of Conferences, 112*(54), 1–8. https://doi.org/10.1051/e3sconf/201911203029

Muranga, F. I., Mutambuka, M., Nabugoomu, F., & Lindhauer, M. G. (2010a). Optimisation of raw tooke flour , vital gluten and water absorption in tooke / wheat composite bread , using response surface methodology (Part II). *African Journal of Food Science, 4*(5), 231–239.

Muranga, F. I., Mutambuka, M., Nabugoomu, F., & Lindhauer, M. G. (2010b). Optimisation of raw tooke flour , vital gluten and water absorption in tooke / wheat composite bread , using response surface methodology (Part II). *African Journal of Food Science*, *4*(5), 231–239.

National Planning Authority (NPA). (2013). *Scaling Up Value Addition in Agriculture Products*. *April*, 24. http://npa.ug/wp-content/uploads/2018/04/NPA-PEC-PAPER-Scaling-up-Value-Addition-in-Agriculture.pdf

Nazari, J., Yadegari, N., Khodam, S., Almasi-Hashian, A., & Amini, S. (2021). Effect of consumption of whole-wheat breads on FBS, HbA1c, and blood lipids in patients with type 2 diabetes. *Preventive Nutrition and Food Science*, *26*(3), 269–274. https://doi.org/10.3746/PNF.2021.26.3.269

Nie, Y., Jin, Y., Deng, C., Xu, L., Yu, M., Yang, W., Li, B., & Zhao, R. (2019). Rheological and microstructural properties of wheat dough supplemented with Flammulina velutipes (mushroom) powder and soluble polysaccharides. *CYTA - Journal of Food*, *17*(1), 455–462. https://doi.org/10.1080/19476337.2019.1596986

Nowakunda, K., Barekye, A., Ssali, R. T., Namaganda, J., Tushemereirwe, W. K., Nabulya, G., Erima, R., Akankwasa, K., Hilman, E., Batte, M., & Karamura, D. (2015). Kiwangaazi (Syn ‘KABANA 6H’) black sigatoka nematode and banana weevil tolerant ‘matooke’ hybrid banana released in Uganda. *HortScience*, *50*(4), 621–623. https://doi.org/10.21273/hortsci.50.4.621

Nwosu, U. L., Elochukwu, C. U., & Onwurah, C. O. (2014). Physical characteristics and sensory quality of bread produced from wheat/African oil bean flour blends. *African Journal of Food Science*, *8*(6), 351–355. https://doi.org/10.5897/ajfs2013.1079

Nyakabau, T., Wokadala, O. C., & Emmambux, M. N. (2013). Effect of steeping additives on tef starch extptraction and its quality. *Starch/Staerke*, *65*(9–10), 738–746. https://doi.org/10.1002/star.201200241

Nyombi, K. (2013). Towards sustainable highland banana production in Uganda: Opportunities and challenges. *African Journal of Food, Agriculture, Nutrition and Development*, *13*(57), 7544–7561. https://doi.org/10.18697/ajfand.57.11080

Olaoye, O. A., & Ade-Omowaye, B. I. O. (2011). Composite Flours and Breads: Potential of Local Crops in Developing Countries. *Flour and Breads and Their Fortification in Health and Disease Prevention*, *December*, 183–192. https://doi.org/10.1016/B978-0-12-380886-8.10017-0

Ollen, W. (2009). *Production risk and input use in banana production in Uganda*. *August*, 93. http://mak.ac.ug/documents/Makfiles/theses/Wanda_Ollen.pdf

Olumba, C. C., & Onunka, C. N. (2020). Banana and plantain in West Africa: Production and marketing. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(2), 15474–15489. https://doi.org/10.18697/AJFAND.90.18365

Omulo, G. (2015). Harnessing of banana ripening process for banana juice extraction in Uganda. *African Journal of Food Science and Technology*, *06*(04). https://doi.org/10.14303/ajfst.2015.039

Onipe, O. O., Jideani, A. I. O., & Beswa, D. (2015). Composition and functionality of wheat bran and its application in some cereal food products. *International Journal of Food Science and Technology*, *50*(12), 2509–2518. https://doi.org/10.1111/ijfs.12935

Ooms, N., & Delcour, J. A. (2019). *How to impact gluten protein network formation during*. 1–27.

Osella, C. A., Robutti, J., Sánchez, H. D., Borrás, F., & de la Torre, M. A. (2008a). Análisis de componentes principales entre propiedades de masa y productos panificados. *Ciencia y Tecnologia Alimentaria*, *6*(2), 95–100. https://doi.org/10.1080/11358120809487633

Osella, C. A., Robutti, J., Sánchez, H. D., Borrás, F., & de la Torre, M. A. (2008b). Dough properties related to baking quality using principal component analysis. *Ciencia y Tecnología Alimentaria*, *6*(2), 95–100.

Pao, S., Kim, C., Jordan, L., Long, W., Inserra, P., & Sayre, B. (2011). Growth of salmonella enterica and staphylococcus aureus in no-knead bread dough during prolonged yeast fermentation. *Journal of Food Protection*, *74*(2), 285–288. https://doi.org/10.4315/0362-028X.JFP-10-319

Petkova, O., & Verkhivker, Y. (2022). Using Water in the Modern Bakery Industry. *Acta Scientific Nutritional Health*, *6*(6), 72–81.

Phillips, K. M., McGinty, R. C., Couture, G., Pehrsson, P. R., McKillop, K., & Fukagawa, N. K. (2021). Dietary fiber, starch, and sugars in bananas at different stages of ripeness in the retail market. *PLoS ONE*, *16*(7 July), 1–21. https://doi.org/10.1371/journal.pone.0253366

Phimolsiripol, Y. (2009). Shelf life determination of frozen bread dough stored under fluctuating temperature conditions. *Kasetsart Journal - Natural Science*, *43*(1), 187–197.

Ploetz, R. C., Kepler, A. K., Daniells, J., & Nelson, S. C. (2007). Species Profiles for Pacific Island Agroforestry Banana and plantain — an overview with emphasis on Pacific island cultivars. *Http://Www.Traditionaltree.Org*, *February*. http://traditionaltree.org

Prates, S. M. S., Sabion, N. A., Nespolo, J. S., Alves, L., & Anastácio, L. R. (2020). Labeling and classification of breads, biscuits and toasts sold as wholegrain in Brazil. *Research, Society and Development*, *9*(10), e1429107350. https://doi.org/10.33448/rsd-v9i10.7350

Preichardt, L. D., & Gularte, M. A. (2013). Gluten formation: Its Sources, composition and health effects. *Gluten: Sources, Composition and Health Effects*, *July*, 55–70.

Prema, S., Saraswathi, A., Chitra, K., & Gopal, V. (2013). *Review Article A Review on*. *21*(1), 314–317.

Rahman, T., Akter, S., Sabuz, A. A., & Rana, R. (2021). *Characterization of Wheat Flour Bread Fortified with Banana Flour Characterization of Wheat Flour Bread Fortified with Banana Flour*. *January*. https://doi.org/10.26855/ijfsa.2021.03.002

Renzyaeva, T. V. (2013). On the role of fats in baked flour goods. *Foods and Raw Materials*, *1*(1), 19–25. https://doi.org/10.12737/1513

Rica, C., Jacome, L., Lepoivre, P., Marin, D., Ortiz, R., Romero, R., & Escalant, J. V. (2002). *Mycosphaerella leaf spot diseases of bananas : present status*. *May*, 20–23.

Richard, A. A. (2020). *https://doi.org/10.18697/ajfand.93.19325*. *20*(5), 16509–16521.

Ronner, E., van de Ven, G. J., Nowakunda, K., Tugumisirize, J., Kayiita, J., Taulya, G., Uckert, G., & Descheemaeker, K. K. E. (2023). What future for banana-based farming systems in Uganda? A participatory scenario analysis. *Agricultural Systems*, *209*(May), 103669. https://doi.org/10.1016/j.agsy.2023.103669

Sachter-smith, G., & Sardos, J. (2019). *Bananas of Samoa A catalogue of banana diversity seen on the island of Upolu*. 40.

Sad, A. A., Hoque, M. M., & Zzaman, W. (2018). Physicochemical and antioxidant properties of banana varieties and sensorial evaluation of jelly prepared from those varieties available in Sylhet region. *International Journal of Food Studies*, *7*(2), 89–97. https://doi.org/10.7455/IJFS/7.2.2018.A8

Sankararao, D., Anjineyulu, K., B, B. H., & D, C. P. (2016). Research Article DEVELOPMENT OF COMPOSITE FLOUR BREAD AND ITS EFFECT ON PHYSICAL, SENSORY AND NUTRITIONAL CHARACTERISTICS. *International*

Journal of Agriculture Sciences, *8*(57), 975–3710.

Sanya, L. N., Sanya, L. N., Sseguya, H., Kyazze, F. B., Diiro, G. M., & Nakazi, F. (2020). The role of variety attributes in the uptake of new hybrid bananas among smallholder rural farmers in central Uganda. *Agriculture and Food Security*, *9*(1), 1–13. https://doi.org/10.1186/s40066-020-00257-7

Savlak, N., Türker, B., & Yeşilkanat, N. (2016). Effects of particle size distribution on some physical, chemical and functional properties of unripe banana flour. *Food Chemistry*, *213*(October 2014), 180–186. https://doi.org/10.1016/j.foodchem.2016.06.064

Shevkani, K., Singh, N., Bajaj, R., & Kaur, A. (2017). Wheat starch production, structure, functionality and applications—a review. *International Journal of Food Science and Technology*, *52*(1), 38–58. https://doi.org/10.1111/ijfs.13266

Shewry, P. (2019). What is gluten—Why is it special? *Frontiers in Nutrition*, *6*(July), 1–10. https://doi.org/10.3389/fnut.2019.00101

Shewry, P. R., Halford, N. G., Belton, P. S., & Tatham, A. S. (2002). The structure and properties of gluten: An elastic protein from wheat grain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *357*(1418), 133–142. https://doi.org/10.1098/rstb.2001.1024

Shewry, P. R., Popineau, Y., Lafiandra, D., & Belton, P. (2000). Wheat glutenin subunits and dough elasticity: Findings of the EUROWHEAT project. *Trends in Food Science and Technology*, *11*(12), 433–441. https://doi.org/10.1016/S0924-2244(01)00035-8

Shittu, T. A., Egwunyenga, R. I., Sanni, L. O., & Abayomi, L. (2014). Bread from composite plantain-wheat flour: I. effect of plantain fruit maturity and flour mixture on dough rheology and fresh loaf qualities. *Journal of Food Processing and Preservation*, *38*(4), 1821–1829. https://doi.org/10.1111/jfpp.12153

Shittu, T. A., Raji, A. O., & Sanni, L. O. (2007). Bread from composite cassava-wheat flour: I. Effect of baking time and temperature on some physical properties of bread loaf. *Food Research International*, *40*(2), 280–290. https://doi.org/10.1016/j.foodres.2006.10.012

Shongwe, S. G., Nkambule, T. P., & Shelembe, J. S. (2022). *Dough rheology and physicochemical and sensory properties of wheat – peanut composite flour bread*. *August 2021*, 1–8. https://doi.org/10.1002/leg3.138

Sirbu, A., Constantin, U., & Pitesti, B. (2015). Bread flavours for a better consumers' acceptance. *Baking Europe*, *September 2014*, 17. http://www.bakingeurope.eu/publications.html

Ssennoga, F., Mugurusi, G., & Oluka, P. N. (2019). Food insecurity as a supply chain problem. Evidence and lessons from the production and supply of bananas in Uganda. *Scientific African*, *3*(April). https://doi.org/10.1016/j.sciaf.2019.e00076

Stępniewska, S., Słowik, E., Cacak-Pietrzak, G., Romankiewicz, D., Szafrańska, A., & Dziki, D. (2018). Prediction of rye flour baking quality based on parameters of swelling curve. *European Food Research and Technology*, *244*(6), 989–997. https://doi.org/10.1007/s00217-017-3014-z

Stevenson, L., Phillips, F., O'sullivan, K., & Walton, J. (2012). Wheat bran: Its composition and benefits to health, a European perspective. *International Journal of Food Sciences and Nutrition*, *63*(8), 1001–1013. https://doi.org/10.3109/09637486.2012.687366

Study, A. C., Java, C., Lestari, E., Wibowo, A., & Rahayu, P. (2021). *Social Cultural Dynamics in the Development of a Banana Center Leading to Sustainable Agricultural Development*. *199*(Icsasard), 104–110.

Subedi, P. P., & Walsh, K. B. (2011). Assessment of sugar and starch in intact banana and mango fruit by SWNIR spectroscopy. *Postharvest Biology and Technology*, *62*(3), 238–

245. https://doi.org/10.1016/j.postharvbio.2011.06.014

Surahman, D. N., Ekafitri, R., Rahman, T., Cahyadi, W., Setyadi, D. A., Astro, H. M., Indriati, A., Andriana, Y., & Anggara, C. E. W. (2022). Organoleptic Characteristics of Banana Flakes Based on Maturity Level of Banana (Musa Paradisiaca) CV. Ambon. *IOP Conference Series: Earth and Environmental Science*, *980*(1). https://doi.org/10.1088/1755-1315/980/1/012036

Toe, E., Dadie, A. T., Dako, E., & Loukou, G. (2018). *Prevalence and potential virulence of Escherichia coli in ready-to-eat raw mixed vegetable salads in collective catering in Abidjan , Côte d ' Ivoire Article information : August*. https://doi.org/10.1108/BFJ-09-2017-0484

Trinh, L., Lowe, T., Campbell, G. M., Withers, P. J., & Martin, P. J. (2015). Effect of sugar on bread dough aeration during mixing. *Journal of Food Engineering*, *150*, 9–18. https://doi.org/10.1016/j.jfoodeng.2014.10.020

Tuhumury, H. (2020). the Effects of Salt on Bread: Technological Considerations for Reduced Salt Levels. *Agrica*, *4*(2), 134–141. https://doi.org/10.37478/agr.v4i2.458

Tumuhimbise, R., Barekye, A., Kubiriba, J., Akankwasa, K., Arinaitwe, I. K., & Tushemereirwe, W. K. (2018). New high-yield cooking banana cultivars with multiple resistances to pests and diseases ('NAROBan1', 'NAROBan2', 'NAROBan3', and 'NAROBan4') released in Uganda. *HortScience*, *53*(9), 1387–1389. https://doi.org/10.21273/HORTSCI13207-18

Unbehend, L., Unbehend, G., & Strelec, I. (2006). Water absorption determination of wheat flours applying centrifuge and its relationship to farinograph water absorption determination. *Deutsche Lebensmittel-Rundschau*, *102*(1), 11–16.

Uthayakumaran, S., Newberry, M., Keentok, M., Stoddard, F. L., & Bekes, F. (2000). Basic rheology of bread dough with modified protein content and glutenin-to-gliadin ratios. *Cereal Chemistry*, *77*(6), 744–749. https://doi.org/10.1094/CCHEM.2000.77.6.744

Valle Guy, D., Hubert, C., Lucio, C., Kamal, K., Kati, K., Amadou, N., Martin, W., & Kaisa, P. (2014). Basic knowledge models for the processing of bread as a solid foam. *Key Engineering Materials*, *611–612*(May), 901–908. https://doi.org/10.4028/www.scientific.net/KEM.611-612.901

Van Steertegem, B., Pareyt, B., Brijs, K., & Delcour, J. A. (2013). The effects of fresh eggs, egg white, and egg yolk, separately and in combination with salt, on Mixogram properties. *Cereal Chemistry*, *90*(3), 269–272. https://doi.org/10.1094/CCHEM-11-12-0160-N

Verheyen, C., & Jekle, M. (2014). *Infl uences on dough development*. *January 2012*, 2–6.

Viljoen, A., Mahuku, G., Massawe, C., Ssali, R. T., Kimunye, J., Mostert, G., Ndayihanzamaso, P., & Coyne, D. L. (2017). *Banana Diseases and Pests Field Guide for Diagnostics and Data Collection Improvement of banana for smallholder farmers in the Great Lakes Region of Africa Improvement of banana for smallholder farmers in the Great Lakes Region of Africa*.

Voicu, G., Constantin, G., Ipate, G., & Tudor, P. (2017). Farinographic parameter variation of doughs from wheat flour with amount of water added. *Engineering for Rural Development*, *16*, 976–981. https://doi.org/10.22616/ERDev2017.16.N200

Wairegi, L. W. I. (2010). Management practices and opportunities in the East African highland banana (Musa AAA-EA) production in Uganda. In *Management practices and opportunities in East African highland banana (Musa spp. AAA-EA) production in Uganda*.

Wilberforce, T., Michael, B., Moses, N., Robooni, T., Alex, B., Ssali, T., Jerome, K., Jum, L.,

& Rony, S. (2014). *Performance of Narita Banana Hybrids in the Preliminary Yield Trial , Uganda*. *November*, 0–35.

World, S., Vol, J., & Corresponding, K. (2017). Physico-chemical analysis and sensory evaluation of bread produced using different indigenous yeast isolates. *Science World Journal*, *12*(1), 33–37.

Yadav, D. N., Patki, P. E., Sharma, G. K., & Bawa, A. S. (2009). Role of ingredients and processing variables on the quality retention in frozen bread doughs: A review. *Journal of Food Science and Technology*, *46*(1), 12–20.

Yang, T., Wang, P., Zhou, Q., Zhong, Y., Wang, X., Cai, J., Huang, M., & Jiang, D. (2022). Effects of Different Gluten Proteins on Starch's Structural and Physicochemical Properties during Heating and Their Molecular Interactions. *International Journal of Molecular Sciences*, *23*(15). https://doi.org/10.3390/ijms23158523

Zain, M. Z. M., Shori, A. B., & Baba, A. S. (2022). Potential functional food ingredients in bread and their health benefits. *Biointerface Research in Applied Chemistry*, *12*(5), 6533–6542. https://doi.org/10.33263/BRIAC125.65336542

Zghal, M. C., Scanlon, M. G., & Sapirstein, H. D. (2001). Effects of flour strength, baking absorption, and processing conditions on the structure and mechanical properties of bread crumb. *Cereal Chemistry*, *78*(1), 1–7. https://doi.org/10.1094/CCHEM.2001.78.1.1

Žilic, S. (2013). Wheat gluten: Composition and health effects. *Gluten: Sources, Composition and Health Effects*, *March*, 71–86.

APPENDICES

Appendix I: BREAD SENSORY EVALUATION FORM

Panellist Name________________________

You are provided with samples of bread. Please taste and record your degree of liking of the samples on a scale of 1 to 9 by placing your score in the box next to the sensory parameter. Please evaluate the breads in the order in which they are presented. Use the water provided to refresh your mouth before and between samples.

PLEASE ANSWER ALL QUESTIONS

Score the product 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.**											
	1	2	3	4	5	6	7	8	9	10	11	12
Appearance												
Colour												
Flavour												
Taste												
General acceptability												

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

....……………………………………

General comments (if any):

……………………………………………………………………………………………

Thank you for participating in this session

Appendix II: Photos of the hybrid cooking bananas used in the study.

A_1: N23

A_2: M9

A_3: M30

A_4: N21

A_5: N15

Appendix III: Photos of the composite bread used in the study.

A1: N15 10%

A2: M30 10%

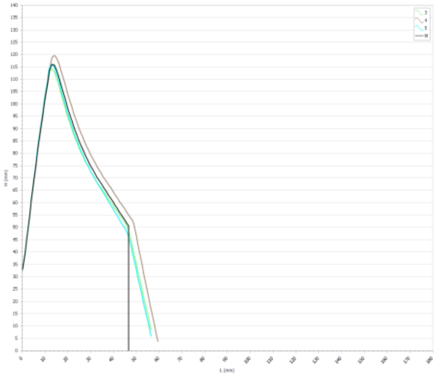
A3: N21 10%

A4: M9 10%

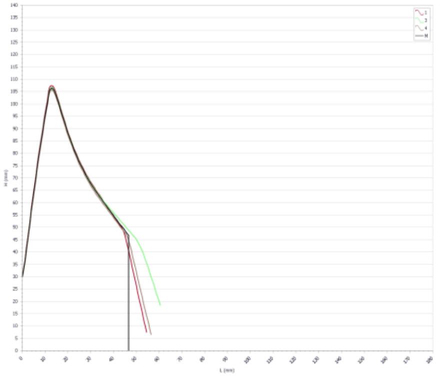
A5: N23 10%

Appendix IV: Alveograph charts showing results of alveograph parameters: peak height, extensibility, ratio of tenacity to extensibility, baking strength, swelling index and flexibility index of the dough from the different hybrid banana flour inclusions

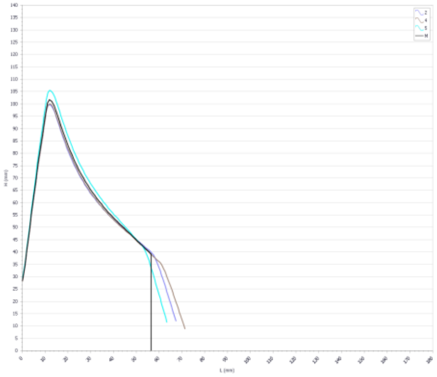
A1: M9 10%



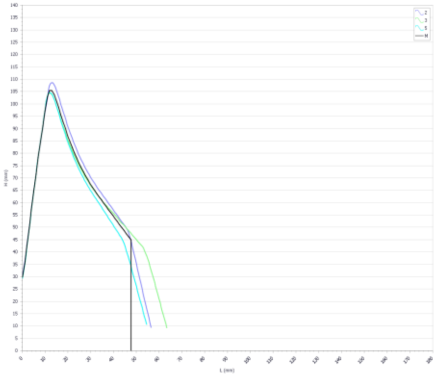
A2: M30 10%



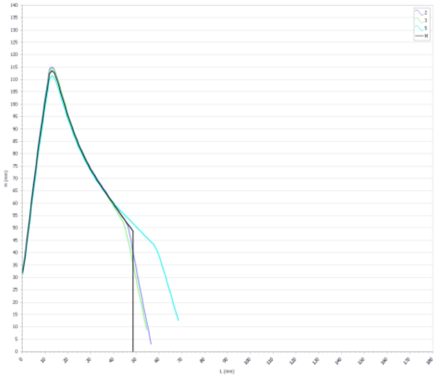
A3: N15 10%



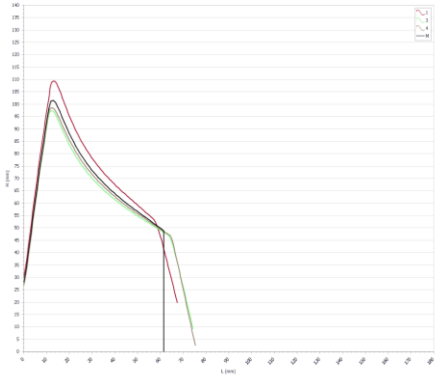
A4: N21 10%



A5: N23 10%

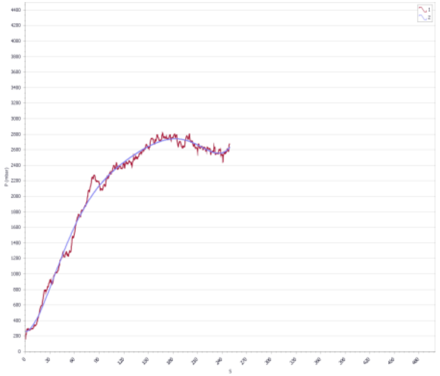


A6: 100% wheat flour (Azam)

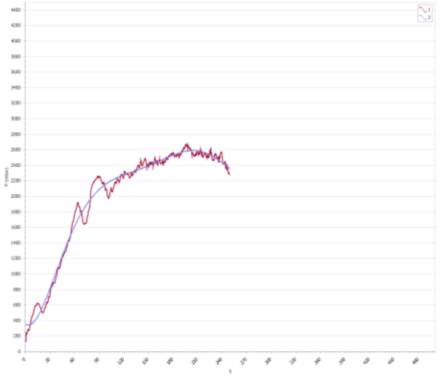


Appendix V: Consistograph charts showing results of consistograph parameters: water absorption capacity and maximum pressure of the dough from the different hybrid banana flour inclusions

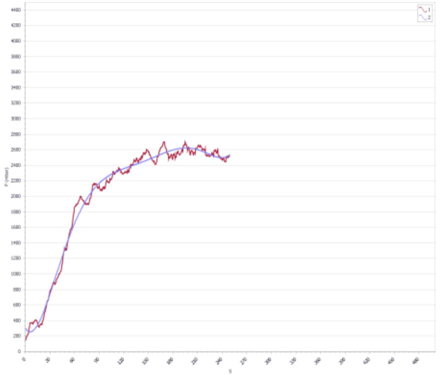
A1: M9 10%



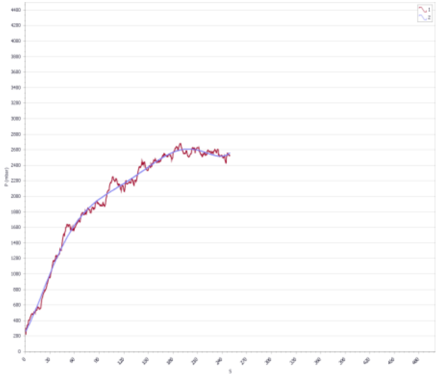
A2: M30 10%



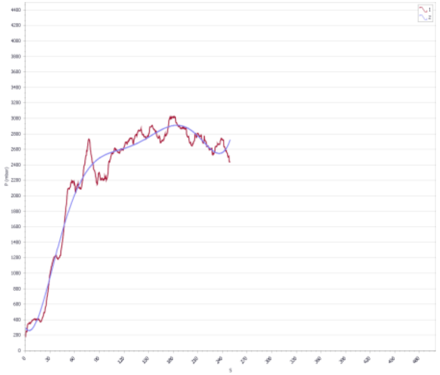
A3: N15 10%



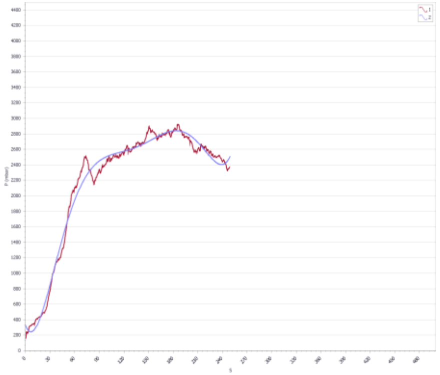
A4: N21 10%



A5: N23 10%



A6: 100% wheat flour (Azam)



APPENDIX VI: 2 way ANOVA, Tests of between-subjects effects for the different dependable variables

Dependent Variable: Water_absorption_capacity_WAC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	159.606[a]	20	7.980	84.214	.000	.988
Intercept	94536.029	1	94536.029	997616.382	.000	1.000
Variety	13.398	4	3.349	35.345	.000	.871
Percentage_inclusion	98.552	3	32.851	346.665	.000	.980
Variety * Percentage_inclusion	31.081	12	2.590	27.332	.000	.940
Error	1.990	21	.095			
Total	112381.620	42				
Corrected Total	161.596	41				

a. R Squared = .988 (Adjusted R Squared = .976)

Dependent Variable: Maximum_pressure_PrMax

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	7931687.619[a]	20	396584.381	793168.762	.000	1.000
Intercept	191992476.457	1	191992476.457	383984952.914	.000	1.000
Variety	582333.400	4	145583.350	291166.700	.000	1.000
Percentage_inclusion	5387172.300	3	1795724.100	3591448.200	.000	1.000
Variety * Percentage_inclusion	1318212.200	12	109851.017	219702.033	.000	1.000
Error	10.500	21	.500			
Total	227556885.000	42				
Corrected Total	7931698.119	41				

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Dependent Variable: Peak_height_P

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	11961.905[a]	20	598.095	1196.190	.000	.999
Intercept	461725.714	1	461725.714	923451.429	.000	1.000
Variety	907.000	4	226.750	453.500	.000	.989
Percentage_inclusion	7997.100	3	2665.700	5331.400	.000	.999
Variety * Percentage_inclusion	3043.400	12	253.617	507.233	.000	.997
Error	10.500	21	.500			
Total	568573.000	42				
Corrected Total	11972.405	41				

a. R Squared = .999 (Adjusted R Squared = .998)

Dependent Variable: Extensibility_L

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	43399.619[a]	20	2169.981	4339.962	.000	1.000
Intercept	116467.457	1	116467.457	232934.914	.000	1.000
Variety	6897.400	4	1724.350	3448.700	.000	.998
Percentage_inclusion	7253.100	3	2417.700	4835.400	.000	.999
Variety * Percentage_inclusion	29211.400	12	2434.283	4868.567	.000	1.000
Error	10.500	21	.500			
Total	181125.000	42				
Corrected Total	43410.119	41				

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Dependent Variable: Baking_strength_W

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	151992.286[a]	20	7599.614	15959.190	.000	1.000
Intercept	1142024.145	1	1142024.145	2398250.704	.000	1.000
Variety	3429.900	4	857.475	1800.698	.000	.997
Percentage_inclusion	108609.075	3	36203.025	76026.352	.000	1.000
Variety * Percentage_inclusion	13577.300	12	1131.442	2376.027	.000	.999
Error	10.000	21	.476			
Total	1357656.000	42				
Corrected Total	152002.286	41				

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Dependent Variable: Development_time_DT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	80.773[a]	20	4.039	18.702	.000	.947
Intercept	363.699	1	363.699	1684.165	.000	.988
Variety	38.764	4	9.691	44.875	.000	.895
Percentage_inclusion	17.611	3	5.870	27.183	.000	.795
Variety * Percentage_inclusion	13.220	12	1.102	5.102	.001	.745
Error	4.535	21	.216			
Total	461.510	42				
Corrected Total	85.308	41				

a. R Squared = .947 (Adjusted R Squared = .896)

Dependent Variable: Mixing_tolerance_index_MTI

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	37671.619[a]	20	1883.581	26.441	.000	.962
Intercept	503700.045	1	503700.045	7070.656	.000	.997
Variety	4268.000	4	1067.000	14.978	.000	.740
Percentage_inclusion	21696.275	3	7232.092	101.520	.000	.935
Variety * Percentage_inclusion	596.600	12	49.717	.698	.736	.285
Error	1496.000	21	71.238			
Total	719128.000	42				
Corrected Total	39167.619	41				

a. R Squared = .962 (Adjusted R Squared = .925)

Dependent Variable: Hardness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	38.779[a]	20	1.939	11.580	.000	.846
Intercept	510.167	1	510.167	3046.756	.000	.986
Variety	2.121	4	.530	3.166	.023	.232
Percentage_inclusion	22.192	3	7.397	44.177	.000	.759
Variety * Percentage_inclusion	10.977	12	.915	5.463	.000	.609
Error	7.033	42	.167			
Total	700.052	63				
Corrected Total	45.812	62				

a. R Squared = .846 (Adjusted R Squared = .773)

Dependent Variable: Springness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.543[a]	20	.027	13.928	.000	.869
Intercept	19.216	1	19.216	9858.532	.000	.996
Variety	.127	4	.032	16.312	.000	.608
Percentage_inclusion	.065	3	.022	11.085	.000	.442
Variety * Percentage_inclusion	.269	12	.022	11.509	.000	.767
Error	.082	42	.002			
Total	22.473	63				
Corrected Total	.625	62				

a. R Squared = .869 (Adjusted R Squared = .807)

Dependent Variable: Cohesiveness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.603[a]	20	.030	17.508	.000	.893
Intercept	7.095	1	7.095	4119.705	.000	.990
Variety	.133	4	.033	19.256	.000	.647
Percentage_inclusion	.078	3	.026	15.108	.000	.519
Variety * Percentage_inclusion	.321	12	.027	15.519	.000	.816
Error	.072	42	.002			
Total	8.505	63				
Corrected Total	.675	62				

a. R Squared = .893 (Adjusted R Squared = .842)

Dependent Variable: Colour

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	382.030[a]	20	19.101	6.237	.000	.177
Intercept	4825.490	1	4825.490	1575.600	.000	.731
Variety	56.916	4	14.229	4.646	.001	.031
Percentage_inclusion	208.740	3	69.580	22.719	.000	.105
Variety * Percentage_inclusion	100.619	12	8.385	2.738	.001	.054
Error	1779.392	581	3.063			
Total	23173.720	602				
Corrected Total	2161.422	601				

a. R Squared = .177 (Adjusted R Squared = .148)

Dependent Variable: Aroma

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	494.345[a]	20	24.717	8.122	.000	.219
Intercept	4003.659	1	4003.659	1315.621	.000	.694
Variety	136.314	4	34.079	11.198	.000	.072
Percentage_inclusion	233.366	3	77.789	25.562	.000	.117
Variety * Percentage_inclusion	113.500	12	9.458	3.108	.000	.060
Error	1768.082	581	3.043			
Total	19871.870	602				
Corrected Total	2262.427	601				

a. R Squared = .219 (Adjusted R Squared = .192)

Dependent Variable: Flavour

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	438.986[a]	20	21.949	7.650	.000	.208
Intercept	3935.770	1	3935.770	1371.766	.000	.702
Variety	138.556	4	34.639	12.073	.000	.077
Percentage_inclusion	178.049	3	59.350	20.686	.000	.097
Variety * Percentage_inclusion	111.682	12	9.307	3.244	.000	.063
Error	1666.962	581	2.869			
Total	19453.520	602				
Corrected Total	2105.948	601				

a. R Squared = .208 (Adjusted R Squared = .181)

Dependent Variable: Taste

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	518.450[a]	20	25.923	8.085	.000	.218
Intercept	3962.856	1	3962.856	1235.998	.000	.680
Variety	156.951	4	39.238	12.238	.000	.078
Percentage_inclusion	196.370	3	65.457	20.416	.000	.095
Variety * Percentage_inclusion	152.745	12	12.729	3.970	.000	.076
Error	1862.801	581	3.206			
Total	19712.509	602				
Corrected Total	2381.252	601				

a. R Squared = .218 (Adjusted R Squared = .191)

Dependent Variable: General_acceptability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	523.310[a]	20	26.165	9.567	.000	.248
Intercept	4343.907	1	4343.907	1588.272	.000	.732
Variety	135.912	4	33.978	12.423	.000	.079
Percentage_inclusion	234.674	3	78.225	28.601	.000	.129
Variety * Percentage_inclusion	138.209	12	11.517	4.211	.000	.080
Error	1589.029	581	2.735			
Total	21037.119	602				
Corrected Total	2112.339	601				

a. R Squared = .248 (Adjusted R Squared = .222)