PROXIMATE COMPOSITION, FUNCTIONAL AND PASTING PROPERTIES OF FLOUR FROM MUSA PARADISIACA AT DIFFERENT LEVELS OF MATURITY AND ITS FEASIBILITY OF DEVELOPING VALUE - ADDED PRODUCTS

Dissertation submitted to

ST. TERESA'S COLLEGE (AUTONOMOUS), ERNAKULAM

Affiliated to
MAHATMA GANDHI UNIVERSITY

In partial fulfilment of requirement for the
AWARD OF THE DEGREE OF MASTER OF SCIENCE IN

HOME SCIENCE (BRANCH C)

FOOD SCIENCE AND NUTRITION

By

AMALA ROSLYN V.A

Register No. AM23HFN002

DEPARTMENT OF HOMESCIENCE AND CENTRE FOR RESEARCH

APRIL 2025

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I hereby declare that the thesis entitled **'Proximate Composition, Functional and Pasting properties of flour from Musa paradisiaca at different levels of maturity and its feasibility of developing value - added products'** is a Bonafide record work done by me during the course of the study, under the supervision and guidance of Dr. Betty Rani Isaac, Associate Professor, Department of Home Science and Centre for Research, St. Teresa's College, Ernakulam.

AMALA ROSLYN V.A

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CERTIFICATE

This is to certify that the thesis entitled ***'Proximate Composition, Functional, and Pasting Properties of flour from Musa paradisiaca at different levels of maturity and its feasibility of developing value – added products'*** is an authentic record of the original research work carried out by **Ms. Amala Roslyn V.A** with **Reg.No - AM23HFN002** under my supervision and guidance during the academic year 2023-25.

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AMALA ROSLYN V.A

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CHAPTER – 1

INTRODUCTION

Musa paradisiaca (Nendran banana variety) is an essential food crop that holds immense significance in India's rich culinary heritage and agricultural landscape. It has been a fundamental part of Indian food systems for centuries, renowned for its versatility, nutritional value, and cultural relevance. Banana cultivation is particularly important in Indian agriculture, especially within small-scale farming systems. The crop is relatively low- maintenance as it requires minimal resources, and can adapt to a wide range of agro – ecological environments. Often grown alongside with other crops, it contribute to income diversification and enhanced agricultural productivity. Additionally, its by – products such as leaves and pseudo stems are utilized as organic fertilizers and livestock feed, fostering sustainable farming practices.

Nutritionally, they are a powerhouse of essential vitamins and minerals. They are an excellent source of potassium, which is vital for maintaining healthy blood pressure and heart function, and vitamin B6, which supports brain development and proper neurological function. The vitamin C content in bananas enhance immune function and acts as a potent antioxidant, while their dietary fiber promotes digestion and provides a sense of fullness. The health benefits of bananas are equally noteworthy. Potassium aids in regulating blood pressure, thereby reducing the risk of heart disease and stroke. The fiber content supports digestive health and prevents constipation. Additionally, the complex carbohydrates present provide a steady energy source, making them a valuable addition to a balanced diet.

Their high perishable nature leads to significant postharvest losses, particularly during peak harvesting seasons when supply exceeds demand. Without adequate storage and processing infrastructure, farmers face economic setbacks, and a considerable amount of food goes to waste. Transforming bananas into flour provides a sustainable solution to these challenges. It not only extends their shelf life and reduces spoilage but also creates an additional income source through value – added products.

Moreover, as demand for gluten–free and nutrient–rich alternatives grows, banana flour emerges as an excellent substitute for traditional flours like wheat and maize. Packed with dietary fiber, resistant starch, and other essential minerals, it caters to health-conscious consumers, including those with gluten intolerance, diabetes, or a focus on improving gut health. Valued for its gluten-free, low glycemic index characteristics, banana flour is commonly used in functional foods like baked goods, baby foods, and dietary supplements. By converting surplus bananas into flour, we not only minimizes food waste but also encourage sustainable farming practices, making it a win-win for farmers, consumers, and the environment alike.

Processing of bananas into flour, has numerous application in the food industry. Understanding the variations in bananas across different maturity stages – tender, mature, and ripe is essential for optimizing their functional, nutritional and technological properties for use in food products. One of the most significant changes that occur during banana ripening is the transformation of its nutritional profile. In the tender stage, bananas are rich in starch, primarily in the form of resistant starch, which offers benefits like a low glycemic index and prebiotic effects that support gut health. As the banana mature, the starch undergoes enzymatic hydrolysis, converting gradually into simple sugars like glucose, fructose, and sucrose. By the time the banana reach the ripe stage, their sugar content increases considerably, imparting natural sweetness that is suitable for various culinary uses. These nutritional changes highlight the importance of studying different maturity stages to align the properties of banana with the specific needs of food products. Studying the different maturity stages is not only essential for improving food quality but also for addressing economic and environmental challenges. Properly utilizing bananas at different maturity stages helps reduce food waste and post-harvest losses, particularly in regions where bananas are a major crop. By understanding the optimal uses for each maturity stage, producers can diversify their product, improve marketability, and promote sustainable food systems that minimize waste.

The functional properties of banana flour – such as water and oil absorption, bulk density, and gelatinization – are also influenced by the maturity stage of the fruit. For instance, flour made from unripe bananas has excellent water absorption and swelling capacity, making it ideal for thickening soups, gravies, and sauces. In contrast, flour from ripe bananas has a finer texture and higher solubility, making it better suited for baked goods, smoothies, and desserts. The starch pasting properties, including viscosity and gelatinization temperature, and breakdown values, also vary significantly across maturity stages. These variations affect the texture, stability, and overall quality of the final product. Tender and mature bananas ae rich in resistant starch, while ripe bananas have higher sugar content. These variations in composition make banana flour nutritionally diverse and adaptable for various food products.

Banana flour's functional properties enhance its value in food product development. Its excellent water absorption and viscosity make it an ideal thickening agent for soups, sauces and bakery items. As a gluten – free ingredient, banana flour serves as a popular substitute for wheat flour, in gluten free recipes, catering to individuals with celiac diseases or gluten intolerance. The resistant starch in banana flour acts as a prebiotic, promoting beneficial gut bacteria and improving gut health. Additionally, its low moisture content extends shelf life, reducing spoilage and waste compared to fresh bananas. The versatility of banana flour has led to its incorporation into a wide range of food products, such as bread, cakes, cookies, smoothies, and baby foods, it is also used in functional snacks and dietary supplements. The diverse functional properties of banana flour allow for innovative applications that can improve nutritional profiles and cater to specific dietary needs.

The current study titled ***'Proximate Composition, Functional, and Pasting Properties of flour from Musa paradisiaca at different levels of maturity and its feasibility of developing value - added products'***, explores how the maturity stage of bananas affects nutritional and physicochemical properties of banana flour. It also evaluates the potential of using this flour to create innovative, value – added food products.

Relevance of the study : Although some studies have examined the nutritional and functional properties of banana flour, there is a gap in research regarding how these properties differ across the tender, mature, and ripe stages within the same banana variety. By focusing on these variations, the study helps to provide a deeper understanding of how ripening influences the characteristics of banana flour. Additionally, by evaluating its feasibility in value-added products, the research contribute to reduce post – harvest losses, promoting sustainable utilization of banana,

Aim of the study : To analyze the proximate composition, functional properties, and pasting properties of banana flour made from Musa paradisiaca at tender, mature, and ripe stages and to evaluate its potential in developing value – added products.

Objectives of the study :

1. To determine the proximate composition of banana flour at different stages.
2. To evaluate the functional properties of the flours.

3. To evaluate the pasting properties of the flours.
4. To compare the differences in nutritional and functional properties across the three stages.
5. To develop value – added product
6. To assess the nutritional composition, microbial safety, and shelf life of the product.

CHAPTER – 2

REVIEW OF LITERATURE

A literature review is a thorough summary and critical evaluation of existing research and publications on a specific topic area of study. The topics which related to the thesis ***'Proximate Composition, Functional and Pasting Properties of flour from Musa paradisiaca at different levels of maturity and its feasibility of developing value - added products'*** is listed below.

2.1 Nutritional significance of banana

2.2 Phytochemical properties

2.3 Changes in nutrient composition during maturation

2.4 Physicochemical changes in banana during maturation

2.5 Industrial and commercial applications of banana

2.1 Nutritional significance of banana

Bananas are among the earliest crops cultivated by humans and continue to be a vital food source for millions in tropical regions. Bananas are a significant source of high-calorie energy and not only provide easily digestible carbohydrates but also offer essential nutrients such as vitamin B and C, along with important minerals like potassium, calcium, and magnesium. Additionally, are recognized for their various medical benefits. They play a key role in the diets of rural and working- class populations, ranking as the fourth most important global commodity by gross producer value, following rice, wheat, and maize/milk products (Rajesh, 2017).

A study examined the impact of different drying techniques – freeze drying, spray-drying, and tray- drying – on the nutrient retention of Musa paradisiaca (ripe Nendran), a staple food in South India, particularly Kerala. Using atomic absorption spectroscopy and high performance liquid chromatography, the availability of minerals and water- soluble vitamins in dried ripe banana powder was analyzed. Freeze- dried banana powder demonstrated superior nutrient retention, with potassium at 486.92 ± 0.12 mg/100g, calcium at 0.60 ± 0.005 mg/100g, sodium at 3.10 ± 0.10 mg/100g, iron at 3.82 ± 0.02 mg/ 100g, vitamin C at 6.28 ± 0.04 mg/ 100g, and vitamin B6 at 0.606 ± 0.005 mg/100g, confirming it as the most effective technique for preserving the nutrients in ripe banana (Kabeer *et al.*, 2023).

Banana is renowned for its traditional, medicinal, and nutritional uses. It is rich in carbohydrates (22.84 g/100g), provides approximately 370 kJ/100g of energy, and is considered one of the best sources of potassium (358 mg/100g), fulfilling 8% of daily recommended value. Along with its unique nutritional profile, banana also exhibits excellent medicinal properties. All parts of the banana, including its flesh and peel, can be processed into products such as banana chips, banana powder, banana biscuits, and banana juice (Ranjha *et al*., 2022).

A study conducted by Oyeyinka and Afolayan evaluated the nutritional and mineral composition of the flesh, and peel extract of *Musa sinersis* L. and *Musa paradisiaca* L., focusing on their nutritional and therapeutic potential. Proximate and antinutritional analyses were conducted using AOAC standard methods, and mineral content was determined with ICP-OES. Results indicated that the flesh and peel of both species contain significant moisture, fiber, and carbohydrates with low fat content. Minerals such as potassium, magnesium, calcium, sodium, phosphorus, and nitrogen were particularly concentrated in the peels and their extracts. Antinutrients, including alkaloids, oxalates, saponins, and phytates, were present in safe amounts as per WHO standards. The findings highlight the potential for utilizing the peel, its extracts, and the flesh of these banana species for the nutritional and therapeutic purposes (Oyeyinka & Afolayan, 2019).

The proximate composition, carbohydrate content, and amino acid profile of green and ripe plantains were analyzed. Ripening significantly increased total sugar content from 3.0 % to 31.6% in the peel and from 1.3% to 17.3% in the pulp, while starch levels declined from 50% to 35 % in the peel and from 83% to 66 % in the pulp. The pulp protein was notably rich in arginine, aspartic acid, and glutamic acid, whereas methionine was least abundant amino acid, with tryptophan and cystine entirely absent (Ketiku,1973).

The proximate, mineral, and vitamin composition of raw, sundried, fermented, boiled, and roasted unripe plantain samples were analyzed using AOAC standard methods, atomic absorption spectroscopy, and spectrophotometric techniques. Unripe plantain contained 59.4g moisture, 7.7g crude protein, 2.5g ash, 1.4g crude fiber, 24.4g carbohydrates, 80 mg sodium, 120 mg potassium, 66.6 mg calcium, 275 mg magnesium, 195 mg phosphorus, 2.5 mg iron, 3.7 mg zinc, and provided 128.6 kcal energy per 100g sample. Processing methods like sun-drying, fermentation, boiling and roasting significantly enhanced crude lipid, ash, crude fiber, carbohydrate, and mineral contents ($p< 0.05$) . The low sodium content combined with high energy makes them beneficial for diabetics. A 100g serving can contribute 6.3 – 15.3% energy, 5.9 – 30.2% protein, 7.8 – 16% calcium, 9.2 – 23.3% iron, and 28.5 – 33.7% zinc towards the Recommended Dietary Allowances (RDAs) (Adepoju *et al*., 2012).

A partial nutritional analysis of banana fruits from six triploid *Musa* accessions grown in the coastal oasis of Southern Tunisia revealed significant variability in their composition. The study recorded levels of glucose, fructose, and sucrose were 2.7, 3.37, and 1.8 g/100g flesh weight (FW), respectively. Total polyphenols ranged from 46.0 to 55.08 mg GAE/100g FW, while vitamin C was found in smaller quantities. There was significant disparities in the mineral content across different samples, with mico – elements like zinc, copper, iron, and magnesium varying by accession. Notably, the iron (Fe) content was high, reaching up to 1945 mg/100g of dried matter, suggesting that banana fruits could be recommended for daily intake of Fe, K, and other essential minerals (Jeridi *et al*., 2023).

2.2 Phytochemical properties

In the study aimed to characterize and evaluate the in vitro bioactive properties of green banana pulp flour (GBPF), peel flour (GBPeF), and mixed pulp/peel revealed that GBPeF had a higher lipid concentration (7.53%) and contained greater levels of free and bound phenolics (577 and 653.1 mg GAE/100g, respectively), while GBPF had a higher resistant starch content (44.11%). Incorporating up to 20 % GBPeF into mixed flour had minimal impact on the starch pasting properties of GBPF. The predominant phenolic compounds in GBPeF were rutin and trans- ferulic acid, while GBPF exhibited different major free phenolics, though its bound phenolics were similar to those in GBPeF. These findings confirm the potential of green banana mixed flour, containing up to 20% GBPeF as a functional ingredient and healthy food products and for mitigating post harvest losses (Viana *et al*., 2024).

Ten banana cultivars, in unripe form, popular in southern India, viz. Yangambi (YAN), Mysore Ethan (ME), Zanzibar (ZAN), Peyan (PEYA), Palayankodan (PALA), Malayannan (MA), Nendran (NEN), Robusta (ROB), Kappa and Monthan (MON), in the unripe form were found to be good sources of resistant starch, with MA being the richest source (41.78 ± 1.29% d/w). the phenolic compounds, free vitamins, and amino acids were estimated and quantified using Liquid Chromatography and Tandem Mass Spectrometry (LC- MS/MS). The antioxidant activity was assessed in terms of DPPH and ABTS free radical scavenging abilities. Among the varieties, MA showed higher phenolic content, whereas flavonoid content was higher for Kappa. LC-MS/MS characterization revealed the presence of significant amounts of phenolic compounds such as shikimic acid, epicatechin, ferulic acid, and rutin; free amino acids like phenylalanine, histidine, glutamine, lysine, and arginine, and free vitamins such pyridoxine, nicotinic acid, and ascorbic acid among the varieties. ROB and PALA demonstrated potential DPPH and ABTS radical scavenging activity, and α- amylase amino acid residues resulted in high binding energies of -5.45 and -5.48 kcal mol^{-1}, respectively, confirming the hypoglycemic potential. The bioactive and nutritional potential of these cultivars, as detailed in the present study, positions them as excellent sources for food, functional food, and nutraceutical applications (Shini *et al*., 2024).

The study undertaken with the objective of conducting a comprehensive comparison of the phytochemical attributes, and bioactivity of green banana pulp and peel extracts found that the total flavonoid content in banana peel (226.22 mg QE/100g) surpassed that of banana pulp (58.21 mg QE/100g), while banana pulp contained the highest total polyphenol content (24.06 mg GAE/100g) compared to banana peel (8.9 mg GAE/100g).Both samples displayed comparable antioxidant capacities. Phytochemical screening indicated the presence of essential compounds, including carbohydrates, proteins, tannins, and flavonoids, in both extracts. Notably, glycosides were absent in both, while saponins were not detected in banana pulp (Aich, 2023).

The bioactive compounds of banana peel including alkaloids, flavonoids, phenolics, and steroids (such as tannic acid, catechol, β -sitosterol, and ferulic acid), help perform various biological activities. These compounds exhibit antitumor, antiparasitic, antibacterial, antifungal, antiaging, antioxidant, and antiviral properties. The mechanism of these bioactive compounds aids in curing infections and diseases. The study highlights that banana peel is a valuable byproduct with numerous benefits, making it suitable for use in various industries, including pharmaceuticals, cosmetics, food, leather, biodiesel, and bioethanol (Hashim *et al*., 2023).

Unripe banana flour is considered a useful ingredient in the food industry because it has high levels, of resistant starch (up to 68% w/w). The beneficial effects of banana flour resistant starch (BFRS) against diabetes, cardiovascular disease, and colorectal cancer emanate from its resistance to hydrolysis and its propensity to escape digestion in the upper gastrointestinal tract, which delays glucose absorption and increases the concentration of colonic short – chain fatty acids (acetate, propionate, and butyrate). Therefore, BFRS can be recommended as an alternative functional ingredients in food products (Dibakoane *et al*., 2023).

2.3 Changes in nutrient composition during maturation

A study which investigated the biochemical changes in banana during maturation and ripening revealed that starch concentration increased significantly during maturation, reaching its peak around 80 – 90 days, followed by a sharp decline during ripening. This pattern indicates that mature bananas have higher starch content, which contributes to greater solid matter (Mohan, Rajesh, Zuhra & Vijitha, 2014).

In a study by Sari et al. found hat ash content increased with ripening. The highest ash content was recorded in physiologically ripe Ambon Kuning banana flour (3.87 % ± 0.04%), while the lowest was in physiologically ripe Ketip banana flour (1.75% ± 0.02%). The authors noted that more overripe banana flesh led to higher ash content, suggesting an increase in mineral content as ripening advanced (Sari *et al*., 2022).

A review titled 'Biochemical changes during banana ripening' emphasizes that during banana ripening, substantial amounts of accumulated starch are converted into sugars, leading to pulp softening and sweetening. This starch – to – sugar metabolism is a critical process in achieving optimal postharvest quality, as the breakdown of starch increases the fruit's osmotic potential, drawing water into the pulp and thereby raising its moisture content (Nascimento *et al*., 2019).

A study titled 'Nutritional Composition of Culinary Musa ABB at Different stages of Development' found that total carbohydrate content increased from tender stage (21.32g/ 100g) to the mature stage (32.15g / 100g) but decreased at ripe stage (27.63g/100g). the researchers explained that this variation is due to the breakdown of starch into sugars as the bananas progress through growth and ripening. During maturation, starch accumulates, leading to higher carbohydrate content, while ripening triggers starch degradation into simpler sugars, resulting in a slight decline in total carbohydrates at the ripe stage (Khawas *et al.*, 2014).

Kumar, Bhowmik & Srivastava observed changes in free amino acid levels in Cavendish bananas, with some amino acids increasing as a result of protein metabolism and enzymatic activity. They found that the protein content in Musa paradisiaca flour was at its lowest in the mature stage but rose significantly as the fruit reached the ripe stage this increase in protein content during ripening is likely due to complex biochemical changes, such as the breakdown of starch and the production of new proteins that contribute to fruit softening and other metabolic shifts (Kumar *et al.*, 2018).

In the study 'Changes in Nutrient Content and Physicochemical Properties of Cavendish Bananas var. Pei Chiao during Ripening', the crude fibre content showed little change overall, staying within a narrow range of 0.58% to 0.68% throughout the ripening process. However, a subtle decrease in crude fiber was noted as the bananas ripened, pointing to a gradual breakdown of fiber components. While the study did not find a significant drop in crude fiber, this slight reduction suggests that insoluble fibers slowly degrade over time, subtly affecting the bananas overall fiber content as it ripens (Huang *et al.*, 2024).

In a study which assessed the nutritional and physiochemical changes in banana (Musa paradisiaca) during ripening, observed a gradual rise in fat content, from 0.60% in the early stages to 0.78% in fully ripened bananas, suggesting that metabolic changes during ripening contribute to lipid accumulation. The study also noted that protein content in Musa paradisiaca increased from 1.20% on the second day of storage to 2.28% by the seventh day, highlighting a clear upward trend as the fruit ripened (Adekalu *et al.*, 2011).

The significant rise in reducing sugar content during banana ripening is widely supported by scientific research. In unripe bananas, starch makes up about 20 – 25% of the pulp's fresh weight, while sugars are present in much smaller amounts, typically around 1-2 %. As ripening progresses, starch breakdown into simpler sugars, causing a dramatic increase in sugar content, which can reach 15 – 20% in fully ripe bananas. This process is driven by enzymatic activity that converts starch into reducing sugars like glucose and fructose, enhancing the fruit's sweetness and making ripe bananas more enjoyable to eat (Ahmad *et al*., 2018).

In a study which explored how organic acid pretreatment influences the physicochemical properties of flour made from three unripe banana cultivars, revealed that the iron content in banana flour changes with the stages of maturity. Specifically, they found that unripe and mature banana flours contain higher iron levels compared to flour from ripe bananas. The difference is likely due to reduced enzymatic activity and mineral leaching as the fruit ripens, preserving more iron in the earlier stages. These findings emphasizes the importance of considering maturity when evaluating nutritional quality of banana flour (Anyasi *et al*., 2013).

In a study, Gamlath noted that calcium levels in banana pulp dropped from 34.1mg/ 100g in unripe stage, to 29.8 mg/100g in the ripe stage, reflecting a steady decline as ripening progresses. This reduction is linked to biochemical changes during ripening, such as the conversion of insoluble pectates into soluble forms, which reduces calcium retention (Gamlath, 2008).

A study focusing on Pei Chiao banana cultivar revealed that potassium levels peaked during the ripe stage, reaching 946.69 mg/100g. Here the potassium content in Musa paradisiaca flour shows a clear upward trend as the fruit ripens, highlighting improved mineral retention in the later stages of maturity. This suggests a consistent accumulation of potassium as the fruit matures. The increase is likely driven by changes in osmotic pressure between peel and pulp, which promote the movement of potassium into the fruit (Huang *et al*., 2024).

2.4 Physicochemical changes in banana during maturation

The study which investigated the variations in banana flour (BF) and banana starch (BS) content at different ripening stages following ethylene treatment revealed that total starch and resistant starch (RS) contents were initially 76.2% and 34.6% respectively, at stage I of ripening, but decreased to 25.3% and 8.8%, respectively, by stage VII. The free sugar content and solubility increased with ripening time, while the swelling power (SP) of BF showed a negative correlation. Notably, as ripening advanced, BS starch particles became rougher and exhibited structural breakage, which affected the rheology and functionality of the starch. The crystalline structure of BS shifted from B- type in the initial stage to Cb- type structure at the later stages of ripening. The starch and RS contents were at their lower between stages III and IV of ripening (Cheng *et al*., 2024).

In the study titled 'Impact of Ripening Stages of Banana Flour on the Quality of Extruded Products', the water absorption capacity (WAC) of the banana flour was examined across different ripening stages. The study revealed that as banana ripens, the breakdown of starch into simpler sugars and changes in the flour's structural composition significantly alter its functional properties, including WAC. Specifically, the study found that ripe banana flour had a higher water absorption capacity compared to unripe banana flour. This increase is likely due to the conversion of resistant starch into more soluble sugars and the breakdown of starch granules, which improves their ability to hold water (Gamlath, 2008).

The oil absorption capacity (OAC) of banana flour tends to decrease as the fruit ripens, primarily due to changes in starch and fiber structure. Adeyanju and Osundahunsi investigated how ripening affects the functional properties of Musa ABB (Cardaba banana) flour and found that unripe banana flour had its highest OAC at 136.7%, while fully ripe banana flour showed a significant drop to 43.3%. This reduction is linked to the breakdown of complex polysaccharides, such as starch, into simpler sugars during ripening, which diminishes the flour's ability to bind oil effectively (Adeyanju & Osundahunsi, 2019).

The impact of varying drying temperature (40,60, and 80 ^{o}C) and banana slice thicknesses (2 and 4 mm) on the physicochemical properties of green banana flour (GBF) was studied. Increasing the drying temperature from 60 to 80 ^{o}C and reducing slice thickness from 4 to 2 mm resulted in higher TPC values (225.69 ± 5.13 GAE/100g DW) and greater DPPH radical inhibition (91.08 ± 2.28%). However, other physicochemical properties such as soluble solids, titratable acidity, pH, and ash content were not significantly affected by the drying temperature and slice thickness, and humidity values remained below 10%. These findings suggest that hot air drying at temperatures between 60 and 80 ^{o}C and using slice thickness less than 4 mm can better preserve the antioxidant capacity in banana flour (Espinoza *et al*., 2023).

A study observed that during banana ripening, sucrose content initially rises as a result of starch hydrolysis, but later declines as it is converted into glucose and fructose. This shift in sugar content impacts the drying behavior of bananas, as the hygroscopic nature of these sugars affects their ability to retain moisture. This explains that ripe banans, with their higher sugar content, often require longer drying times compared to less mature stages (Michon *et al*., 2010).

In the study aimed to compare the changes in physicochemical properties of starch isolated from three banana cultivars (Musa AAA group, Cavendish subgroup; Musa ABB group, Pisang Awak subgroup; Musa AA group, Huangdijiao subgroup) at five different maturity stages revealed that amylose content and particle size of the starches increased with the ripeness of the banana. Light microscopy and scanning electron microscopy revealed that starch particles of the three starches had different microscopic characteristics, with the banana starch morphology remaining mostly unchanged across various growth stages. Moreover, the pasting and thermal properties of the banana starches differed significantly across the growth stages. The resistant starch content of the three banana cultivars remained about 80% at all growth stages, with the Musa AAA group, Cavendish subgroup, having the highest resistant starch content at stage V (Wang *et al*., 2024).

Maturity of fruit can be identified using physical and chemical properties such as color, smell, taste, firmness, sugar content, and antioxidants. Many of these properties, including acidity, sugar content, and firmness were analyzed. It revealed that the sugar content in bananas changes with maturity, making it a suitable indicator of ripeness. However, banana maturity is commonly identified using peel color. Recently, a non–invasive technique called NIR spectroscopy (a nondestructive method) has been utilized to evaluate fruit quality. This study employed a low cost AS7263 NIR sensor to predict the maturity level of bananas, characterized by their sugar content (Brix). The correlation between the NIR spectrum and Brix was developed using Multi Linear Regression (MLR) and Artificial Neural Network (ANN) models. The correlation model successfully classified banana maturity levels into four categories: raw, underripe, ripe, and overripe (Kapse *et al*., 2023).

The physicochemical and physiological attributes of three contrasting commercial varieties of Musaceae- Dominico Harton (plantain), Guineo (cooking banana), and Gros Michel (dessert banana) - were evaluated and statistically analyzed during post – harvest ripening. The study found that quality attributes differed significantly among the varieties, both in fresh fruits and during ripening. Variety (V) had a significant effect ($P<0.001$) on all attributes except total soluble solids (TSS), carotenes, and total chlorophyll. Storage time (ST) significantly affected all attributes except for color parameter b* and total carotenes. The starch levels decreased significantly

(P<0.001) during ripening, with nearly complete hydrolysis in Gros Michel, followed by Guineo and Dominico Harton. Discriminant analysis revealed that central diameter, TSS of the pulp, color parameter a*, and total starch had the highest weight in differentiating among varieties (Moreno *et al*., 2021).

The ripening process of bananas divided into eight stages based on peel appearance, ranging from mature green (stage 1) to overripe (stage 8). The study observed a significant increase (P<0.05) in PPR, while the firmness of both peel and pulp gradually decreased as ripening progressed. A similar trend was noted in the color parameters 'L', 'b', and Croma 'C' for both peel and pulp. TA, TSS, MC, AC, AA, glucose, sucrose, and fructose levels significantly increased (P<0.05), whereas SC and TFC significantly decreased (P<0.05) during ripening. The study identified 38 volatile compounds across all ripening stages, with 1 -butanol, 3- methyl- acetate; butanoic acid, 1- methylbutyl ester; butanoic acid, 3- methyl- 3 methylbutyl ester contributing significantly to the advanced ripening stages (Watharkar *et al*., 2020).

2.5 Industrial and commercial applications of banana

Despite their potential, the byproducts of banana are often discarded as waste. The growing body of research underscores the innovative potential of bananas and their by – products, advocating for their utilization as a sustainable source of income in the agricultural industry (Kumari, Gaur & Tiwari, 2023).

The peel constitutes about 30 – 40% of a whole banana, with the remainder being pulp. Due to its rich composition, banana peel has found applications across various industries, including cosmetics, medicine, food processing, beverages, textiles, energy production, paper manufacturing, bio - absorbents, biofuel production, and agriculture. in agriculture, banana peel is used as a fertilizer to improve soil quality, crop yield, and overall agricultural productivity, primarily due to its high potassium content. Additionally, the fiber – rich nature of banana peels aids in treating constipation, while their anti- inflammatory properties make them useful in managing inflammation and infections in everyday home remedies. Given its accessibility, banana peel can also serve as a cost – effective organic cosmetic. Moreover, industries leverage banana peel for producing paper, fiber, and textiles, demonstrating its versatile applications across sectors (Bhavani *et al*., 2023).

The large amount of banana biomass waste generated is often discarded in agricultural fields, combusted, or dumped in plantations, leading to significant environmental concerns. One promising approach to addressing this issue is the extraction of nanocellulose (NC) from banana biomass, which can enhance its value due to the exceptional properties of NC, such as high surface area, aspect ratio, tensile strength, and thermal stability. These attributes make nanocellulose highly suitable for applications in the food industry, either as a functional ingredient, additive, or in food packaging. This review identifies two main applications of banana biomass – derived nanocellulose: (i) as a material for food packaging and (ii) as a food stabilizer. It highlights relevant studies on extraction of nanocellulose from banana biomass for use in food products, along with discussions on the safety and regulatory aspects of its application. However, the review emphasizes the need for further research to draw clear conclusions regarding the safety of banana biomass nanocellulose, its potential hazards in food applications, and the establishment of validated standards for further commercialization (Zaini *et al*., 2023).

The Cavendish group, which includes cultivars such as Grand Nain, Williams, Chinese, and Valery, is a particularly favored for its high yield potential and marketability in both domestic and international markets. However, challenges such as incomplete identification of cultivars, issues in producing flour and developing innovative products, and significant postharvest losses hinder expansion of banana production. Therefore, the identification of suitable cultivars and determining the optimal stage of unripe bananas are crucial steps for enhancing their use in various food and industrial applications (Maseko *et al*., 2024).

Most edible bananas are cultivated primarily for their fruits, leading to the generation of several tons of underused by – products and waste from banana farms. These by- products, including leaves, inflorescence, pseudostem, and rhizomes, are often undervalued, with limited commercial application, and are sometimes, considered agricultural waste. The present review highlights yhe potential of banana by – products such as peels, leaves, pseudostem, pseudostem juice, stalk, and inflorescence for various industrial uses. These include applications as thickening agents, alternative sources of renewable energy, nutraceuticals, livestock feed, natural fibers, coloring agents, bioactive compounds, and bio-fertilizes. Utilizing banana waste in this manner not only provides valuable products but also helps conserve renewable resources and provides additional income for farming industries (Gupta *et al*., 2023).

A study was conducted to develop environmental friendly silver nanoparticles (AgNPs) using banana peel extract. Banana blocks coated with Na-CMC + AgNPs showed better preservation, with no mold growth observed throughout the 5 -day storage period. Meanwhile, banana blocks coated with only Na-CMC showed mold growth starting on the 3rd day. This preliminary study evidenced that Na-CMC incorporate with AgNPs could prolong shelf life of bananas against mold growth (Goh *et al*., 2023).

Different components of the banana plant, including the fruit, fruit skin, flower buds, leaves, and pseudo-stem (banana trunk), are employed for diverse industrial applications. The pseudo-stem constitutes a significant proportion of the biomass derived from banana waste and possesses high-quality fiber that exhibits promising potential for various industrial applications. These applications include the production of sanitary pads, textiles, pulp and paper, food products, reinforced composite materials for automobiles, construction materials, aerospace components, and other composite materials. Additionally, the residual waste generated from its production can be effectively employed for the development of bio- based products, thereby making a direct contribution to a country's economy (Iqbal *et al*., 2023).

Biodegradable plastic from banana peels were produced as a substitute for commercial plastics and it proved that the starch in banana peel could be used in the production of biodegradable plastics, the strength was determined by an elongation test and by comparing it with synthetic plastic. In the soil burial degradation test, the intensity of degradation was tested by comparing it with synthetic plastic. Biodegradable plastic degraded at a rapid rate, while synthetic plastic did not degrade at all. Based on the entire test, bioplastic from banana peels can be used in industry for various applications such as molding, packaging, and making carry bags, while simultaneously rescuing the environment from potential harm by synthetic plastics (Arjun *et al*., 2023).

Processing fruits and vegetables results in substantial waste, including skins, seeds, stones, and unused flesh. This waste poses environmental challenges due to improper disposal and legal restrictions. However, these by- products are rich in valuable compounds like colorants, proteins, dietary fibers, flavorings, antimicrobials, and antioxidants. They hold potential as natural food additives and supplements with high nutritional value. The recovery and utilization of these by-products for producing food additives can be economically advantageous and environmentally beneficial, diving interest in their advanced use (Sarafrazy & Sidiqi, 2020).

The utilization of underutilized compounds from fruit and vegetable processing by – products in biodegradable packaging films is getting attraction due to their availability, cost- effectiveness, environmental benefits, and desirable physical properties. These by- products, including husks, seeds, and leaves, are rich in fibrous and plant proteins like starch, cellulose, and pectin. Recycling these waste materials into high – value biopolymers for packaging reduces environmental pollution and supports sustainable development. This review explores the conversion of fruit and vegetable by- products into functional biopolymer films and coatings, offering an eco- friendly alternative to synthetic plastics (Sani *et al*., 2023).

The global rise in population and lifestyle changes have significantly increased food waste across industrial, agricultural, and household setting. Approximately one- third of all food produced annually is wasted, leading to severe resource depletion and environmental threats. Food waste is rich in bioactive compounds such as polyphenols, dietary fiber, proteins, lipids, vitamins, organic acids, and minerals – often in higher concentrations than in market – accepted parts. These compounds present opportunities for converting food waste into valuable products across various fields including nutritional foods, bioplastics, bioenergy, biosurfactants, biofertilizers, and single-cell proteins (Liu *et al*., 2023).

The use of banana peel, a by- product from banana chip production, in creating fiber- fortified bread was studied. The research highlights banana peel powder as a valuable source of fiber, amino acids, and carotenoids. The study involved pretreatments, dying processes, and colorimeter tests to determine the optimal conditions for incorporating banana peel powder into bread. The resulting fiber- fortified bread showed a significant increase in fiber content, which supports digestive health and weight management, and introduced a unique flavor and color. Consumer feedback favored formulations with 95% flour and 5% peel. This approach not only improves the nutritional profile of bread but also addresses sustainability by repurposing banana peels, thereby reducing food waste. Chemical analysis revealed higher moisture, protein, fiber, fat, and ash contents in bread made with banana peel flour (Paul *et al*., 2024).

The study exploring the 3D printability of banana peel (BP) powder combined with guar gum (GG), characterizes the particle properties of BP powder, which exhibited irregular and clumped microscopic morphology. The printability of BP and BP + GG mixtures was optimized by varying extrude pressure, motor speed, and nozzle diameter. Optimal conditions were found to be a pressure of 6 bar, motor speed of 150 rpm, a 1.2 mm nozzle, a printing speed of 500 mm/min, and a printing rate of 0.186 ± 0.002g/min. A nozzle height of 0.8 mm was also determined to be ideal. This research successfully demonstrates how non- printable BP can be made printable, potentially advancing the development of unique and customized food packaging solutions (Nida *et al*., 2023).

The sensory properties of bread made from composite flours of wheat, carrot, and banana were evaluated. Five bread samples were produced using different ratios of wheat, carrot, and banana flours: 90%: 5%: 5% (blend one), 80%: 10%: 10% (blend two), 70%: 15%: 15% (blend three), and 60%: 20%: 20% (blend four), with 100% wheat flour servings as control. The analysis revealed that there was no significant difference in overall acceptability between the composite bread samples, the bread made with the 60%: 20%: 20% ratio (blend four) was particularly favored by consumers. The study highlights that incorporating carrot and banana flours into wheat flour can enhance nutritional value of bread, offering a viable option to improve nutrition and combat malnutrition (Ewunetu *et al*., 2023).

The incorporation of unripe banana flour (UBF) and fermented unripe banana flour (FUBF) in biscuits at varying proportions (0%, 15%, and 30%) was studied and evaluated their impact on physical, textural, and functional properties. It was found that the addition of FUBF positively influenced the spread ratio of biscuits compared to UB F ($P<0.05$). Both UBF and FUBF significantly increased the total phenolic content (TPC) and antioxidant activity ($P<0.05$), with the highest TPC (1167.88 mg GAE/kg) observed in biscuits containing 30% FUBF. However, fermentation did not significantly affect antioxidant activity ($P>0.05$). Despite the nutritional benefits, all biscuit samples had high glycemic index (GI) values, with the control sample at 78.59 and the 30% FUBF sample at 72.74, classifying them as high GI foods. The addition of UBF or FUBF also resulted in a significant decrease in biscuit hardness ($P<0.05$), although fermentation did not significantly affect this parameter ($P>0.05$). this research highlights the potential of UBF and FUBF as functional ingredients that can enhance the health benefits of biscuits while maintaining desirable textural properties (Cetin-Babaoglu *et al*., 2024).

The potential of substituting wheat flour with banana flour in a chiffon cake production was studied, aiming to establish an optimal replacement ratio and evaluate the physical, chemical, and sensory properties of the resulting cakes. The research employed a randomized nested design with two major factors: raw banana flour (P1) and pregelatinized banana flour (P2). The minor factors were varying ratios of wheat flour to banana flour (0:100, 25:75, 50:50, and 75:25). The optimal ratio for making chiffon cake using raw banana flour was determined to be 50:50, yielding desirable characteristics such as a 104.25% development volume, 0.562mm^2 pore uniformity, 226.30g hardness, 0.62 cohesiveness, 7.73mm springiness, 21,244.03 ppm antioxidant activity, and a total phenol content of 9.78 mg GAE/g. for chiffon cakes made with pregelatinized banana flour, the best ratio was 75:25, which resulted in a development volume 121.22%, 0,57mm^2 pore uniformity, 240.40 g hardness, 0.64 cohesiveness, 7.76 mm springiness, 25,306.65 ppm antioxidant activity, and a total phenol content of 8.57 mg GAE/g. Sensory evaluations revealed that panelists could not distinguish between the chiffon cakes made with 100% wheat flour and those made with banana flour (Aulia *et al*., 2024).

The impact of various physical treatments, including pre- gelatinization (PBF), annealing (ANN), and combinations of these treatments (PBF+ANN and ANN +PBF), on the characteristics of banana flour and its suitability for use in gluten – free chip production was studied. The analysis focused on evaluating the color, swelling capacity, solubility, oil absorption index, and pasting properties of both native and modified banana flour samples. The findings revealed that pre-gelatinized significantly altered the color of the banana flour. The pasting properties of the modified samples showed a marked decrease, with PBF- treated samples displaying a substantial reduction in breakdown value compared to the native and annealed samples. The PBF treatment also resulted in higher oil absorption and swelling power, alongside lower solubility, making the flour more suitable for dough formation in banana chip production. These modified properties contributed to the distinct texture profiles of the resulting chips (Kunyanee *et al*., 2024).

The functional properties, resistant starch (RS) content, and glycemic index (GI) of fresh noodles substituted with banana flour (BF) was studied. The substitution levels of BF in the noodles ranges from 0% to 40%. As the BF content increased, the noodles exhibited higher viscoelastic properties but a reduction in the tensile strength and elasticity, which decreased from 52.23 gf to 26.84gf and from 44.65 mm to 15.04 mm, respectively. The GI of the noodles dropped from 77.05 to 62.62, and the RS content significantly increased from 5.56% to 23.31%. The noodles with the highest BF substitution were classified as intermediate GI foods due to their reduced GI and elevated RS content. Additionally, the study explored the impact of adding hydrocolloids – xanthan gum (XG), guar gum (GG), and carboxymethyl cellulose (CMC) – at 1.0% and 1.5% levels to dried noodles substituted with 30% BF (DBF30). The findings showed that DBF30 with XG had the shortest rehydration time of 6.5 minutes, while DBF30 with CMC had the longest rehydration time of 8.5 minutes. The incorporation of hydrocolloids improved the noodle's rehydration, decreased cooking loss, and enhanced tensile strength and elasticity. Furthermore, the addition of these hydrocolloids increased the RS content and further reduced the GI of DBF30 (Tangthanantorn *et al*., 2021).

Gluten – free muffins using green banana flour was developed and evaluated their physical-chemical properties and sensory appeal. The muffins had a moisture content of 26.7%, ash content of 2.39%, lipids at 15.4%, proteins at 10.3%, fibers at 1.2%, and carbohydrates at 44.0%, with total caloric value of 261.2 kcal. The muffins also demonstrated high protein digestibility and moderate antioxidant activity, suggesting potential health benefits. The sensory analysis revealed an acceptability index of 84.5%, indicating that the gluten- free muffins not only offer a nutritionally rich alternative but also possess appealing sensory qualities, making them a promising option for those seeking gluten- free products (Radunz *et al*., 2021).

CHAPTER – 3
METHODOLOGY

Research methodology is a systematic and organized approach used to conduct research, encompassing the methods, techniques, and procedures utilized for data collection, analysis, and interpretation. Study was conducted in two phases. Phase 1 focused on the comparative analysis of banana flours derived from tender, mature, and ripe stages of Musa paradisiaca. Phase 2 involved the application of these flours in the development of value – added products.

Methodology of the present study ***'Proximate Composition, Functional, and Pasting Properties of flour from Musa paradisiaca at different levels of maturity and its feasibility of developing value – added products'***, is discussed under the following main headings :

3.1 Phase 1 – Comparative study of the flour

3.2 Phase 2 – Development of value – added products

3.1 Phase 1 – Comparative study of the flour

Phase 1 includes the comparative study of the flour which involves, analyzing and comparing various aspects of flour derived from Musa paradisiaca at different stages of maturity. It includes the following steps:

3.1.1 Selection of Sample

3.1.2 Sample Collection

3.1.3 Preparation of Flour

3.1.4 Proximate Composition

3.1.5 Microbiological Assessment

3.1.6 Functional Properties

3.1.7 Pasting Properties

3.1.1 Selection of sample

The sample selected is Musa paradisiaca (Nendran variety of Kerala), a highly valued banana variety for its unique characteristics and a staple food in South Indian cuisine. This variety is primarily cultivated in Kerala, where the tropical climate and fertile soil provides ideal growing conditions. It is available year – round, with peak harvests during certain months. The Nendran variety is widely accessible in Kerala, making it a dependable choice for sample collection

Plate 3.1 – Nendran banana plant

3.1.2 Sample Collection

Bananas of different maturity stages (tender, mature and ripe) were procured from K Banana, a store in Vailathur, Tirur, known for sourcing bananas directly from local cultivators and farmers. It ensures the authenticity and quality of the samples. Each maturity stage was selected to reflect its unique characteristics, which impact the nutritional, functional and pasting properties of the flour.

3.1.2.1 Selected of samples at various stages of maturity

Bananas were selected at three different maturity stages to examine their varying characteristics and flour properties. Banana samples were chosen using color - based banana ripening scale developed by Don Edwards from UC Davis (1996). According to this tender bananas were selected at stage 1, where peel is completely green. Mature bananas were picked at stage 3, when the peel is more green than yellow. Ripe bananas were chosen at stage 6, which is characterized by a fully yellow peel,

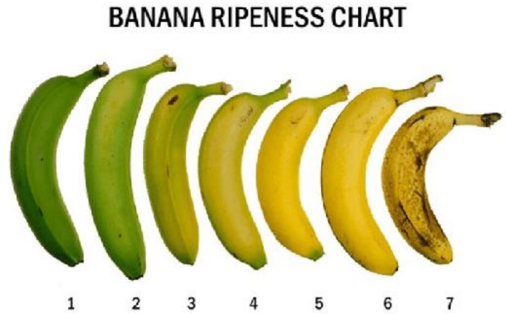


Plate 3.2 - Banana ripening scale. Don Edwards, UC Davis, Postharvest, California, USA

This color – based approach allowed for a clear differentiation between the maturity stages, which was essential for analyzing the proximate composition, functional properties, and pasting properties of Musa paradisiaca flour. The ripening scale provided a standardized and consistent method for selecting the samples, ensuring accuracy and reliability in the study.

Plate 3.3 – Bananas at different stages of maturity

3.1.3 Preparation of Flour

The process of preparing banana flour from different stages of Musa paradisiaca includes cleaning, peeling, drying and powdering.

Procedure for flour preparation:

Cleaning : About 12 kg of bananas were chosen at tender, mature and ripe stages and washed them under running water to remove external impurities.

Peeling : These bananas were carefully peeled to remove the outer skin. After peeling, they were thoroughly washed to eliminate any dirt or impurities.

Drying : They were then sliced into thin, uniform pieces to ensure even drying, maintaining consistency in slice thickness. The banana slices were placed in the cabinet dryer at $65^{o}C$. Tender and mature banana slices required 10 hours, while the drying time of ripe banana slices was extended to 20 hours due to high moisture content.

Powdering : After dehydration, the dried slices were ground into fine powder using a mixer grinder.

Plate 3.4 – Preparation of tender Musa paradisiaca flour

Plate 3.5 – Preparation of mature Musa paradisiaca flour

Plate 3.6 – Preparation of ripe Musa paradisiaca flour

3.1.3.1 Physical Characteristics of the flour

The physical characteristics of the banana flour, such as color, smell, taste, and texture, were carefully evaluated to identify variations across different maturity stages (tender, mature, and ripe).

Color**:** Both tender and mature stage flours appeared to be off – white, with tender stage having a a slightly deeper undertone and the mature stage displaying a very faint yellowish tint. In contrast, the ripe stage flour had a deeper yellow color with slight browning, reflecting the advanced ripening process.

Tender

Mature

Ripe

Plate 3.7 – Tender, Mature and Ripe banana flour

Smell : The tender stage flour had a subtle, grassy aroma, while the mature stage flour gave off a slightly sweet and fruity scent. The ripe stage flour, however, had a much stronger, sweet, and distinctly banana – like fragrance.

Taste : The tender stage flour tasted neutral with a slightly starchy note. The mature stage flour had a mild sweetness, and the ripe stage flour was notably sweeter with a rich, banana – like flavor.

Texture : The texture of the flour was examined for particle size and smoothness. The tender and mature stage flours had a finer and smoother texture, while the ripe flour was coarser, likely due to changes in starch composition and fiber content as the banana ripened.

3.1.4 Proximate Composition

Proximate composition includes analyzing the basic nutritional components of a food product, such as moisture, protein, fat, ash, and carbohydrate content. This analysis provides a detailed overview of the food's nutritional profile, which is crucial for understanding its value and potential applications.

3.1.4.1 Ash

Method: Muffle Furnace Method

Procedure:

- Weigh a clean, dry crucible and record its weight (W_1).
- Add approximately 5g of the sample into the crucible and weigh it again (W_2).
- Place the crucible with the sample in a muffle furnace and incinerate at 550oCfor 4 – 6 hours, or until a grayish – white ash is obtained.
- Allow the crucible to cool inside the furnace overnight to prevent thermal shock.
- Transfer the cooled crucible to a desiccator to reach room temperature and prevent moisture absorption.
- Weigh the crucible with the ash (W_3).

Calculation: Ash Content (%) = $\frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$

3.1.4.2 Moisture

Method: Oven Drying Method

Procedure:

- Weigh a clean, dry crucible and record its weight (W_1).
- Add approximately 1 gram of the sample into crucible and weigh it again (W_2).
- Place the crucible with the sample in a hot air oven at 105^{o}C for 3 – 5 hours.
- After drying, remove the crucible and allow it to cool in a desiccator to prevent moisture absorption.
- Weigh the cooled crucible with the dried sample (W_3).
- Repeat the drying and weighing process until a constant weight is achieved to ensure complete moisture removal.

Calculation: Moisture Content (%) = $\frac{(W_2 - W_1)}{(W_2 - W_3)} \times 100$

3.1.4.3 Total carbohydrate

Method: Phenol Sulfuric Acid Method

Procedure:

I. Preparation of Standard Curve

- Prepare a series of glucose standards by pipetting 0.2, 0.4, 0.6, 0.8, and 1.0 mL of the glucose working standard (0.1 mg/mL) into separate boiling tubes.
- Adjust the final volume in each tube to 1mL by adding distilled water.
- Add 1 mL of 5% phenol solution to each.
- Add 5 mL of 96% sulfuric acid to each tube and shake well after each addition to ensure thorough mixing.
- Let the tubes stand for 10 minutes at room temperature.
- Place the tubes in a water bath maintained at 25 – 30^{o}C for 15 minutes.
- Prepare a blank using 1 mL of distilled water instead of the glucose standard, and treat it similarly with phenol and sulfuric acid.
- Measure the absorbance of each standard solution at 490 nm using a spectrophotometer.
- Plot a standard curve with glucose concentration (mg/mL) on the x-axis and absorbance on the y-axis.

II. Analysis of Samples:

- Pipette 0.2 mL of each sample into separate boiling tubes.
- Adjust the final volume to 1 mL by adding distilled water.
- Repeat steps 3 – 8 from the standard curve preparation (adding phenol, sulfuric acid, incubation, and measuring absorbance).
- Use the standard curve to determine the carbohydrate concentration in the samples based on their absorbance values.

3.1.4.4 Protein

Method: Lowry assay method

Procedure:

I. Prepare a Protein Standard Curve

- Prepare a series of BSA standard dilutions in distilled water with concentrations of 0.5, 0.1, 2, 4, 6 and 8 µg/ mL.
- Add 2% (w/v) sodium carbonate solution to each standard and mix well. Incubate at room temperature for 10 minutes to denature the proteins.
- Add 0.5% (w/v) copper sulfate solution to each standard and mix. Incubate for 10 minutes at room temperature to allow the formation of a copper – protein complex.
- Add 1% (v/v) Folin – Ciocalteu reagent to each solution, mix thoroughly, and incubate for 30 minutes at room, temperature.
- Measure the absorbance values against the corresponding protein concentrations to generate a standard curve.

II. Measure the Protein Concentration of the Sample

- Prepare the sample by diluting it with distilled water if necessary to ensure it falls withing the range of the standard curve.
- Add 2% (w/v) sodium carbonate solution to the sample and mix well. Incubate at room temperature for 10 minutes to denature the proteins.
- Add 0.5% (w/v) copper sulfate solution to the sample and mix. Incubate for 10 minutes at room temperature to form the copper – protein complex.
- Add 1% (v/v) Folin – Ciocalteu reagent to the sample, mix thoroughly, and incubate fo 30 minutes at room temperature.
- Measure the absorbance of the sample at 750 nm using a spectrophotometer.
- Use the standard curve to determine the protein concentration of the sample based on its absorbance value.

3.1.4.5 Fat

Method: Soxhlet Extraction Method

Procedure:

- Weigh 2 – 5 grams of banana flour and place it into a thimble.
- Assemble the Soxhlet extractor and place the thimble inside it.
- Add petroleum ether (boiling point 40 – 60^{o}C) to the extraction flask.
- Perform the extraction process for 6 – 8 hours, allowing the solvent to cycle repeatedly and dissolve the fat from the sample.
- After extraction, carefully evaporate the solvent from the flask using a heating mantle or water bath.
- Dry the remaining residue (extracted fat) in an oven to remove the moisture.
- Weigh the extracted fat.

Calculation: Fat Content (%) = $\frac{\text{Weight of the extracted fat}}{\text{Weight of the sample}} \times 100$

3.1.4.6 Crude Fiber

Method: Acid – Base Digestion Method

Procedure:

- Weigh approximately 8 grams of defatted sample.
- Boil it with 1.25% sulfuric acid (H_2SO_4) for 30 minutes to digest soluble components.
- Filter the mixture and wash the residue thoroughly with hot water to remove any remaining acid.
- Boil the residue with 1.25% sodium hydroxide (NaOH) for another 30 minutes to further digest soluble materials.
- Filter the mixture again and wash the residue with hot water, followed by acetone to remove any remaining impurities.
- Dry the residue in an oven at 105^{o}C until completely dry, then weigh it.
- Incinerate the dried residue in a muffle furnace at 550^{o}C to burn off organic matter, leaving only ash.
- Cool the ash in a desiccator and re- weigh it.

Calculation: Crude Fiber (%) = $\frac{\text{(Weight of residue – Weight of ash)}}{\text{Weight of sample}} \times 100$

3.1.4.7 Minerals

In mineral estimation sodium, potassium, and calcium were measured using Flame Emission Spectroscopy method, which identifies metal ions based on their unique emission spectra. Iron and phosphate were analyzed using the Colorimetric method, which determines their concentration by measuring intensity of the color.

Phosphate

Method: Colorimetric method

Procedure:

I. Preparation of Calibration Standards

- Prepare a series of calibration standards by transferring 0, 5, 10, 15, and 20 mL aliquots of the standard phosphate solution into separate 50 mL volumetric flasks.
- Add 10 mL of vanadate – molybdate reagent to each.
- Dilute each flask to 50 mL mark with distilled water.

II. Analysis of the sample

- Shake the sample thoroughly to ensure proper mixing.
- Transfer a 25 mL aliquot of the sample into each of two 50 mL volumetric flasks.
  - Add 10 mL of vanadate – molybdate reagent to one flask (for sample analysis).
  - The second flask acts as a sample blank (no reagent added).
- Dilute both flasks to the 50 mL mark with distilled water.
- Shake well to ensure proper mixing.
- Repeat the process for all samples.
- Allow the prepared solutions (including calibration standards) to stand for at least 10 minutes for full color development.
- Measure the absorbance of each standard, sample, and blank at 470 nm using a spectrophotometer.
- Plot a calibration graph of absorbance (y-axis) versus phosphorous concentration (x-axis, in µ/mL) for standard solutions.
- Use the calibration graph to determine the phosphate concentrations (as P) in each sample.
  - Account for the dilution factor in calculations.

- Subtract the sample blank reading from the corresponding sample reading to correct for background interference.

Iron

Method: Colorimetric method

Procedure:

I. Preparation of sample solution:

- Weigh 0.1g of banana flour and dissolve it in 50 mL of distilled water.
- Add 10 drops of 3 M sulfuric acid (H_2SO_4) to acidify the solution.
- Filter the solution to remove any undissolved particles.
- Add 5 mL of 10% hydroxylamine hydrochloride ($NH_2OH\cdot HCl$) to reduce Fe^{3+} to Fe^{2+}. Mix well and let it stand for 5 minutes.
- Add 5 mL of 0.3% o-phenanthroline solution to the mixture. Mix thoroughly and allow the color to develop for 15 minutes at room temperature.
- Add 5 mL of 1 M ammonium acetate ($NH_4C_2H_3O_2$) to maintain pH at 3.5.

II. Preparation of standard solutions:

- Prepare iron standard solutions by diluting Fe^{3+} solution to concentration of 0.0005 mg/mL, 0.0010 mg/ mL, 0.0015 mg/mL, and 0.0020 mg/mL.
- Treat each standard solution with the same reagents (hydroxylamine HCl, o-phenanthroline and ammonium acetate) following steps 4 – 6 above.
- Use distilled water as blank solution.

III. Spectrophotometric Measurement:

- Set the spectrophotometer to a wavelength of 510 nm.
- Measure the absorbance of the blank, standard solutions, and sample solution.
- Plot a calibration curve using the absorbance values of the standard solutions against their respective iron concentrations.
- Determine the iron concentration in the sample by comparing its absorbance to the calibration curve.

Calcium, Sodium, Potassium

Method: Flame emission spectroscopy

Procedure:

I. Preparation of Standard solutions:

- Prepare stock solutions of sodium (Na), potassium (K), and calcium (Ca) at 1000 ppm concentration.
- Dilute the stock solutions with distilled water to prepare working standards at concentrations of 1 ppm, 5 ppm, 10 ppm, and 20 ppm.
- Add 0.1 M HCl to all solutions to prevent precipitation of salts.

II. Preparation of Sample solutions:

- Weigh 1 g of banana flour and dissolve it in 50 mL of distilled water.
- Add 5 mL of 0.1 M HCl to maintain pH and ensure complete dissolution of salts.
- Filter the solution using Whatman No. 1 filter paper to remove any undissolved solids.
- Transfer the filtrate into a clean 100 mL volumetric flask and dilute to the mark with distilled water.

III. Instrument Calibration:

- Turn on the flame photometer and allow it to stabilize for 10 minutes.
- Set the wave length for each element:
    - 589 nm for sodium (Na^+)
    - 766 nm for potassium (K^+)
    - 622 nm for calcium (Ca^+)
- Aspirate the blank solution (distilled water) to set the baseline.
- Aspirate the standard solutions (Na, K, and Ca) and record their emission intensities.
- Plot a calibration curve for each element (concentration vs emission intensity).

IV. sample measurement:

- Aspirate the prepared banana flour solution into the flame photometer.
- Measure the emission intensity for sodium, potassium, and calcium.

- Compare the intensity values with the standard ciliation curves to determine the concentration of each metal in the sample.

3.1.4.8 Acid insoluble ash

Procedure:

- Weigh the crucible containing the previously determined total ash.
- Add 25 mL dilute hydrochloric acid (HCl) to the ash in the crucible.
- Allow the crucible to cool, then filter the contents through Whatman filter paper No.42.
- Wash the residue with distilled water until the washings are free from acid (test with pH paper).
- Transfer the filter paper and residue back into the crucible.
- Place the crucible in an oven at 100oC for 3 hours to dry.
- Ignite the crucible in a muffle furnace at 550oC for 1 hour.
- Cool the crucible in a desiccator and weigh it.

Calculation: Acid insoluble ash (%) = $\frac{\text{(Final weight of the residue)}}{\text{Initial sample weight}} \times 100$

3.1.4.9 Reducing Sugar

Method: Dinitrosalicylic acid (DNS) method

Procedure:

- A series of clean test tubes were labelled 1-6 respectively and volumes of standard stock glucose was added – 0, 0.2, 0.4, 0.6, 0.8, and 1.0 mL.
- Add corresponding volume of distilled water, to make each tubes 1 ml.
- 2 ml of DNS reagent was added to each test tubes. The solution was mixed well and the tubes were placed in boiling water bath for 5 minutes.
- The tubes were allowed to cool and 7 ml of distilled water was added to each of them, and the absorbance was measured in a spectrophotometer at 540 nm using tube 1 as blank (control).
- The absorbance readings were plotted against glucose concentrations to get a standard curve.
- The curve was used to determine the concentration of the unknown sample in mg/ml.

II. Testing for the sample

- One milliliter of the sample was dispensed in clean test tubes. Two milliliter of DNS reagent was added. The mixture was heated in a boiling water bath for 5 minutes. It was allowed to cool, after which 7 ml of distilled water was added. The absorbance was measured with a UV – spectrophotometer at 540 nm, using blank as control.

3.1.5 Microbial assessment of the flour

Microbial load was assessed at the starting of 6^{th} month of storage to ensure the keeping quality of the flour. For microbial assessment using the spread plate method, 0.1g of banana flour sample is dissolved in 10 ml of sterile water to prepare the initial suspension. Agar plates are prepared based on the type of microbial assessment: Plate Count Agar (PCA) for total bacterial load, potato Dextrose Agar (PDA) for fungal growth, and Eosin Methylene Blue Agar (EMB) for coliform detection. A 0.1 ml aliquot of the appropriate dilution is pipetted onto the agar surface under specific conditions: PCA at 37oC for 24 – 48 hours for bacterial count, PDA at 25oC for 3 – 5 days for fungal growth, and EMB at 37oC for 24 – 48 hours for coliform detection. After incubation, colony growth is observed and counted, with microbial load expressed as colony-forming units per gram (CFU/g) using the formula:

$$CFU/g = \frac{\text{Number of colonies x Dilution factor}}{\text{Volume plated (ml)}}$$

3.1.6 Functional Properties

Functional properties refer to the physical and chemical characteristics of food ingredients such as flour, that influence their behavior during processing and preparation. These properties include factors like water absorption, emulsification, and gelatinization, which are crucial for determining the texture, stability, and overall quality of the final product. To assess the functional properties of banana flour from the tender, mature and ripe stage of Musa paradisiaca, various analytical methods are employed.

3.1.6.1 Bulk density and Tapped density

Bulk and tapped density are key physical properties of Musa paradisiaca flour. Bulk density measures the mass of loosely packed flour per unit volume while tapped density represents the mass per unit volume after compaction through tapping or vibration. These values help determine the Carr Index and Hausner Ratio, which assess the flour's flowability and compressibility. The Carr Index, calculated as the percentage difference between tapped and bulk density, indicates how easily the flour flows. The Hausner Ratio, the ratio of tapped to bulk density, reflects flow characteristics, with values closer to 1.0 signifying better movement. Understanding these properties is essential for optimizing banana flour in value added food products ensuring efficient storage, handling and mixing during formulation.

Procedure:

Bulk density measurement:

- Weigh an appropriate quantity of the sample.
- Transfer the sample into a graduated measuring cylinder of known volume
- Note initial volume of the sample in the cylinder without tapping. This is the bulk volume

Calculation: $\text{Bulk density} = \dfrac{\text{Mass of Sample (g)}}{\text{Bulk volume (ml)}}$

Tapped density measurement:

- Tap the cylinder multiple times using a tapped density tester or by manually tapping the cylinder on a hard surface at a consistent height.
- Record the final volume after tapping, where no further volume reduction is observed.

Calculation: $\text{Tapped density} = \dfrac{\text{Mass of sample (g)}}{\text{Tapped volume (ml)}}$

Carr's Index calculation:

- Calculate Carr's Index (%) to determine flowability using the formula:

$$\text{Carr's Index} = \frac{\text{(Tapped density} - \text{Bulk density)}}{\text{Tapped density}} \times 100$$

Hausner Ratio calculation:

- Calculate Hausner Ratio for compressibility using the formula:

$$\text{Hausner Ratio} = \frac{\text{Tapped density}}{\text{Bulk density}}$$

3.1.6.2 Water Absorption Capacity (WAC)

Water absorption capacity (WAP) refers to the ability of flour to absorb and retain water when mixed together. This key functional property affects the flour's hydration behavior, texture, and processing characteristics in food applications.

Method: Centrifugation method

Procedure:

- Weigh 1g of the sample and transfer it into a pre – weighed centrifuge tube.
- Add 10 mL of distilled water to the sample and mix thoroughly to ensure even hydration.
- Allow the mixture to stand for 1 hour to ensure complete hydration of the sample.
- Centrifuge the sample at 3500 rpm for 30 minutes to separate the absorbed water from the unabsorbed water.
- Carefully decant the excess water from the tube.
- Invert the tube over absorbent paper and let it drain completely to remove any remaining unabsorbed water.
- Weigh the centrifuge tube again and determine the weight of absorbed water by subtracting the initial weight of the tube and sample from the final weight.
- Repeat the experiment in triplicate to ensure accuracy and calculate the mean value of the absorbed water.

Calculation: $$\text{WAC (\%)} = \frac{W_2 - W_1}{W_3} \times 100$$

Where:

W_1 = weight of sample

W_2 = weight of empty tube + sample used

W_3 = weight of empty tube + sample + water absorbed

3.1.6.3 Oil absorption Capacity

Oil absorption capacity (OAC) refers to the ability of flour to absorb and retain oil. This functional property plays a key role in determining the texture, mouthfeel and flavor retention of food products. Understanding OAC helps determine the flour's effectiveness in food formulations, its impact on texture and its potential to enhance sensory qualities in various products.

Method: Centrifuge method

Procedure:

- Weigh 1 g of the sample and transfer it into a pre – weighed centrifuge tube.
- Add 10 mL of oil to the sample and mix thoroughly to ensure even distribution.
- Allow the mixture to stand for 1 hour to ensure proper absorption of the oil by the sample.
- Centrifuge the sample at 3500 rpm for 30 minutes to separate the unabsorbed oil.
- Invert the tube over absorbent paper and let it drain completely to remove any remaining unabsorbed oil.
- Weigh the centrifuge tube again and determine the weight of absorbed oil
- Repeat the experiment in triplicate to ensure accuracy and calculate the mean value of the absorbed oil.

Calculation: $$OAC\ (\%) = \frac{W_2 - W_1}{W_3} \times 100$$

Where:

W_1 = weight of sample

W_2 = weight of empty tube + sample used

W_3 = weight of empty tube + sample + oil absorbed

3.1.6.4 Foaming Capacity and Stability

Foam capacity and stability refers to a flour's ability to trap air and maintain a stable foam when whipped or agitated and is expressed as percentage. Foam capacity measures how effectively the flour generates foam, while foam stability indicates how well the foam retains its structure over time without collapsing. These properties are essential in food applications such as baked goods, beverages, and emulsified products, where aeration and texture are important.

Procedure:

Foaming capacity measurement

- Weigh 2g of the sample and dissolve it in 100 mL of distilled water.
- Transfer the solution into a calibrated 100 mL measuring cylinder.
- Shake the cylinder vigorously for 5 minutes to incorporate air and create foam.
- Immediately measure the foam volume formed and record the initial foam height.

Calculation: $FC\ (\%) = \frac{\text{Foam volume}}{\text{Original sample volume}} \times 100$

Foam stability (FS) measurement:

- Let the foam stand undisturbed in the measuring cylinder.
- Measure the foam volume at intervals (e.g., 10, 30, and 60 minutes).
- Record the foam height at each time point and compare it with the initial foam volume.

Calculation: $FS\ (\%) = \frac{\text{Foam volume at time (t)}}{\text{Initial foam volume}} \times 100$

3.1.6.5 Swelling capacity

Swelling capacity refers to the ability of flour to absorb water and increase in volume when mixed with a fixed amount of water, without the need for heat. This functional property plays a key role in determining the flour's hydration, viscosity, and texture in food products. Understanding swelling capacity helps optimize the flour's performance in various food formulations.

Procedure:

- Weigh 5g of banana flour and transfer it into a calibrated measuring cylinder (50 or 100mL).
- Add 50 mL of distilled water to the flour and stir gently to ensure uniform dispersion
- Allow the cylinder to stand at room temperature for 1 hour to permit complete hydration and swelling of the flour.
- After the settling period, record the final volume of the swollen flour.

- Calculate the swelling capacity using the formula:

$$\text{Swelling capacity (\%)} = \frac{\text{Final volume of swollen flour – initial volume of water}}{\text{Mass of sample (g)}} \times 100$$

3.1.6.6 Shape of Granule

The shape of the granules refers to the morphological structure and appearance of starch granules in the flour.

Method: Microscopy

Procedure:

- Place a small amount of banana flour on a clean glass slide.
- Add a few drops of distilled water disperse the granules evenly. A drop of safranin solution is added as staining agent to ensure visibility.
- Gently place a cover slip over the sample to prevent air bubbles and ensure uniform observation.
- Examine the slide under a light microscope at 40x magnification.
- Observe and note the shape of the granules.

3.1.6.7 Gelatinization Temperature

Gelatinization temperature is the temperature range at which starch granules absorb water, swell, and los their crystalline structure, forming a viscous paste. This process plays a key role in determining the functional and textural properties of starch based food products.

Procedure:

- Weigh 5g of banana flour and disperse it in 50 mL of distilled water in a 250 mL beaker.
- Place the beaker on a water bath or hot plate and stir the mixture continuously to ensure uniform heating.
- Insert a thermometer into the suspension to monitor the temperature.
- Heat the mixture at a controlled rate while observing for changes in consistency.
- Continue heating until the flour begins to thicken and form a gel – like consistency, indicating the onset of gelatinization.
- Record the temperature at which this change first occurs as the gelatinization temperature.

3.1.6.8 Microscopic Picture of Gelatinized Flour

The microscopic image of gelatinized flour provides a visual representation of starch granules under microscope after undergoing gelatinization. In this study, it is performed to observe how different maturity stages affect starch granule breakdown, water absorption, and paste formation.

Method: Microscopy after gelatinization

Procedure:

- Disperse 5g of banana flour in 50 mL of distilled water in a beaker.
- Heat the mixture in a water bath until gelatinization occurs, stirring continuously to ensure uniform heating.
- Take a small amount of gelatinized sample and place it on a clean glass slide.
- Add a drop of safranin into to the sample to enhance visibility of the granules.
- Gently mix the sample and cover it with a cover slip.
- Observe the slide under a light microscope at 100x magnification.
- Analyze the shape of the gelatinized granules, noting any changes such as swelling, rupture, or loss of distinct granule structure.

3.1.7 Pasting Properties

Pasting properties are crucial for understanding how starches in flour react to heating and cooling, affecting the texture and quality of food products. This property play a crucial role in determining the flour's thickening, gelling, and stability characteristics, making them essential for various food applications such as baking, sauces, and soups.

3.1.7.1 Viscosity

Viscosity measures the resistance of a fluid or semi-fluid to flow, indicating its thickness or consistency. In food products, it is a key factor in determining texture, mouthfeel, and stability, influencing applications such as sauces, batters, and pastes.

The viscosity of Musa paradisiaca flour at different stages of maturity was assessed using a cup viscometer (B4 ISO 3944).

Procedure:

- Weigh 2g of banana flour and disperse it in 100 mL of distilled water in a beaker.

- Mix thoroughly using a stirrer to ensure uniform dispersion.
- Heat the mixture in a microwave oven for 1 minute to induce gelatinization.
- Transfer the sample into the B4 ISO 3944 cup viscometer placed over a graduated collecting container.
- Allow the sample to flow through the viscometer's orifice while starting a stopwatch.
- Record the time (in seconds) taken for the entire sample to flow out of the cup.

3.2 *Phase 2 – Development of value-added products*

Phase 2 includes the development of value – added products which involves enhancing the nutritional, functional, or economic value of the banana flour by transforming them into improved or innovative food products. It includes the following steps:

3.2.1 Development of cookies

3.2.2 Microbial assessment

3.2.3 Sensory evaluation

3.2.4 Selection of the best product

3.2.5 Nutrient analysis

3.2.6 Packaging and labelling

3.2.7 Assessment of shelf life

3.2.1 Development of cookies

Cookies were developed from banana flours of all the three maturity stages utilizing its natural sweetness, fiber content, and functional properties to enhance the nutritional profile and sustainability of the product. The procedures for the preparation of cookies are given below:

Banana Flour Cookie Recipe –

Preparation of dry ingredients:

- 1 cup banana flour
- ½ cup ragi flour
- ½ cup powdered sugar
- ¼ tsp baking powder
- ¼ tsp baking soda

   - 1/8 tsp salt
- Set aside

Preparation of wet ingredients:

   - 1 cup butter
   - 1 tsp vanilla essence
   - 1 egg

Creaming the Butter and Sugar:

- In a separate mixing bowl, beat ½ cup butter with icing sugar until light and fluffy.

Incorporating wet ingredients:

- Add 1 egg to the creamed butter – sugar mixture and mix using a beater.
- Add 1 tsp vanilla essence and beat well until the sugar is completely dissolved.

Combining dry and wet ingredients:

- Gradually add the sieved dry ingredients into the wet mixture, mixing gentlyin parts.
- Continue mixing until a cookie dough consistency is achieved.

Shaking and Baking:

- Grease a baking tray with butter and place the cookie dough, shaping as desired.
- Preheat the oven to 180^{o}C.
- Bake for 40 minutes until the cookie turn golden brown.




Plate 3.8 – Preparation of Tender Banana Flour Cookies

Plate 3.9 – Preparation of Mature Banana Flour Cookies

Plate 3.10 – Preparation of Ripe Banana Flour Cookies

3.2.2 Microbial assessment

For microbial assessmentof cookies, 0.1 g of the sample was dissolved in 10 mL of sterile distilled water to prepare the suspension. A 0.1 mL aliqout of this suspension was directly spread plated onto prepared agar plates using a sterile glass or L-shaped spreader. The plates were prepared as follows: Plate Count Agar (PCA) for total bacterial load, Potato Dextrose Agar (PDA) for fungal growth, and Eosin Methylene Blue Agar (EMB) for coliform detection. The plates were then incubated under specific conditions. PCA at 37^{o}C for 24 – 48 hours, PDA at 25^{o}C for 3 – 5 days, and EMB at 37^{o}C for 24 – 48 hours. After incubation, colony growthwas observed and counted, with microbial load expressed as colony – forming units per gram (CFU/g) using the formula:

$$\text{CFU/ g} = \frac{\text{Number of colonies x Dilution factor}}{\text{Volume plated (mL)}}$$

3.2.3 Sensory evaluation

The sensory evaluation of cookies was conducted by a panel of 15 members, including research scholars and instructors from Dr. Johns Biotech Centre for Research and Development, Kollam. The evaluation was based on a 5 – point hedonic scale, which assessed key sensory attributes such as Appearance, Aroma, Taste, Texture, and Overall Acceptance. Each panelist rated the cookies on a scale of 1 to 5, where:

5 – Very Good

4 – Good

3 – Fair

2 – Average

1 – Poor

After data collectiom, the average score for each parameter was calculated to determine the overall acceptability of the cookies.

3.2.4 Selection of the best product

The sensory evaluation was conducted using a 5- point hedonic scale to assess appearance, aroma, taste, texture, and overall acceptance. The sensory scores provided by the panelists were averaged, and the cookie variant with the highest overall rating was chosen as the best product for further nutritional analysis.

3.2.5 Nutrient analysis of the cookie

The nutritional composition of the selected cookie was analyzed by detemining its moisture, carbohydrate, protein, and fat content. Carbohydrate content was estimated using the Phenol – Sulfuric Acid method, protein content was determined using the Lowry Assay method, and fat content was analyzed by Soxhlet Extraction. The energy value of the cookies was calculated usingthe Atwater general factors, which assign specific values to macronutrients:

Energy (kcal) = [Carbohydrate (g) x 4] + [Protein (g) x 4] + [Fat (g) x 9]

The detailed protocols for moisture, carbohydrate, protein, and fat estimation were previously discussed.

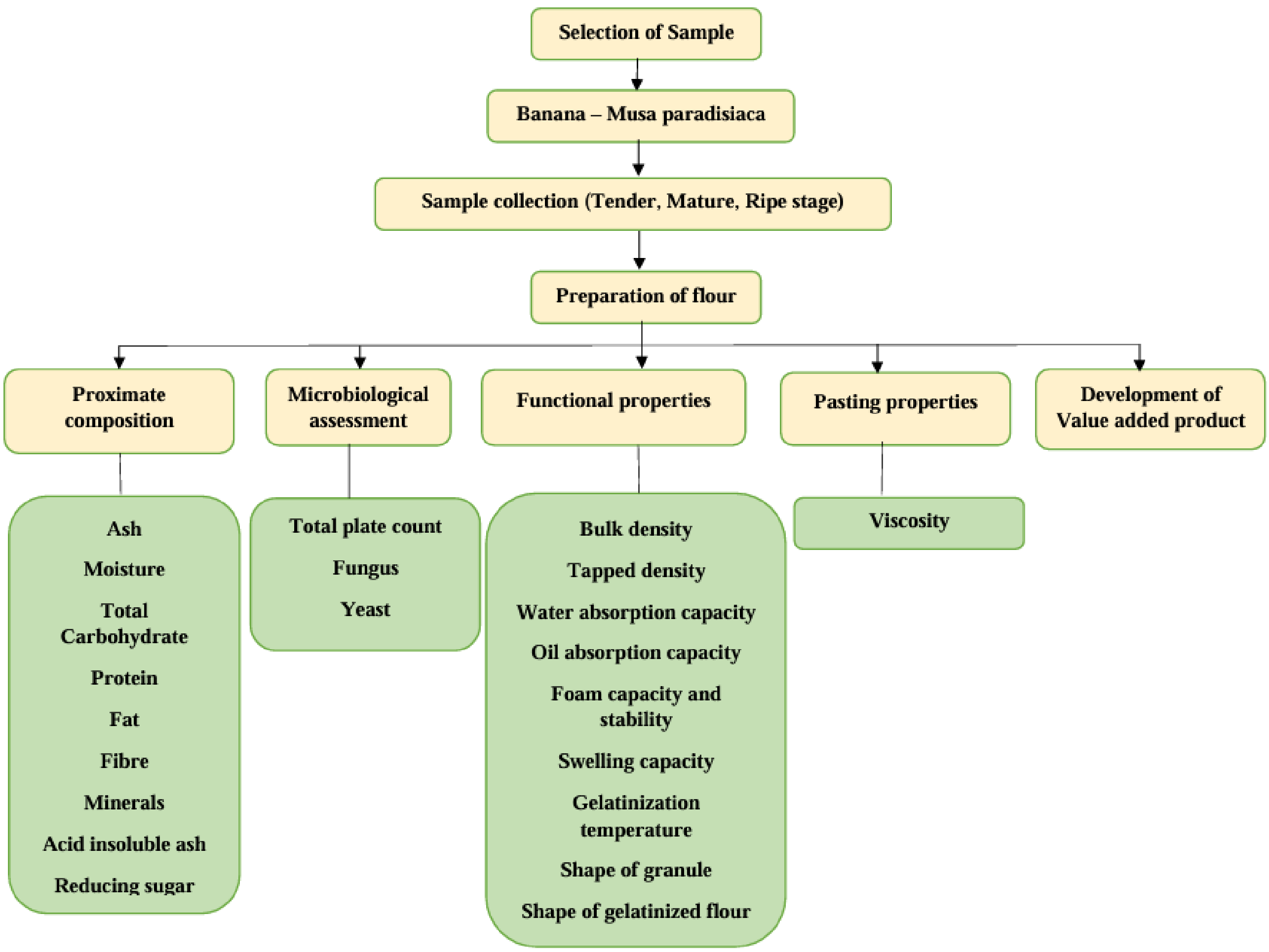
3.2.6 Packaging and labelling

The selected cookie variant was packed in a glass airtight container to ensure protection from moisture, microbial contamination, and oxidation, thereby maintaining its quality and shelf stability. The container was properly sealed to prevent external exposure and preserve freshness. Labelling followed FSSAI (Food Safety and Standards Authority of India) guidelines and included essential details such as the product name, ingredient list, nutritional informations, storage instructions, manufacturing and expiry dates, net weight, and batch number. The labelled and packaged product was then used for shelf – life studies and consumers with clear and accurate product information.

3.2.7 Assessment of Shelf Life

The shelf life of the selected cookies was assessed through sensory evaluation and microbial analysis on the 30th and 45th day of storage. Sensory evaluation was conducted using a 5- point hedonic scale, where panelists assessed appearance, aroma, taste, texture, and overall acceptance to monitor any quality deterioation over time. Microbial assessment was performed using the spread plate method, where 0.1g of the stored cookie sample was dissolved in 10 mL of sterile water and plated onto PCA (for total bacerial load), PDA (for fungal growth), and EMB (for coliform detection). The plates were incubated under standard conditions, and microbial growth was observed to evaluate the safety and shelf stability of the cookie over time, this combined approach ensured a comprehensive assessment of both sensory quality and microbial safety during storage.

METHODOLOGY FRAME WORK



CHAPTER – 4

RESULTS & DISCUSSION

The results of the present study entitled ***'Proximate Composition, Functional and Pasting properties of flour from Musa paradisiaca and its feasibility in developing value added products'*** are discussed as 2 phases. Phase 1 focused on the comparative analysis of banana flours obtained from the tender, mature, and ripe stages of Musa paradisiaca (Nendran variety). Phase 2 involved the application of these flours in the development of cookies. The results from both phases provide valuable insights about the potential of banana flour as a versatile ingredient in the development of value – added products.

The results of the study is discussed under the following headings:

4.1 ***Phase 1 – Comparative study of the flour***

4.1.1 Yield of the flour

4.1.2 Proximate composition

4.1.3 Microbiological assessment

4.1.4 Functional properties

4.1.5 Pasting properties

4.2 ***Phase 2 - Development of value – added product***

4.2.1 Development of cookies

4.2.2 Microbiological assessment

4.2.3 Sensory evaluation

4.2.3 Selection of the best product

4.2.5 Nutrient analysis

4.2.6 Packaging and labelling

4.2.7 Assessment of shelf – life

4.1 Phase 1 – Comparative study of the flour

A comparative study of the flour involves analyzing and comparing various aspects of flour derived from Musa paradisiaca at different stages of maturity. This research examines how the flour's characteristics- such as yield, nutritional content, microbial safety, functional properties, and pasting properties – vary depending on the maturity levels of the banana. It helps to understand how the stage of maturity influences the quality and potential applications of the flour.

4.1.1 Yield of the flour

The yield of flour refers to the quantity of flour produced after processing Musa paradisiaca into flour. It is usually calculated as a percentage of total weight of the raw bananas used in the process. This measurement helps evaluate the efficiency of converting banana into flour, providing insight into how much usable flour can be obtained from a given amount of raw material.

Table 4.1 slows the total yield obtained after powdering the banana of different maturity levels.

Table 4.1 – Total yield of the flour

Sample	Initial weight(kg)	Drying temperature (^{O}C)	Time required (Hr)	Yield (kg)	Yield percentage (%)
Tender	12	65	10	1.868	15.5
Mature	12	65	10	2.500	20.8
Ripe	12	65	20	1.800	15

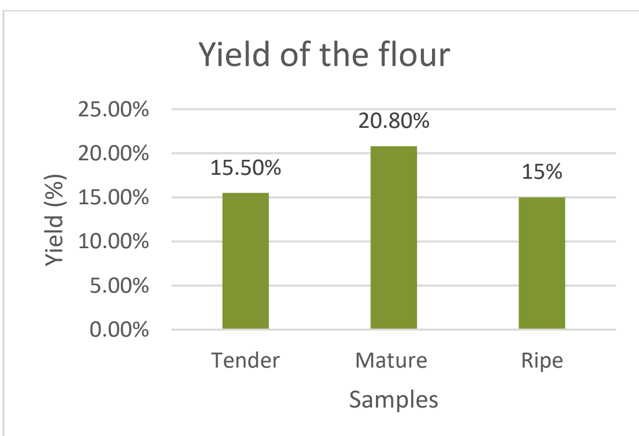


Fig 4.1 – Total yield %of the flour

The present study found that mature banana powder yielded approximately 2.5 kg of flour, while the tender and ripe stages yielded about 1.86 kg and 1.8 kg, respectively. The higher yield at the mature stage is likely due to its increased solid content and reduced moisture, which facilitates greater flour production. In contrast, the lower yield at the ripe stage can be attributed to its higher moisture content and greater loss during the dehydration process.

Consistent with these findings, a study by Mohan, Rajesh, Zuhra, & Vijitha, (2014) investigated the biochemical changes in bananas during maturation and ripening. The study revealed that starch concentration increased significantly during maturation, reaching its peak around 80 – 90 days, followed by a sharp decline during ripening. This pattern indicates that mature bananas have higher starch content, which contributes to greater solid matter and, as a result, higher flour yields.

The drying time for ripe bananas was 20 hours, while tender and mature bananas required only 10 hours. This longer drying time for ripe bananas is likely due to their higher moisture content, which increases the amount of water that must be evaporated during the drying process. In contrast, tender and mature bananas, with their lower moisture levels, dry more quickly, making them more efficient to process into flour. A study by Michon *et al*., (2010) observed that during banana ripening, sucrose content initially rises as a result of starch hydrolysis, but later declines as it is converted into glucose and fructose. This shift in sugars affects their ability to retain moisture. This explains why ripe bananas, with their higher sugar content, often require longer drying times compared to less mature stages.

4.1.2 Proximate Composition

Proximate composition refers to the basic nutritional analysis of a food sample, which identifies its macronutrient contents and biochemical components. This analysis is essential for finding the nutritional value and functional properties of banana flour at various stages of maturity. By understanding these components, researchers can determine how the flour's nutritional profile and potential applications change as the bananas mature.

Ash

Ash content refers to the total mineral residue left after a food sample is completely burned at high temperatures, usually between 550^{o}C and 660^{o}C. This residue represents the inorganic portion of the sample, containing essential minerals like calcium, potassium, magnesium, iron, phosphorous, and trace elements. Measuring ash content helps determine the mineral composition of the sample, providing insight into its nutritional value and quality.

Table 4.2 shows the ash content of each stages of Musa paradisiac flour. The results obtained are given below:

Table 4.2 -Ash content of the flour

Sample	Wt. of the sample (g)	Ash content (%)
Tender	5	1.51
Mature	5	1.54
Ripe	5	2.22

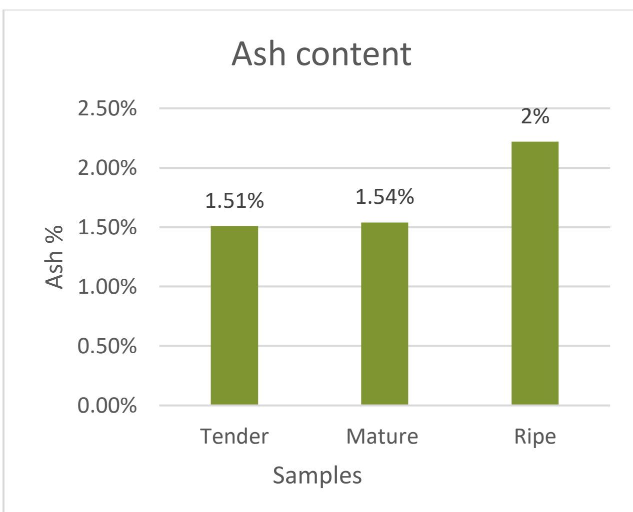


Fig 4.2 – Ash content (%) of the flour

The data in the table shows that the ash content of Musa paradisiaca flour varies at different stages of maturity. In the tender stage, the ash content is the lowest at 1.51%. It slightly increases to 1.54% in the mature stage and reaches its highest at 2.22% in the ripe stage. This trend suggests that ash content, and possibly the mineral composition, increases as the banana matures from tender to the ripe stage.

Ash content during banana maturation and ripening can vary depending on the specific banana cultivar and environmental factors. As a result, while some studies report a decrease in ash content as banana mature, others note an increase, underscoring the complexity of compositional changes that occur during different developmental stages.

In a study by Sari *et al*., (2022) found that ash content increases with ripening. The highest ash content was observed in physiologically ripe Ambon Kuning banana flour (3.87% ± 0.04%) while the lowest was in physiologically ripe Ketip banana flour (1.75% ± 0.02%). The authors noted that more overripe banana flesh led to higher ash content, suggesting an increase in mineral content as ripening advanced. These contrasting findings highlight the variability in ash content trends, which may depend on banana cultivar, ripeness, and environmental factors.

Moisture

Moisture content refers to the amount of water in a food sample, calculated as a percentage of its total weight. It is measured by drying the sample at a specific temperature, usually around 105oC, until its weight stabilizes. This process helps determine how much moisture is present in the samples, which is crucial for assessing its quality, shelf life, and suitability for various applications.

Table 4.3 shows the moisture content in each stages of Musa paradisiaca flour. The results obtained are given below:

Table 4.3 – Moisture content of the flour

Sample	Wt. of the sample (g)	Moisture content (%)
Tender	1	2.5
Mature	1	2.6
Ripe	1	6

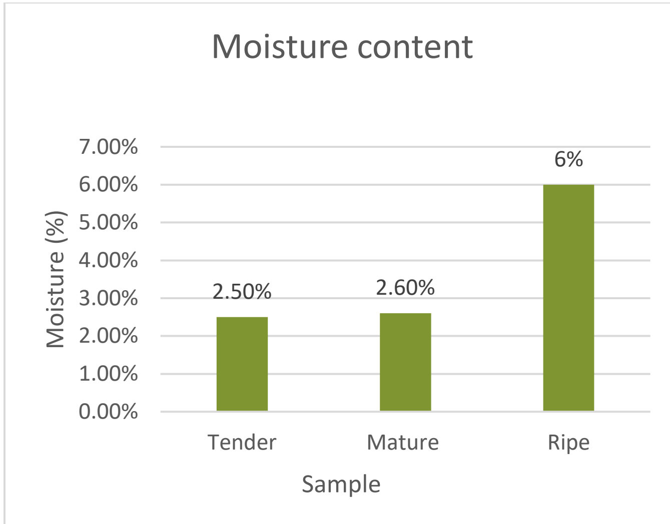


Fig 4.3 – Moisture content of the flours

The table highlights the moisture content of Musa paradisiaca flour across various maturity stages. At tender stage, the moisture content is 2.5%, increasing slightly to 2.6% in mature stage. In the ripe stage, it rises significantly to 6%. This indicates that the moisture content increases as the banana ripens, likely due to the conversion of starch into simple sugars and enhanced water retention during ripening. The increase in moisture content of banana flour from tender to ripe stage is supported by studies.

Mohapatra *et al*., (2016) conducted a study on red bananas, noting a continuous increase in pulp moisture content during the ripening process. They attributed this rise to the migration of water from the peel to the pulp, which coincides with starch breakdown and subsequent sugar formation. Additionally, a review by do Nascimento *et al*., (2019) emphasizes that during banana ripening, substantial amounts of accumulated starch are converted into sugars, leading to pulp softening and sweetening. This starch to sugar conversion is a critical process in achieving optimal postharvest quality, as the breakdown of starch increases the fruit's osmotic potential, drawing water into the pulp and thereby raising its moisture content.

Carbohydrate

Carbohydrate content refers to the total amount of sugars and starch present in a food sample. In this study, it was analyzed using Phenol – Sulfuric Acid Method, a colorimetric technique known for its accuracy in quantification. This analysis is vital for evaluating the nutritional value of the sample, as carbohydrates serve as a primary energy source. It also provides insights into how starch and sugar levels change across different maturity stages, which directly impacts the functional properties of banana flour. Furthermore, carbohydrate content plays a significant role in determining the texture, sweetness, and potential applications of the flour in developing value added products.

Table 4.4 shows the absorbance values for the carbohydrate standard curve, obtained using the phenol – sulfuric acid method to estimate total carbohydrate content.

Table 4.4 - Absorbance values for carbohydrate standard curve

Carbohydrate	
Concentration	**Absorbance**
0	0
10	0.24
20	0.388
40	0.84
60	1.362
80	1.686

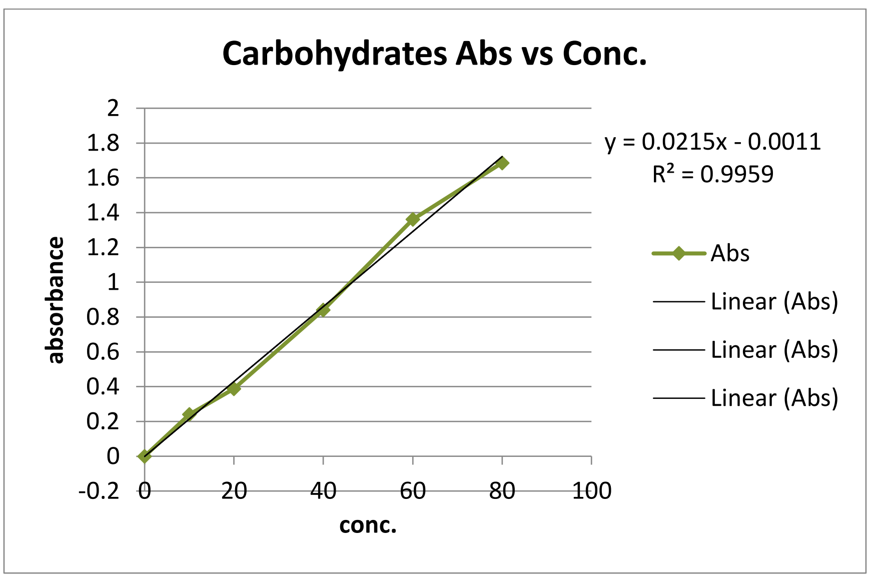


Fig 4.4 – Carbohydrate standard curve

The concentration of the unknown samples were calculated by matching its absorbance value to the standard curve generated using known carbohydrate concentrations. Table 4.5 shows the estimated total carbohydrate content in the flour.

Table 4.5 -Estimation of carbohydrate in samples

Sample	Wt. of the sample (g)	Carbohydrate (g/100g)
Tender	5	24.75
Mature	5	25.5
Ripe	5	24.7

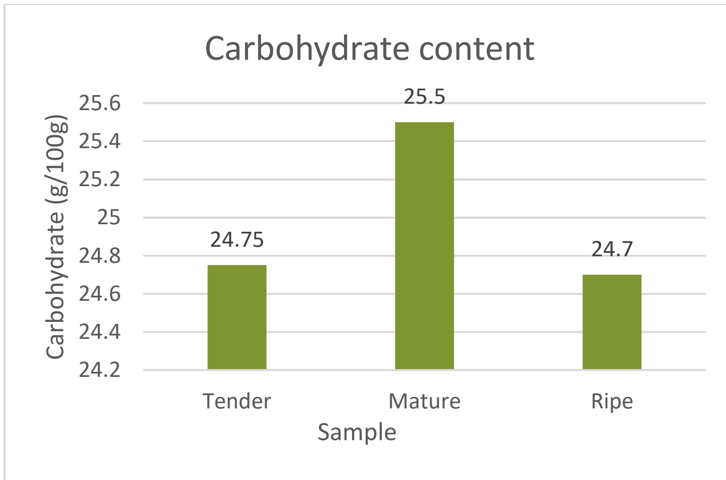


Fig 4.5 – Carbohydrate content of the flours

The carbohydrate content of Musa paradisiaca flour across different stages of maturity shows minimal variation. The tender banana flour contains 24.7g/ 100g carbohydrate, while the mature banana flour has a slightly higher carbohydrate content of 25.5g/100g. the ripe banana flour has a carbohydrate content of 24.7g/100g. These results suggest that the carbohydrate content remains relatively consistent throughout the stages, with mature banana flour showing a marginal increase.

A study titled by Khawas *et al*., (2014) found that total carbohydrate content increased from the tender stage (21.32g/100g) to the mature stage (32.15 g/100g) but decreased at the ripe stage (27.63g/100g). the researchers explained that this variation is due to the breakdown of starch into sugars as the banana progress through growth and ripening. During maturation, starch accumulates, leading to higher carbohydrate content, while ripening triggers starch degradation into simpler sugars, resulting in a slight decline in total carbohydrate at ripe stage.

Protein

Protein is a crucial macronutrient, playing a key role in growth, tissue repair, and overall bodily functions. In this study, the protein content was analyzed using Lowry Protein Assay, a widely recognized colorimetric method for accurately measuring protein concentration. Understanding protein content is important because it varies across different maturity stages of banana flour, directly impacting its nutritional quality and functional properties.

Table 4.6 shows the absorbance values for protein standard curve, obtained using Lowry protein assay method to estimate protein content of the flours.

Table 4.6 - Absorbance values for protein standard curve

Protein	
Concentration	**Absorbance**
0	0
40	0.053
80	0.089
120	0.12
160	0.15
200	0.178

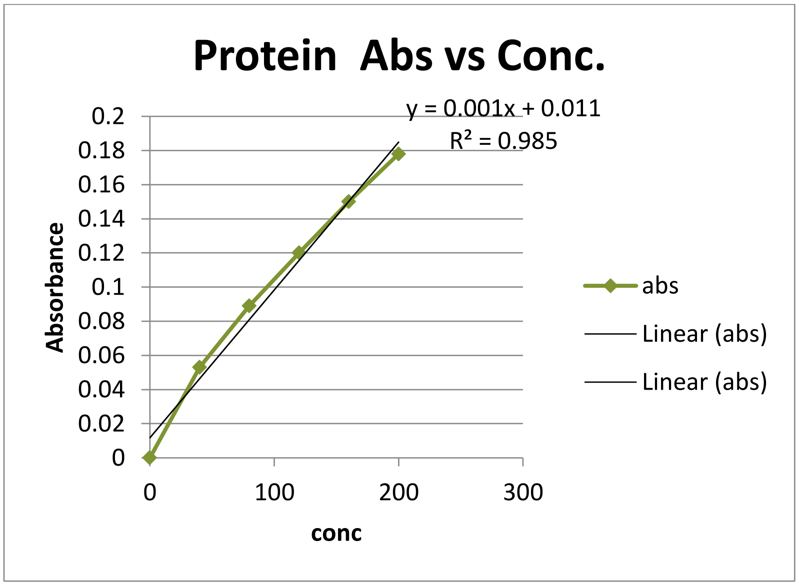


Fig 4.6 – Protein standard curve

The concentration of the unknown samples were calculated by matching its absorbance value to the standard curve generated using known protein concentrations. Table 4.7 shows the estimated protein content in the flours.

Table 4.7 -Estimation of protein in samples

Sample	Wt. of the sample (g)	protein (mg/100g)	Protein (g/100g)
Tender	5	3742	3.7
Mature	5	2966	2.9
Ripe	5	6084	6

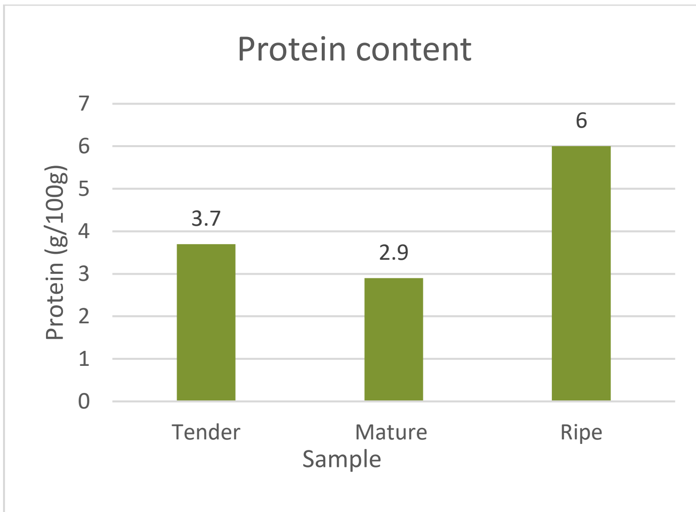


Fig 4.7 – Protein content of the flours

The table presents the protein content of Musa paradisiaca flour at different stages of maturity. In the tender stage, the protein content is 3.7g/100g. It decreases to 1.9g/100g in mature stage, but increases significantly to 6g/100g in the ripe stage. This trend suggests that protein content is lowest in the mature stage and rises considerably as the banana ripens, likely indicating changes in protein composition during the ripening process.

Researches have shown that the protein content in bananas tends to rise as they ripen. For instance. Adekalu *et al*., (2011) noted that the protein content in Musa paradisiac increased from 1.20% on the second day of storage to 2.28% by the seventh day, highlighting a clear upward trend as the fruit ripened. Similarly, Dominguez – Puigjaner *et al*., (1992) discovered that certain proteins accumulate more significantly during ripening, with specific polypeptides becoming more abundant in ripe bananas. This points to the synthesis of particular proteins as part of the natural ripening process. Further, supporting this, Kumar *et al*., (2018) observed changes in free amino acid levels in Cavendish bananas, with some amino acids increasing as a result of protein metabolism and enzymatic activity. These findings resonate with the current analysis, which found that the protein content in Musa paradisiaca flour was at its lowest in the mature stage but rose significantly as the fruit reached the ripe stage. This increase in protein content during ripening is likely due to complex biochemical changes, such as breakdown of starch and the production of new proteins that contribute to fruit softening and other metabolic shifts.

Fat

Fat is a macronutrient that acts as a concentrated energy source and significantly influences food texture, flavor, and stability. In this study, fat content is analyzed to examine its variations across different maturity stages of banana flour, as it directly impacts the nutritional profile and shelf stability of the flour. Additionally, it plays a role in determining the flour's application in value added products by contributing to mouthfeel and overall sensory qualities. Understanding fat content is essential for assessing the suitability of banana flour for various food formulations and storage conditions, ensuring its optimal use in diverse culinary applications.

Table 4.8 shows the fat content in each stages of Musa paradisiaca flour. The results obtained are given below:

Table 4.8 – Fat content of the flour

Sample	Wt. of the sample (g)	Fat content (g/100g)
Tender	8	0.648
Mature	8	0.613
Ripe	8	0.796

Fig 4.8 – Fat content of the flours

The table presents the fat content of Musa paradisiaca flour at different maturity stages. At the tender stage, the fat content is 0.648g/100g. In the mature stage, it decreases slightly to 6.13g/100g, while the ripe stage shows the highest fat content at 0.796g/100g. these findings indicate that fat content increases slightly as the banana ripens, with the highest fat content observed in the ripe stage compared to the tender and mature stages.

Adekalu *et al*., (2011) in his study observed a gradual rise in fat content, from 0.60% in the early stages to 0.78% in fully ripened bananas, suggesting that metabolic changes during ripening contribute to lipid accumulation. Similarly, Siddiq *et al*., (2018) found that fat content in ripened bananas ranged from 0.66 to 2.59 g/100g, compared to 1.38 to 2.51 g/100g in unripe bananas, indicating that ripening may promote lipid synthesis or retention. Additionally, Sun *et al*., (2020) noted that while the total lipid content remained relatively stable, there were significant shifts in composition, particularly an increase in unsaturated fatty acids. These findings collectively highlight how ripening influences the fat content and composition in bananas.

Crude Fibre

Crude fibre refers to the indigestible portion of plant material, which cannot be broken down by human digestive enzymes. It plays a crucial role in supporting digestive health, regulating bowel movements, and lowering the risk of chronic diseases. In this study, crude fibre content is analyzed to evaluate its variations across different maturity stages of banana flour. Higher fibre content not only enhances the health benefits of the flour but also makes it more suitable for creating value added products that contribute to improved dietary fibre intake. This analysis helps determine the flour's potential for promoting better nutrition and health outcomes.

Table 4.9 shows the crude fibre content in each stages of Musa paradisiaca flour. The results obtained are given below:

Table 4.9 – Crude fiber content of the flour

Sample	Wt. of the defatted sample (g)	Crude fiber content (g/100g)
Tender	8	0.513
Mature	8	0.651
Ripe	8	0.518

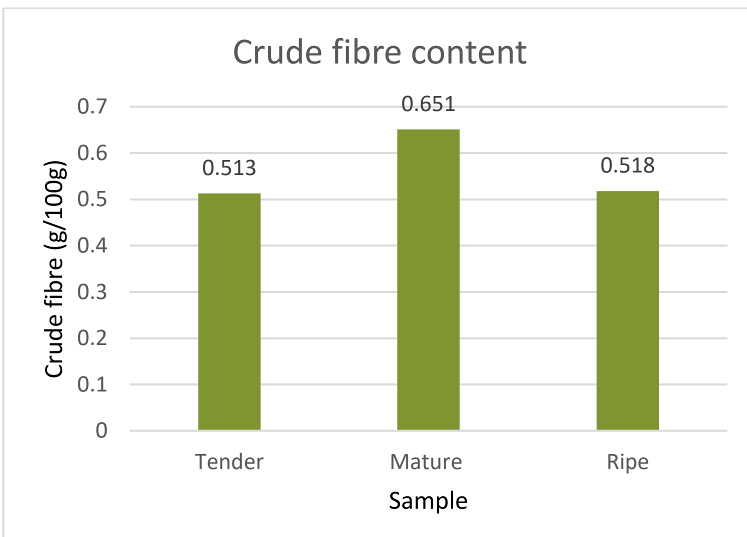


Fig 4.9- Crude fiber content of the flours

The table presents the crude fibre content of Musa paradisiac flour after defatting at different maturity stages. The tender stage has a crude fibre content of 0.513 g/100g. In mature stag the crude fiber content increases slightly to 0.651g/110g. In ripe stage it decreases slightly to 0.518g/100g. These results suggest a slight increase in crude fibre content from the tender to mature stage followed by a slight decrease in ripe stage. The variations in crude fibre content may be attributed to the composition of the banana as it ripens. The mature stage shows the highest crude fibre content.

In the study by Huang *et al*., (2024), the crude fibre content showed little change overall, staying within a narrow range of 0.58% to 0.68% throughout the ripening process. However, a subtle decrease in crude fibre was noted as bananas ripened, pointing to a gradual breakdown of fibre components. While the study did not find a significant drop in crude fibre, this slight reduction suggests that insoluble fibers slowly degrade over time, subtly affecting the banana's overall fibre content as it ripens.

Minerals

Minerals are essential inorganic nutrients that play a critical role in various physiological functions. In this study, the mineral composition of banana flour was analyzed to assess its nutritional value across different maturity stages. Sodium, potassium, and calcium were measured using the Flame Emission Spectroscopy Method, which identifies metal ions based on their unique emission spectra. Meanwhile, iron and phosphate were analyzed using Colorimetric method, which determines their concentration by measuring color intensity. Understanding the mineral content is important because it contributes to the overall nutritional quality of banana flour.

Phosphate

Phosphate content in banana flour represents the concentration of phosphorous in the form of phosphate compounds, which are vital for numerous biological and functional properties. Of the flour. Phosphorous, as an essential mineral, plays a key role in energy metabolism, supporting processes like ATP production, as well as maintaining bone health and facilitating enzymatic reactions.

Table 4.10 shows the absorbance values for the phosphate standard curve, obtained using colorimetric method to estimate phosphate content of the flour.

Table 4.10 - Absorbance values for phosphate standard curve

Phosphate	
Concentration	**Absorbance**
0	0
1	0.04
2	0.08
3	0.11
4	0.15
5	0.19

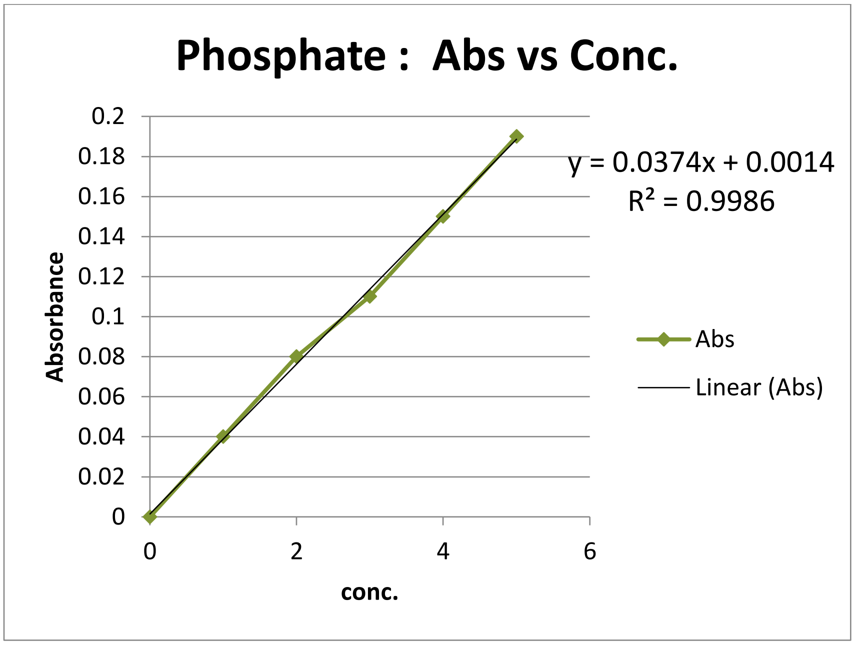


Fig 4.10– Phosphate standard curve

The concentration of the unknown samples were calculated by matching its absorbance value to the standard curve generated using known phosphate concentrations. Table 4.11 shows the estimated phosphate content of the flours at different levels of maturity.

Table 4.11 – Estimated Phosphate content in the flour

Sample	Wt. of the sample (g)	Phosphate (mg/100g)
Tender	5	*BDL
Mature	5	BDL
Ripe	5	BDL

*BDL- Below Detectable Limit

The mineral analysis of Musa paradisiaca flour at various stages revealed that phosphate levels were undetectable in all samples, even when using 5g sample for testing. This suggests that phosphate is either absent or present in extremely low amounts in the flour across all stage of ripeness.

Iron

The iron content in banana flour indicates the levels of iron, a vital mineral necessary for transporting oxygen, supporting enzyme functions, and maintaining overall metabolism. Analyzing this helps to evaluate the nutritional benefits of banana flour.

Table 4.12 shows the absorbance values for the iron standard curve, obtaining using colorimetric method to estimate iron content of the flours.

Table 4.12 - Absorbance values for iron standard curve

Iron	
Concentration	**Absorbance**
0	0
1	0.04
2	0.06
3	0.09
5	0.15
10	0.3

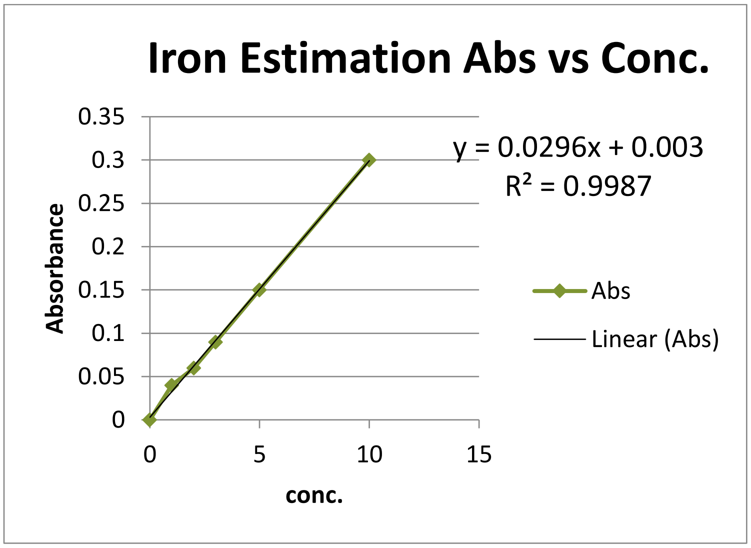


Fig 4.11 – Iron standard curve

The concentration of the unknown samples was determined by comparing their absorbance values to the standard curve created with known iron concentrations. Table 4.13 shows the estimated iron content of the flours at different levels of maturity.

Table 4.13 – Estimated iron content in the flour

Sample	Wt. of the sample (g)	Iron (mg/100g)
Tender	5	2.3
Mature	5	6.39
Ripe	5	1.28

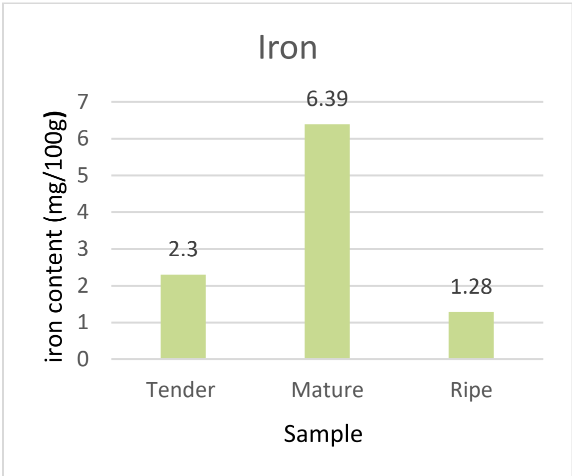


Fig 4.12 – Iron content (mg/100g) of the flours

The mineral analysis of Musa paradisiaca flour revealed interesting changes in iron content across its growth stages. The mature stage had the highest iron concentration at 6.39 mg/100g, while the tender stage showed a moderate level of 2.3 mg/100g. interestingly, the ripe stage had the lowest iron content at 1.28 mg/100g. this suggests that iron levels are at their peak during mature stage, gradually decreasing as the fruit ripens.

Anyasi, Jideani and Mchau (2013) explored how organic acid pretreatment influences the physicochemical properties of flour made from three unripe banana cultivars. Their research revealed that the iron content in banana flour changes with the stage of maturity. Specifically, they found that unripe and mature banana flours contain higher iron levels compared to flour from ripe bananas. This difference is likely due to reduced enzymatic activity and mineral leaching as the fruit ripens, preserving more iron in the earlier stages. These findings emphasize the importance of considering maturity when evaluating the nutritional quality of banana flour (Anyasi *et al*., 2013).

Sodium

The sodium content in banana flour indicates the level of sodium, a key mineral that plays a role in regulating fluid balance, supporting nerve function, and aiding muscle contractions. This measurement is important for understanding the nutritional profile of banana flour, especially for those who need to monitor their sodium intake, such as individuals managing conditions like high blood pressure.

Table 4.14 shows the estimated sodium content in different stages of Musa paradisiaca flour.

Table 4.14 – Estimated sodium content in the flour

Sample	Wt. of the sample (g)	Sodium (mg/100g)
Tender	5	8.76
Mature	5	4.65
Ripe	5	3.99

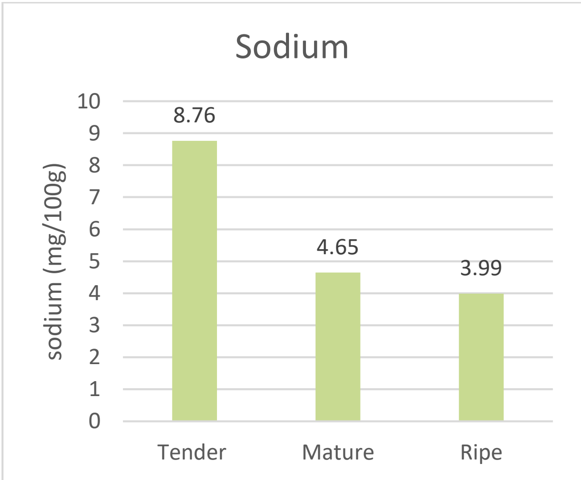


Fig 4.13- Sodium content (mg/100g) of the flours

The sodium content in Musa paradisiaca flour shows notable variations across its growth stages. The tender stage has the highest sodium concentration at 8.76 mg/100g, while the mature stage contains 4.65 mg/100g. The ripe stage has the lowest sodium level at 3.99 mg/100g. This gradual decline in sodium content as the banana matures may be attributed to metabolic changes, increased moisture content, or the redistribution of minerals during the ripening process.

Potassium

The potassium content in banana flour represents the level of potassium, an essential mineral crucial for maintaining electrolyte balance, supporting muscle function, and facilitating nerve signaling. Since bananas are naturally high in potassium, studying its presence in banana flour helps determine its nutritional value and how it can contribute to a balanced diet.

Table 4.15 shows the estimated potassium content in different stages of Musa paradisiaca flour.

Table 4.15 – Estimated Potassium content in the flour

Sample	Wt. of the sample (g)	Potassium (mg/100g)
Tender	5	144.8
Mature	5	148.5
Ripe	5	159.2

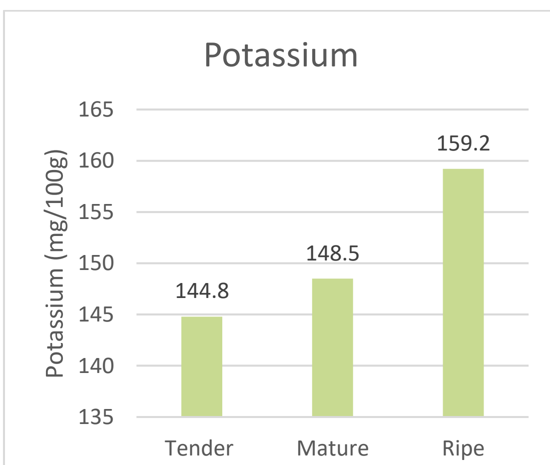


Fig 4.14 – Potassium content (mg/100g) of the flours

The potassium content in Musa paradisiaca flour shows a steady increase across its growth stages. In the tender stage, the potassium level is 144.8 mg/100g, rising slightly to 1.48.5 mg/100g in the mature stage, and reaching its peak at 159.2 mg/100g in the ripe stage.

The potassium content in Musa paradisiaca flour shows a clear upward trend as the fruit ripens, highlighting improved mineral retention in the later stages of maturity. A study focusing on the 'Pei Chiao' banana cultivar revealed that potassium levels peaked during the ripe stage, reaching 946.69 mg/100g. This suggests a consistent accumulation of potassium as the fruit matures (Huang *et al*., 2024). The increase is likely driven by changes in osmotic pressure between the peel and pulp, which promote the movement of potassium into the fruit. These findings underscore the dynamic nature of mineral composition during ripening and its impact on nutritional quality of banana flour.

Calcium

The calcium content in banana flour represents the level of calcium, a vital mineral impotant for maintaining strong bones, supporting muscle function, enabling nerve signaling, and facilitating enzymatic processes. This measurement is studied to evaluate the nutritional benefits of banana flour, especially in terms of how it can contribute to meet daily calcium requirements.

Table 4.16 shows the estimated calcium content in different stages of Musa paradisiaca flour.

Table 4.16 – Estimated Calcium content in the flour

Sample	Wt. of the sample (g)	Calcium (mg/100g)
Tender	5	23.18
Mature	5	21.65
Ripe	5	21.34

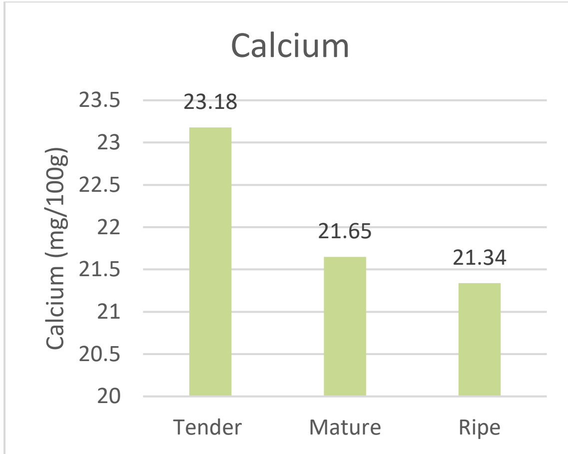


Fig 4.15 – Calcium content (mg/100g) of the flours

The calcium content in Musa paradisiaca flour exhibits a gradual decline across its growth stages. The tender stage has the highest calcium concentration at 23.18 mg/100g, which decreases slightly to 21.65 mg/100g in the mature stage and further to 21.34 mg/100g in the ripe stage. This subtle downward trend suggests that calcium levels diminish as the banana matures.

The calcium content in Musa paradisiac flour gradually decreases as the fruit matures, aligning with the findings from some earlier studies. Gamlath (2008) noted that calcium levels in banana pulp dropped from 34.1 mg/100g in the unripe stage to 29.8 mg/100g in the ripe stage, reflecting a steady decline as ripening progresses. This reduction is linked to the biochemical changes that occur during ripening, such as the conversion of insoluble pectates into soluble forms, which reduces calcium retention. Similarly, Campuzano et al., (2018) observed a decrease in calcium levels in banana flour as the fruit advanced in maturity, reinforcing the pattern of declining calcium content.

Acid insoluble ash

Acid insoluble ash refers to the portion of total ash that does not dissolve in dilute hydrochloric acid. It primarily made up of silica, sand, and other non – nutritive contaminants. In this study, it was analyzed to evaluate the purity and quality of banana flour across different maturity stages. Additionally, it assesses the effectiveness of processing methods in reducing unwanted residues, of the final product.

Table 4.17 shows the acid insoluble ash content in each stages of Musa paradisiaca flour. The results obtained are given below:

Table 4.17 – Acid insoluble compounds of the flour

Sample	Wt. of the sample (g)	Acid insoluble compounds (g/100g)
Tender	5	7.4
Mature	5	9.4
Ripe	5	10.3

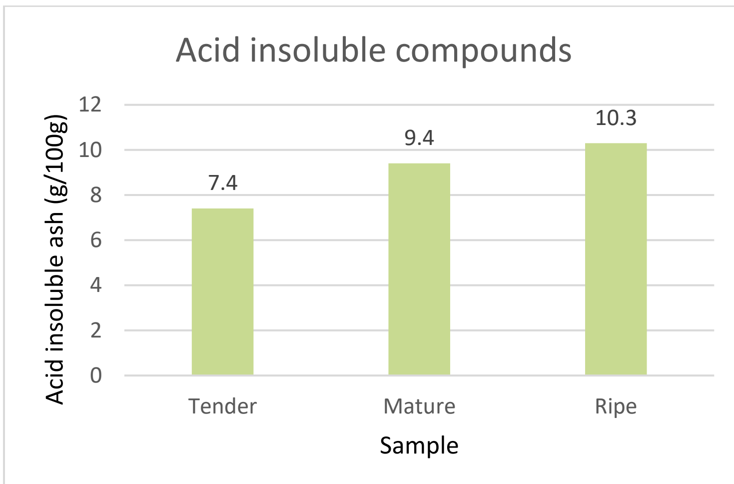


Fig 4.16 – Acid insoluble ash content (g/100g) of the flours

The table presents the acid insoluble ash content of Musa paradisiaca flour at different maturity levels. At the tender stage, the acid insoluble ash content is 7.4 g/100g. in the mature stage, it increases to 9.4 g/100g, and in the ripe stage, it reaches the highest level at 10.3 g/100g. These findings suggest that the content of acid insoluble ash rises as the banana matures, with the highest observed in the ripe stage.

The rise in acid insoluble ash content in Musa paradisiaca flour as the banana matures is supported by other studies on ash content during ripening. Adeyami and Oladiji (2009) noted that the ash content increased from 0.68% in unripe bananas to 0.80% in ripe bananas, pointing to a buildup of mineral and insoluble compounds as the ripening progresses. Similarly, Ayo *et al.*, (2020) reported an increase in ash content from 4.55% in unripe banana peels to 5.23% in ripe peels, further supporting the idea that ripening increases the presence of insoluble components. This trend may be due to the concentration of certain minerals and structural changes in banana tissues as the fruit ripens.

Reducing sugar

Reducing sugars are carbohydrates that contain free aldehyde or ketone groups, enabling them to take part in reduction reactions, such as maillard reaction, which impacts the colour and flavour of food products. In this study, reducing sugar content was analyzed to examine its variation across different maturity stages of banana flour. As banana ripen, starch is converted to simple sugars, leading to an increase in reducing sugar content. Tis change affects the sweetness, browning potential and functional properties of the flour. Understanding these variations is essential fo identifying the optimal stage of maturity of food formualtions, ensuring the flour meets desired quality and application requirements.

Table 4.18 shows the absorbance values for the reducing sugar standard curve, obtained using the Dinitrosalicylic acid (DNS) method to estimate reducing sugar content.

Table 4.18 - Absorbance values for reducing sugar standard curve

Reducing sugar	
Concentration	**Absorbance**
0	0
100	0.233
200	0.365
500	1.002
700	1.148
1000	1.616

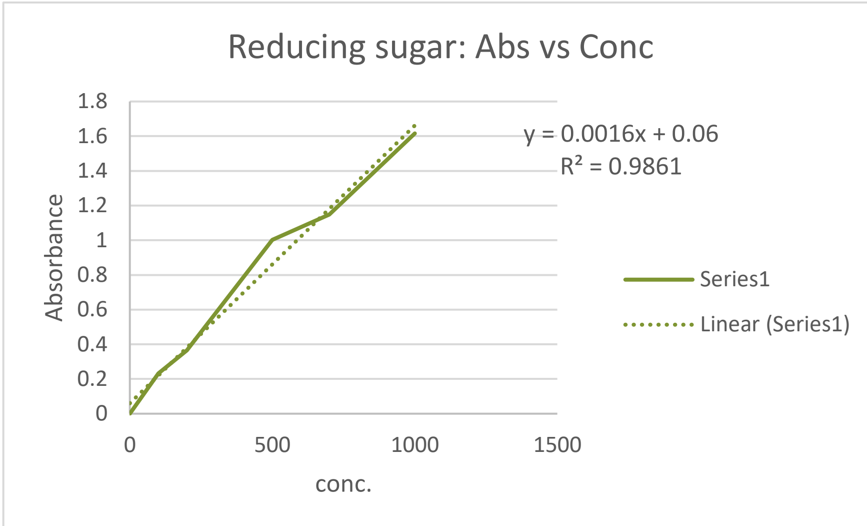


Fig 4.17– Reducing sugar standard curve

The concentration of the unknown samples were determined by comparing their absorbance values to the standard curve created with known reducing sugar concentrations. Table 4.19 shows the estimated reducing sugar concentration of the flour.

Table 4.19 -Estimation of reducing sugar in samples

Sample	Wt. of the sample (g)	Reducing sugar (mg/100g)	Reducing sugar (g/100g)
Tender	1	1600	1.6
Mature	1	4100	4.1
Ripe	1	22406	22.4

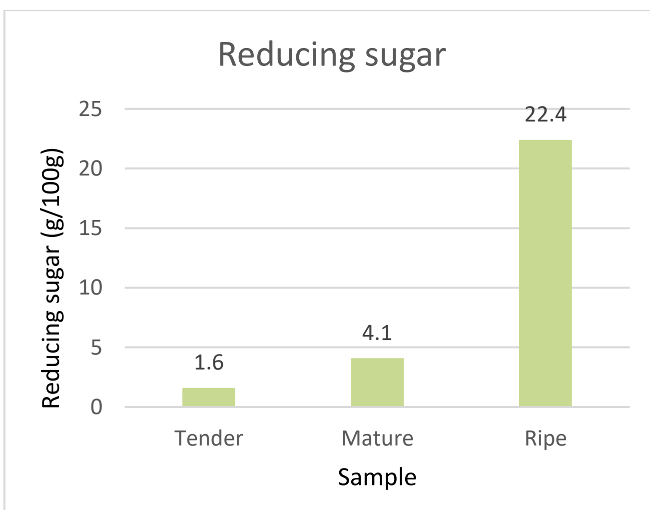


Fig 4.18 – Reducing sugar content of the flours

The table presents the reducing sugar content of Musa paadisiaca flour at different stages of maturity. At the tender stage, the reducing sugar content is 1.6g/100g. In the mature stage, it rises significantly to 4.1g/100g, and in the ripe stage, it peaks at 22.4 g/100g. These results indicate a substantial increase in reducing sugars as the banana ripens, with the highest concentration found in the ripe stage, likely due to the conversion of starches into simple sugars during ripening.

The significant rise in reducing sugar content during banana ripening is widely supported by scientific research. In unripe bananas, starch makes up about 20 – 25% of the pulp's fresh weight, while sugars are present in much smaller amounts, typically around 1- 2%. As ripening progresses, starch is broken down into simpler sugars, causing a dramatic increase in sugar content, which can reach 15 – 20% in fully ripe bananas (Ahmad *et al*., 2018). This process is driven by enzymatic activity that converts starch into reducing sugars like glucose and fructose (Zhang *et al*., 2005), enhancing the fruit's sweetness and making ripe bananas more enjoyable to eat. These findings are supporting the observed data, which shows a steady increase in reducing sugar content – from, 1.6 g/100g in the tender stage to 4.1 g/100g in the mature stage, and peaking at 22.4 g/100g in the ripe stage. This transformation underscores the critical role of ripening in improving the sensory and nutritional qualities of bananas.

4.1.3 Microbiological assessment

A microbial assessment of banana flour was conducted to ensure its safety, quality, and shelf life. Spread plate method was used to check for total plate count, yeast, fungus and coliforms, to help to identify any microbial contamination. This evaluation was conducted at the start of 6th month of storage to assess how well the flour was preserved. The goal was to determine whether the drying process (cabinet drying at 65oC) and storage conditions effectively prevented microbial growth. Monitoring of microbial load is essential to keep banana flour safe for consumption and suitable for use in value added products over time.

Table 4.20 shows the microbiological assessment of Musa paradisiaca flour using spread plate method. The results obtained are given below:

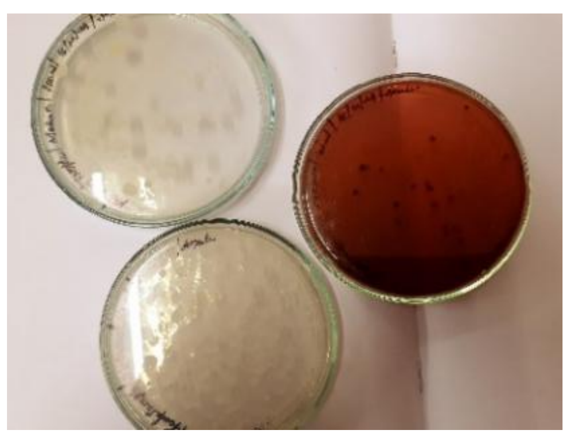
Table 4.20 -Microbial assessment of Musa paradisiaca flour

Sample	Total plate count (cfu/ml)	Coli forms	Aspergillus	Yeast
Tender	78 x 10^2	Absent	Absent	Absent
Mature	82 x 10^2	Absent	Absent	Absent
Ripe	32 x 10^2	Absent	Absent	Absent

The microbiological assessment of Musa paradisiaca flour, conducted using spread plate method showed that the total plate count (cfu/ml) is highest in the mature stage (82 x 102), followed by the tender stage (78 x 102), and lowest in the ripe stage (32 x 102). Total plate count (TPC) serves as a general indicator of the microbial load present in a food sample, reflecting the overa;; level of microorganisms in the product. Coliforms, Asperigillus, and yeast were absent in all stages (tende, mature and ripe). These findings indicate some variations in the total plate count across the stages, but the absence of Coliforms, Asperigillus, and yeast suggests that the flour samples exhibit good microbial quality.

The results of the microbial examination was compared to the acceptable levels of microbial load in food flours, outlined in the FSSAI Food Safety and Standards (Food Product Standards and Food Additives) Regulations. As per FSSAI regulations, the general microbiological requirements for flour, including cereal flour, millet flour, and similar products, specify that the Total Plate Count (TPC) should not exceed 105 CFU/g. The microbial load of tender mature and ripe banana flour was found to be 7,800 CFU/ml, 8,200 CFU/ml, and 3,200 CFU/ml, respectively, which are well within the acceptable limit of ≤ 105 CFU/g as per FSSAI regulations, indicating that the samples meet the required microbiological safety standards.

Tender banana flour



Mature banana flour

Ripe banana flour

Plate 4.1 – Microbial assessment of tender, mature and ripe banana flour

4.1.4 Functional properties

Functional properties refer to the physical and chemical characteristics of food ingredients such as flour, that influence their behavior during processing and preparation. These properties include factors like water absorption, emulsification, and gelatinization, which are crucial for determining the texture, stability, and overall quality of the final product. To assess the functional properties of banana flour from the tender, mature and ripe stage of Musa paradisiaca, various analytical methods are employed.

Density, Compressibility, and Flow characteristics of the flour

Bulk and tapped density are key physical properties of Musa paradisiaca flour that affect its storage, handling, and processing. Bulk density measures the mass of loosely packed flour per unit volume while tapped density represents the mass per unit volume after compaction through tapping or vibration. These values help determine the Carr Index and Hausner Ratio, which assess the flour's flowability and compressibility. The Carr Index, calculated as the percentage difference between tapped and bulk density, indicates how easily the flour flows and lower values suggests good flowing property, while higher values indicate poor flowing property. The Hausner Ratio, the ratio of tapped to bulk density, reflects flow characteristics, with values closer to 1.0 signifying better movement. Understanding these properties is essential for optimizing banana flour in value added food products ensuring efficient storage, handling and mixing during formulation.

Table 4.21 shows the bulk density, tapped density, Carr index and Hausner ratio of Musa paradisiaca flour at different stages. The result obtained are given below:

Table 4.21- Bulk density, Tapped density, Carr Index and Hausner ratio of the flour

Sample	Wt. of the sample (g)	Bulk density (g/cm^3)	Tapped density (g/cm^3)	Carr Index (%)	Hausner ratio
Tender	20	0.57	0.80	28.75	1.4
Mature	20	0.58	0.81	28.39	1.3
Ripe	20	0.45	0.50	10	1.1

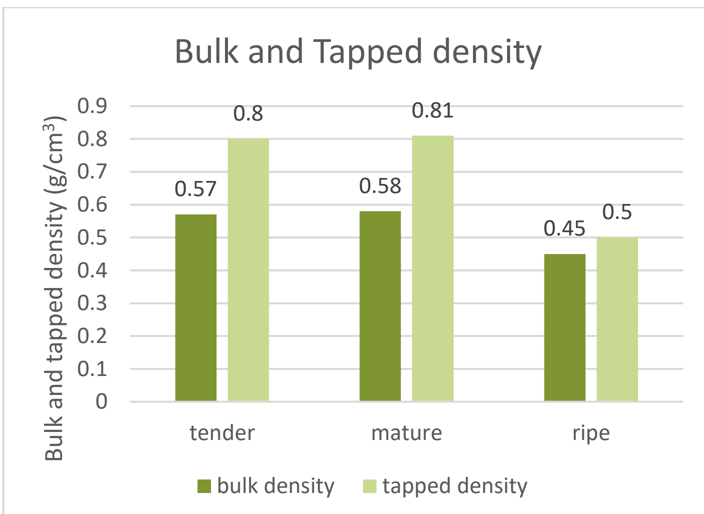


Fig 4.19 – Bulk density and tapped density of the flours

The bulk density, tapped density, Carr index and Hausner ratio of Musa paradisiaca flour were analyzed to assess its packing and flow properties at different maturity stages. Bulk density ranged from 0.45 g/cm3 in ripe flour to 0.58 g/cm3 in mature flour, with corresponding tapped densities between 0.50 g/cm3 and 0.81 g/cm3. This indicates that tender and mature flours have more compact structure compared to ripe flour. The Carr Index was highest in tender (28.75%) and mature (28.39%) flours, suggesting poor flowability and greater compaction, whereas ripe flour (10%) exhibited better flow properties. Similarly, the Hausner Ratio indicated lower flowability in tender (1.4) and mature (1.3) flours, while ripe flour (1.1) had improved flow characteristics. These findings suggest that tender and mature banana flours, being compact and less flowable, are better suited for applications requiring higher density, whereas ripe banana flour's superior flowability makes it more suitable for easier handling and mixing in food formulations.

Water absorption capacity

Water absorption capacity (WAP) refers to the ability of flour to absorb and retain water when mixed together. It is expressed as the percentage of water absorbed relative to flour's weight. This key functional property affects the flour's hydration behavior, texture, and processing characteristics in food applications. A higher WAC indicates better water binding ability, which plays a crucial role in dough formation, moisture retention, and structural integrity in baked and processed foods. In this study, WAC was analyzed to understand how the maturity stages of Musa paradisiaca flour influence its water absorption, impacting its suitability for applications such as baking, thickening, and extrusion. Evaluating WAC helps optimize the flour's performance in food formulations and enhance overall product quality.

Table 4.22 shows the water absorption capacity of Musa paradisiaca flour at different levels of maturity.

Table 4.22- Water absorption capacity

Sample	Wt. of the sample (g)	WAC (%)
Tender	1	71.5
Mature	1	71.5
Ripe	1	72.7

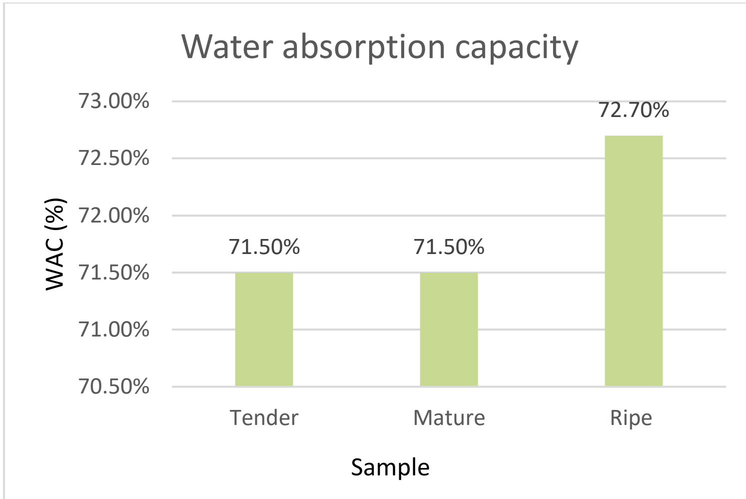


Fig 4.20 – Water absorption capacity of the flours

The water absorption capacity (WAC) of Musa paradisiaca flour varies slightly across different maturity stages. The tender and mature stages both exhibit a WAC of 71.5%, indicating a comparable water retention capacity. However, the ripe stage shows a slightly higher WAC of 72.7%. This increase in the ripe stage may result from compositional changes during ripening.

In the study by Gamlath (2008), the water absorption capacity (WAC) of banana flour was examined across different ripening stages. The research revealed that as banana ripen, the breakdown of starch into simple sugars and changes in the flour's structural composition significantly alter its functional properties including WAC. Specifically, the study found that ripe banana flour had a higher water absorption capacity compared to unripe banana flour. This increase is largely due to the conversion of resistant starch into more soluble sugars and the breakdown of starch granules, which improves their ability to hold water.

Oil absorption capacity

Oil absorption capacity (OAC) refers to the ability of flour to absorb and retain oil, expressed as the percentage of oil absorbed relative to the flour's weight. This functional property plays a key role in determining the texture, mouthfeel and flavor retention of food products. A higher OAC enhances the flour's ability to retain moisture and fat, making it useful in applications such as baked goods, meat extenders, and fried products. In this study, OAC was analyzed to assess how

Musa paradisiaca flour at different maturity stages interacts with oil, influencing its suitability for food applications that require fat retention. Understanding OAC helps determine the flour's effectiveness in food formulations, its impact on texture and its potential to enhance sensory qualities in various products.

Table 4.23 shows the oil absorption capacity of Musa paradisiaca flour at different levels of maturity.

Table 4.23- Oil absorption capacity

Sample	Wt. of the sample (g)	OAC (%)
Tender	1	77.1
Mature	1	75.2
Ripe	1	73.1

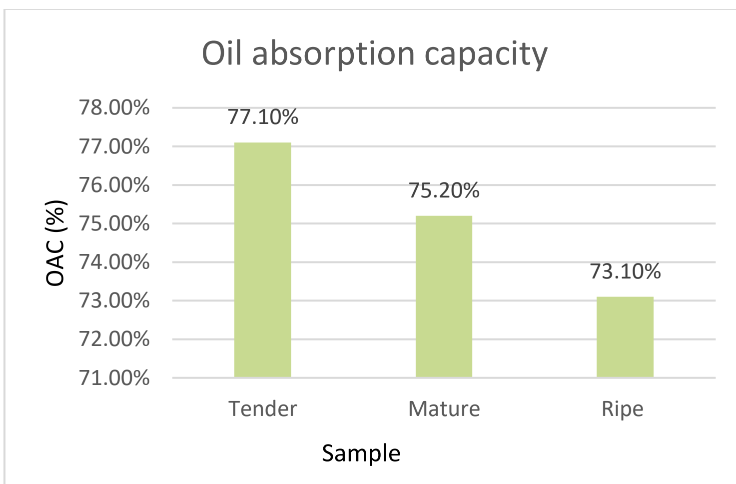


Fig 4.21 – Oil absorption capacity of the flours

The oil absorption capacity (OAC) of Musa paradisiaca flour varies slightly across different stages of maturity. The tender stage exhibits the highest OAC at 77.1%, followed by the mature stage with an OAC of 75.2%. the ripe stage shows the lowest OAC at 73.1%. These variations suggest a gradual decrease in OAC as the banana progresses from tender to ripe stage.

The OAC of tends to decrease as the fruit ripens, primarily due to changes in starch and fibre structure. Adeyanju and Osundahunsi (2019) investigated how ipening affects the functional properties of Musa ABB (Cardaba banana) flour and found that unripe banana flour had the highest OAC (136.7%), while fully ripe banana flour showed a significant drop to 43.3%. This reduction is linked to the breakdown of complex polysaccharides, such as starch, into simple sugars during ripening, which diminishes flour's ability to bind oil effectively.

Foam capacity and stability

Foam capacity and stability refers to a flour's ability to trap air and maintain a stable foam when whipped or agitated and is expressed as percentage. Foam capacity measures how effectively the flour generates foam, while foam stability indicates how well the foam retains its structure over time without collapsing. These properties are essential in food applications such as baked goods, beverages, and emulsified products, where aeration and texture are important. In this study, foam capacity and stability were analyzed to understand how Musa paradisiaca flour at different maturity stages affects aeration, influencing the texture, lightness, and structure of food products. Assessing these properties helps determine the flour's potential for use in foamed food formulations, enhancing its applications in bakery, confectionery, and protein rich products.

Table 4.24 shows the foam capacity and stability of Musa paradisiaca flour at different levels of maturity. The results are given below:

Table 4.24 – Foam capacity and foam stability of flours

Sample	Foam capacity (%)	Foam stability (%)
Tender	15.78	50
Mature	17.07	57.1
Ripe	13.15	20

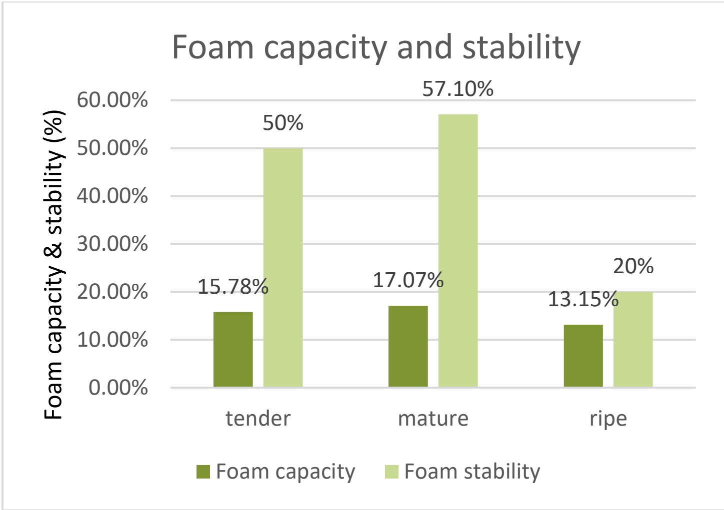


Fig 4.22 – Foam capacity and stability of the flours

The foam capacity and foam stability of Musa paradisiaca flour differ across the stages of maturity. Mature stage shows the highest foam capacity (17.07%) and foam stability (57.1%), indicating excellent air trapping and foam maintenance. Tender stage exhibits moderate foam capacity (15.78%) and stability (50%). Ripe stage has the lowest foam capacity (13.15%) and stability (20%), with significant drop in foam stability, possibly due to structural protein changes or higher sugar content that may disrupt foam formation and stability. These findings suggest that flour from the mature stage is best suited for applications requiring strong foaming properties, such as aerated food products, whereas flour from the ripe stage may be less effective for such purposes.

Swelling capacity

Swelling capacity refers to the ability of flour to absorb water and increase in volume when mixed with a fixed amount of water, without the need for heat. This functional property plays a key role in determining the flour's hydration, viscosity, and texture in food products. It affects water binding ability, bulk formation, and textural characteristics, making it essential for applications such as baking, thickening, and gel formation. Understanding swelling capacity helps optimize the flour's performance in various food formulations, enhancing its functionality in different culinary and industrial applications.

Table 4.25 shows the swelling capacity of Musa paradisiaca flour at different maturity levels. The results obtained are given below:

Table 4.25 – Swelling capacity of flours

Sample	Wt. of the sample (g)	Volume of water (ml)	Swelling capacity (%)
Tender	5	25	60
Mature	5	25	160
Ripe	5	25	20

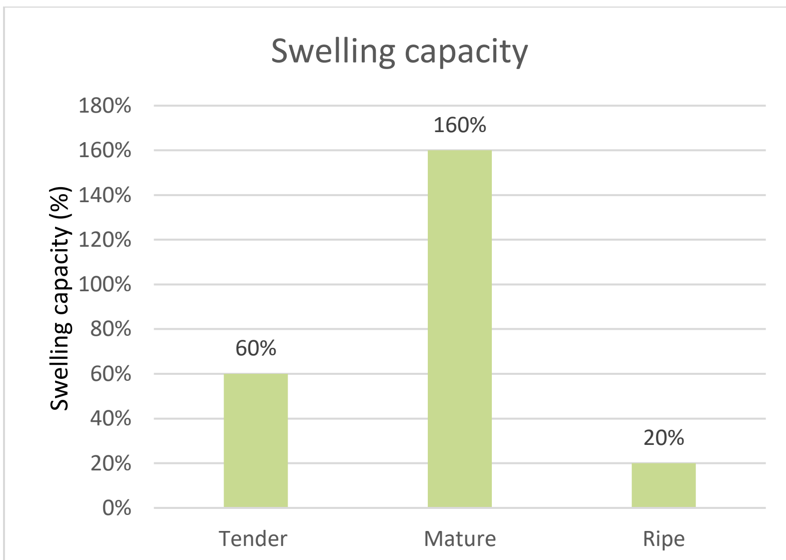


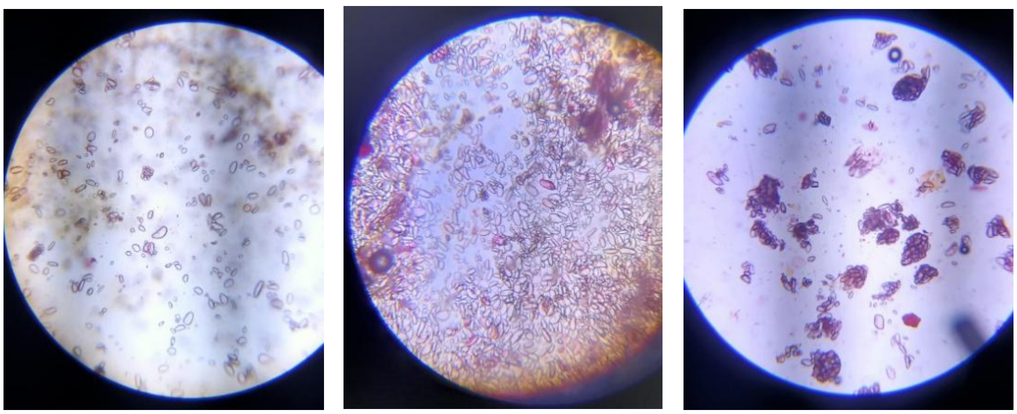
Fig 4.23 – Swelling capacity of the flours

The swelling capacity of Musa paradisiaca flour varies significantly across different stages of maturity. Mature stage exhibits the highest swelling capacity at 160%, indicating its superior ability to absorb water and expand, likely due to optimal starch structure and composition. Tender stage shows a moderate swelling capacity of 60%. Ripe stage has the lowest swelling capacity at 20%, likely due to the breakdown of starch into simpler sugars during ripening, which reduces the starch's ability to retain water.

Shape of the granule

The shape of the granules refers to the morphological structure and appearance of starch granules in the flour, which can take various forms such as spherical, oval, polygonal, or irregular.

The microscopic images showing the shape of granules of Musa paradisiaca flour at different maturity stages are given below:



Tender Mature Ripe

Plate 4.2 – Microscopic image of Tender, Mature and Ripe banana flour

In the microscopic image the granules of tender banana flour appear mostly oval to elliptical in shape, with some variations in size.

The microscopic image of mature banana flour reveals a higher density of granular structures, where the shape is primarily irregular, with a mix of elongated and oval granules. This image shows areas where the granules are clumped together with varying sizes.

In the microscopic image of ripe banana flour, the structures consist of aggregated clusters along with dispersed oval or elliptical granules. These clusters are denser and have irregular shapes, with some exhibiting a slightly rounded or lobed appearance.

Gelatinization temperature

Gelatinization temperature is the temperature range at which starch granules absorb water, swell, and los their crystalline structure, forming a viscous paste. This process plays a key role in determining the functional and textural properties of starch based food products. The gelatinization temperature varies based on factors such as starch source, granule size, and the amylose- to-amylopectin ratio. In this study, the gelatinization temperature of Musa paradisiaca flour was analyzed to understand how different maturity stages influence its thermal properties, cooking behavior, and suitability for applications like baking, thickening, and extrusion cooking.

Table 4.26 shows the gelatinization temperature of Musa paradisiaca flour at different maturity levels.

Table 4.26 – Gelatinization temperature of the flours

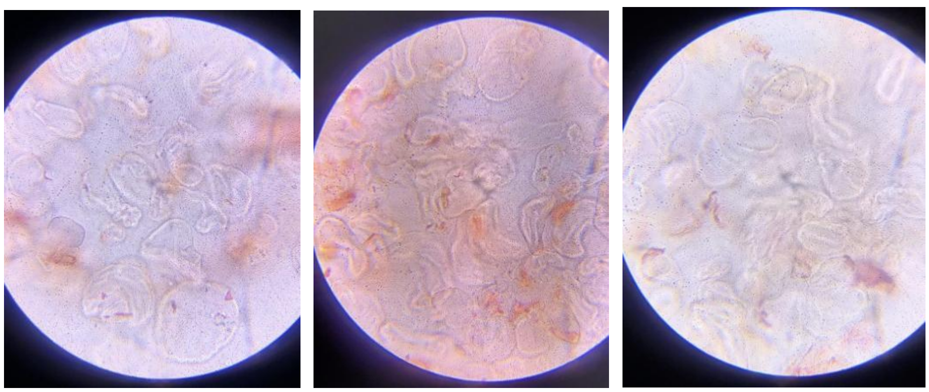
Sample	Gelatinization temperature (^{0}C)	Time taken (min)
Tender	57.1	5
Mature	55.2	4
Ripe	54.8	4

The gelatinization properties of Musa paradisiaca flour exhibit a slight decrease in both gelatinization temperature and time as the banana ripens. The tender stage has the highest gelatinization temperature at 57.1^{o}C and requires 5 minutes for gelatinization. In comparison, the mature stage has a slightly lower temperature of 55.2^{o}C and takes 4 minutes. The ripe stage shows the lowest gelatinization temperature at 54.8^{o}C and also requires 4 minutes for gelatinization.

Microscopic picture of gelatinized flour

The microscopic image of gelatinized flour provides a visual representation of starch granules under microscope after undergoing gelatinization. This analysis helps in understanding the structural changes that occur during heating and hydration, which impact the flour’s viscosity, texture, and overall functional properties. In this study, the microscopic examination of gelatinized Musa paradisiaca flour was performed to observe how different maturity stages affect starch granule breakdown, water absorption, and paste formation. These insights help evaluate the flour's behavior in various food applications.

The microscopic image of gelatinized Musa paradisiaca flour at different maturity levels are given below:



Tender Mature Ripe

Plate 4.3 – Microscopic image of gelatinized flours

Microscopic examination of gelatinized Musa paradisiaca flour from all the three maturity stages revealed that starch granules absorbed water and swelled to the point where their outlines were no longer distinguishable.

4.1.5 Pasting properties

Pasting properties describe the changes in viscosity and gelatinization behavior of starch when heated with water, affecting the texture and consistency of food products. These properties play a crucial role in determining the flour's thickening, gelling, and stability characteristics, making them essential for various food applications such as baking, sauces, and soups. Understanding pasting properties helps to optimize processing conditions and improve the functionality of flour in different formulations.

Viscosity

Viscosity measures the resistance of a fluid or semi-fluid to flow, indicating its thickness or consistency. In food products, it is a key factor in determining texture, mouthfeel, and stability. In this study, the viscosity of Musa paradisiaca flour was analyzed using a cup viscometer to evaluate its flow behavior and consistency in flour-based formulations. Understanding viscosity helps optimize processing and improve the quality of food products.

Table 4.27 shows the viscosity of Musa paradisiaca flour at different maturity levels.

Table 4.27 – Viscosity of the flours

Sample	Wt. of the sample (g)	Volume of water (ml)	Time of flow (sec)
Tender	2	100	13.06
Mature	2	100	13.28
Ripe	2	100	12.38

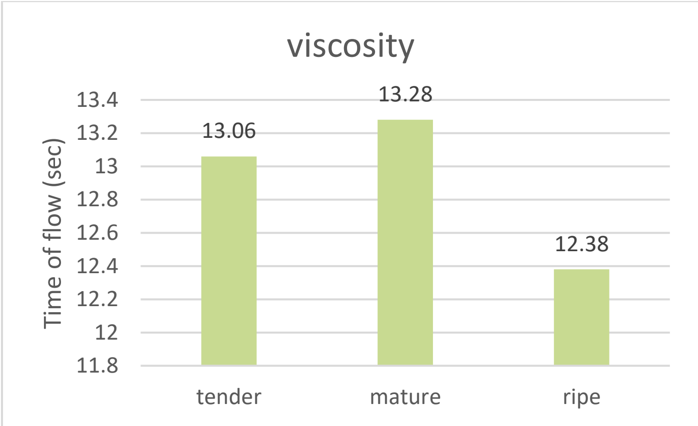


Fig 4.24 – Viscosity of the flours

The viscosity of Musa paradisiaca flour at different stages of maturity was assessed using a cup viscometer (B4 ISO 3944), with the following results. In the tender stage time of flow was 13.06 seconds. In mature stage time of flow was 13.28 seconds. In ripe stage time of flow was 12.38 seconds. These results indicate a slight decrease in the time of flow as the banana ripens, suggesting a reduction in viscosity. The ripe flour appears to flow slightly faster than the tender and mature stages.

The viscosity of *Musa paradisiaca* flour decreases as the banana ripens, as evidenced by shorter flow times measured using a cup viscometer. This trend is supported by the findings of Campuzano *et al*., (2018), who studied the physicochemical and nutritional properties of banana flour at various ripening stages. Their research revealed a notable decline in both total and resistant starch content between the second and third ripening stages, which directly correlated with a reduction in pasting properties, a key indicator of viscosity.

Phase 2 : Development of value product

The development of value-added products involves enhancing the nutritional, functional, or economic value of raw materials by transforming them into improved or innovative food products. In this study, Musa paradisiaca flour from different maturity stages was used to create nutritious, functional, and sustainable food product. By utilizing banana flour in value-added applications, this approach helps reduce food waste, increase market value, and expand its potential uses in the food industry.

4.2.1 Development of cookies

In this study, cookies were developed using Musa paradisiaca flour from different maturity stages, utilizing its natural sweetness, fiber content, and functional properties to enhance the nutritional profile and sustainability of the product. This approach offers a healthier alternative to conventional cookies while promoting banana flour as a functional ingredient. By incorporating banana flour, the study also supports food waste reduction and expands its market potential in the food industry.

- **Tender banana flour cookies :**A total of 24 cookies were obtained from 1 cup of tender banana flour and 1/2 cup of ragi flour, each with a diameter of 4.5 cm and a thickness of 1 cm. The cookies had cracked edges, which is characteristic of the dense texture due to the higher fiber content in the tender banana flour. The average weight of one cookie was approximately 15 g.
- **Mature banana flour cookies :** A total of 18 cookies were obtained from 1 cup of mature banana flour and 1/2 cup of ragi flour, each with a diameter of 6 cm and a thickness of 1

cm. The cookies had smooth edges, reflecting the consistency of the dough. The average weight of one cookie was approximately 20 g.

- **Ripe banana flour cookies :** A total of 35 cookies were obtained from 1 cup of ripe banana flour and 1/2 cup of ragi flour, each with a diameter of 4.5cm and a thickness of 0.7 cm. Cookies had smooth edges and slight browning during baking. The average weight of one cookie was approximately 6 g.

4.2.2 Microbiological assessment of cookies

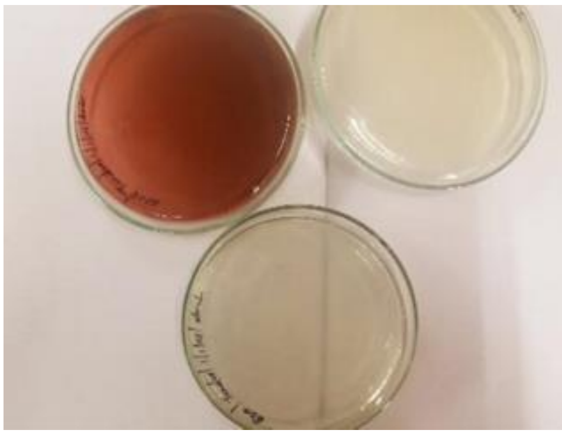
The microbial assessment of banana flour cookies focused on evaluating their safety and shelf stability by analyzing the total plate count, mold, yeast, and coliform levels. The spread plate method was used to quantify microbial load, ensuring the cookies met food safety standards. Monitoring mold and yeast was essential to detect potential fungal contamination, while coliform assessment helped identify any hygienic lapses during processing. This study plays a key role in determining the cookie's suitability for consumption, their shelf life, and their resistance to microbial spoilage over time.

Table 4.28 shows the microbiological assessment of cookies developed from Musa paradisiaca flour using spread plate method. The results obtained are given below:

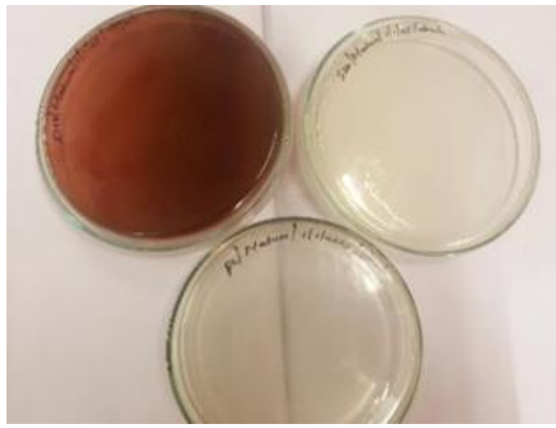
Table 4.28 – Microbial assessment of cookies

Sample	Total plate count (cfu/ml)	Coli forms	Asperigillus	Yeast
Tender banana flour cookies	Absent	Absent	Absent	Absent
Mature banana flour cookies	Absent	Absent	Absent	Absent
Ripe banana flour cookies	Absent	Absent	Absent	Absent

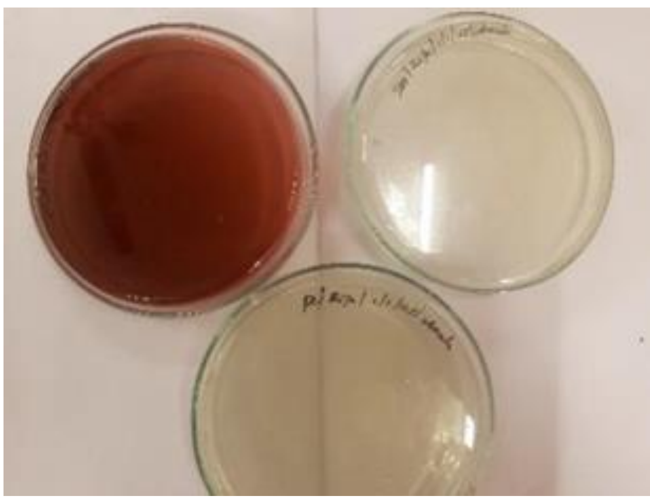
The microbial assessment of cookies made from Musa paradisiaca flour at different stages of maturity reveals no microbial presence in any of the samples. Comparing to the microbial assessment of the corresponding flours, it can be concluded that while the baking process, the high heat treatment, effectively eliminated all microbial contamination. The absence of microbial growth in the cookies, despite the flour's composition, highlights the effectiveness of heat treatment in ensuring the safety and hygiene of the final product.



Tender banana flour cookies



Mature banana flour cookies



Ripe banana flour cookies

Plate 4.4 – Microbiological assessment of tender, mature and ripe banana flour cookies

4.2.3 Sensory evaluation of cookies

Sensory evaluation of cookies involves systematically assessing their taste, texture, aroma, appearance, and overall acceptability through a panel of evaluators. In this study, sensory evaluation was conducted to determine the acceptability of cookies made with Musa paradisiaca flour and to compare their sensory characteristics across different maturity stages. This analysis is essential for product development, quality enhancement, and marketability, ensuring that the cookies align with consumer expectations and industry standards.

Sensory evaluation of the cookies developed from Musa paradisiaca flours of different maturity levels were done by a panel of 15 members. The result obtained are concluded in the given table below:

Table 4.29 -Mean value of the sensory evaluation of the products developed

Name of the product	Appearance (5)	Aroma (5)	Taste (5)	Texture (5)	Overall acceptance (5)	Average (5)
Tender banana flour cookies	4.25	4.42	4	3.82	4.15	4.12
Mature banana flour cookies	4.3	3.8	3.6	3.05	3.8	3.71
Ripe banana flour cookies	4.8	4.5	4.2	4.5	4.5	4.5

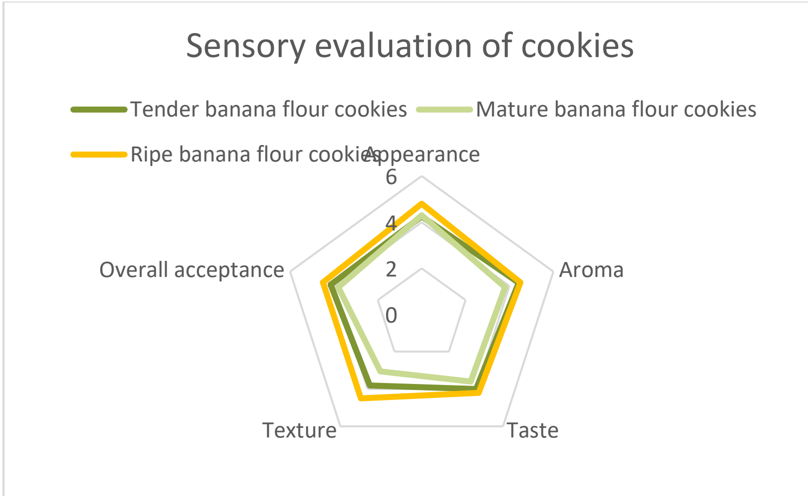


Fig 4.25 – Sensory evaluation of the cookies

The sensory evaluation of cookies made from Musa paradisiaca flour at different stages of maturity revealed that ripe banana flour cookies scored the highest across all sensory attributes, including appearance, aroma, taste, texture, and overall acceptance, with an overall score of 4.5. These cookies exhibited the best sensory qualities, particularly in texture and aroma. The tender banana flour cookies also performed well, especially in aroma and overall acceptance, but received slightly lower ratings for texture compared to the ripe variety, with an overall score of 4.15. In contrast, the mature banana flour cookies received the lowest ratings, particularly in taste and texture, with an overall acceptance score of 3.8. This suggests that mature flour may not be as suitable for producing desirable cookie characteristics. Overall, ripe banana flour provided the most favorable sensory qualities for cookies, followed by tender banana flour, while mature flour was less favorable in terms of taste and texture.

4.2.4 Selection of the best product

Based on the sensory evaluation, ripe banana flour cookies emerged as the best product, scoring the highest across all sensory attributes, including appearance, aroma, taste, texture, and overall acceptance. This makes them an ideal choice for further nutritional assessments. One significant advantage of selecting ripe banana flour for cookie production is its natural sweetness, which allows for a reduction in added sugar content, offering a healthier alternative. Additionally, using ripe banana flour helps reduce food waste by efficiently utilizing ripe bananas that are at risk of spoiling. This contributes to a more sustainable food system. In comparison, the wastage rate of tender and mature bananas is relatively lower, making ripe banana flour cookies a more practical solution for utilizing bananas nearing the end of their shelf life. Overall, ripe banana flour cookies not only offer excellent sensory qualities but also provide nutritional, economic, and environmental benefits.

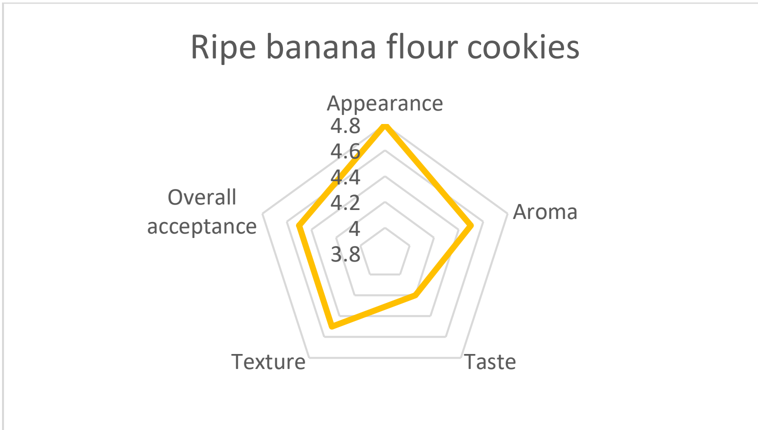


Fig 4.26 – Sensory attributes of ripe banana flour cookies

4.2.5 Nutrient analysis of ripe banana flour cookies

The nutritional assessment of ripe banana flour cookies focused on analyzing their moisture, carbohydrate, protein, and fat content—key factors that determine their nutritional value and shelf stability. Based on these values, the energy content was calculated to estimate their caloric contribution.

This assessment highlighted the benefits of incorporating ripe banana flour, particularly its natural sweetness, fiber content, and essential macronutrients. Evaluating these parameters is essential to support accurate product labeling, and enhance their appeal in the functional food market.

Table 4.30 shows the result of nutrient analysis of ripe banana flour cookies. The results obtained are:

Table 4.30 – Nutrient analysis of the product

Name of the product	Moisture (%)	Energy (kcal)	Carbohydrate (g/100g)	Protein (g/100g)	Fat (g/100g)
Ripe banana flour cookies	4.3	373	35.6	3.44	24.1

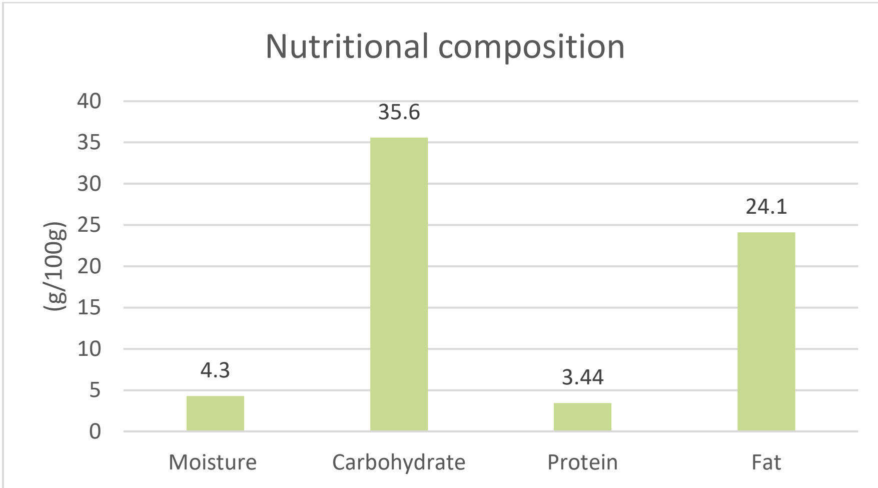


Fig 4.27- Nutritional composition of ripe banana flour cookies

The nutritional composition of ripe banana flour cookies reveals a moisture content of 4.3%, indicating they are well-baked with minimal water content. The cookies contain 35.6g/100g carbohydrates, serving as a significant energy source. The protein content is moderate at 3.44g/100g, while the fat content is relatively high at 24.1g/100g, contributing to the cookie's richness and texture. Based on the carbohydrate, protein and fat content, the total calorie was calculated as 373kcal/100g These nutritional values emphasize the energy-dense nature of the product, offering a balanced mix of macronutrients that make it a satisfying snack option.

4.2.6 Packaging and labelling

Packaging and labeling play a crucial role in protecting, preserving, and presenting food products while providing essential product information. Proper packaging helps maintain the quality, freshness, and shelf life of the cookies by preventing moisture loss, microbial contamination, and physical damage.

Labeling includes key details such as the ingredient list, nutritional facts, manufacturing and expiry dates, storage instructions, and branding, ensuring consumer awareness and regulatory compliance. In this study, suitable packaging and labeling for ripe banana flour cookies were considered to enhance their marketability, convenience, and safety for consumers.


Banana delights
WHOLESOME AND DELICIOUS BANANA COOKIES!
made with Love

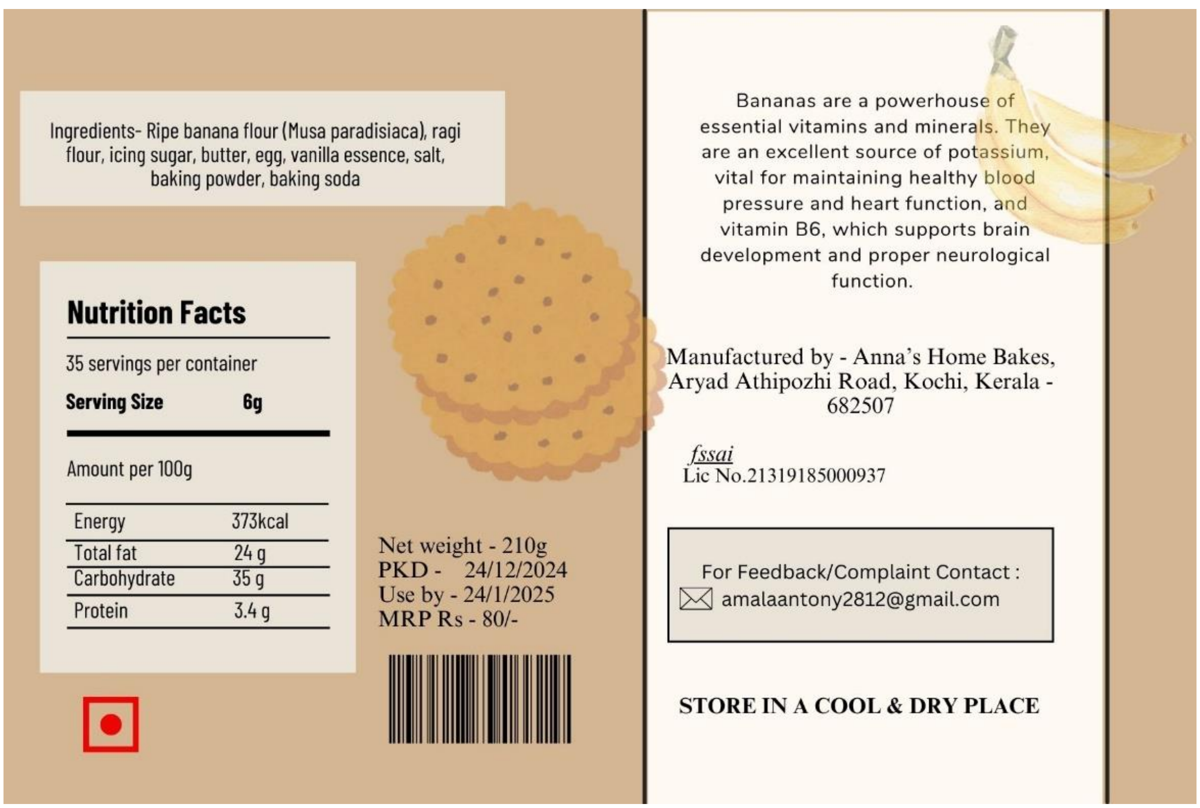

Ingredients- Ripe banana flour (Musa paradisiaca), ragi flour, icing sugar, butter, egg, vanilla essence, salt, baking powder, baking soda
Nutrition Facts
35 servings per container
Serving Size 6g
Amount per 100g
Energy 373kcal
Total fat 24 g
Carbohydrate 35 g
Protein 3.4 g
Net weight - 210g
PKD - 24/12/2024
Use by - 24/1/2025
MRP Rs - 80/-
Bananas are a powerhouse of essential vitamins and minerals. They are an excellent source of potassium, vital for maintaining healthy blood pressure and heart function, and vitamin B6, which supports brain development and proper neurological function.
Manufactured by - Anna's Home Bakes, Aryad Athipozhi Road, Kochi, Kerala - 682507
fssai
Lic No.21319185000937
For Feedback/Complaint Contact :
amalaantony2812@gmail.com
STORE IN A COOL & DRY PLACE

Plate 4.5 – Packaging and labelling

After labelling and packaging the cookies were stored in an airtight glass container to maintain their freshness and prevent them from becoming stale or absorbing moisture. This method of storage helps preserve the flavor, texture, and quality of the cookies for a longer period.

4.2.7 Assessment of Shelf life

Shelf life assessment involves evaluating a product’s stability, safety, and quality over time to determine how long it remains suitable for consumption. In this study, the shelf life of ripe banana flour cookies was analyzed by monitoring microbial load on the 30th and 45th days, specifically checking for total plate count, *Aspergillus*, yeast, and coliforms.

This evaluation helps understand microbial growth, spoilage potential, and the storage conditions required to maintain product safety. Assessing shelf life is essential for ensuring food safety, determining expiration dates, and optimizing packaging and storage recommendations.

Sensory evaluation after 30 days of storage

To assess its shelf life, the cookie was stored in an air-tight container for one month. On the 30th day, a sensory evaluation was conducted, and the microbial load was analyzed to determine its stability and safety over time. Table 4.31 shows the result of sensory evaluation on 30th day of storage.

Table 4.31 – Sensory evaluation of ripe banana flour cookies after 30 days

Name of the product	Appearance (5)	Aroma (5)	Taste (5)	Texture (5)	Overall acceptance (5)	Average (5)
Ripe banana flour cookies	4.5	4.3	4	4.5	4	4.26

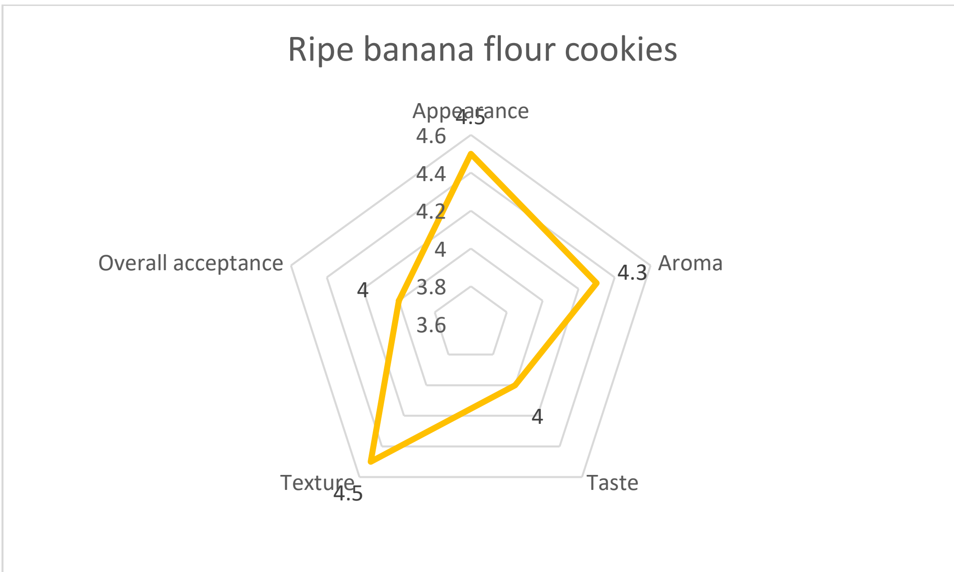


Fig 4.28 – Sensory attributes of ripe banana flour cookies after 30 days

The sensory evaluation of ripe banana flour cookies, conducted on a 5-point hedonic scale, revealed strong consumer approval. The cookies received high scores, with 4.5 for appearance, 4.3 for aroma, 4.0 for taste, and 4.5 for texture, along with an overall acceptance score of 4.0. These results suggest that the cookies are visually attractive, pleasantly aromatic, and have a desirable texture, making them well-liked by consumers.

Microbial assessment after 30 days of storage

The microbial load was analyzed after 30 days of storage to assess the safety and shelf life of the product. Table 4.32 shows the microbial load of ripe banana flour cookies after 30 days of storage.

Table 4.32 – Microbial assessment of cookies after 30 days

Sample	Total plate count (cfu/ml)	Coli forms	Asperigillus	Yeast
Ripe banana flour cookies	86 x 10^2	Absent	Absent	Absent

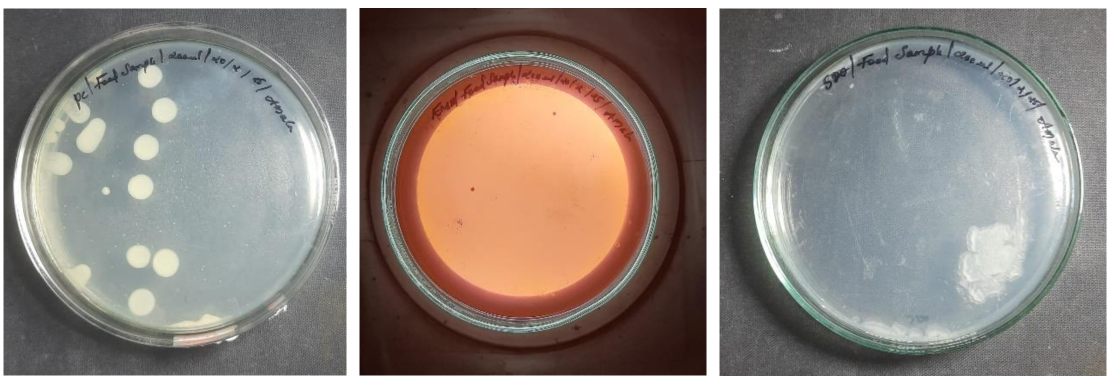


Plate 4.6 – Microbiological assessment of ripe banana flour cookies after 30 days

The microbial load of the ripe banana flour cookies was measured at 86 x 10^2 CFU/mL, which is equal to 8,600 CFU/g after accounting for the dilution factor. According to FSSAI regulations, the permissible limit for Total Plate Count (TPC) in cookies is ≤10,000 CFU/g. This means the cookies fall within the acceptable safety range, confirming they are safe for consumption and comply with the required standards.

Sensory evaluation after 45 days of storage

On the 45th day, of storage sensory evaluation was conducted, and the microbial load was analyzed to determine its stability and safety over time. Table 4.33 shows the result of sensory evaluation on 45th day of storage.

Table 4.33 – Sensory evaluation of ripe banana flour cookies after 45 days

Name of the product	Appearance (5)	Aroma (5)	Taste (5)	Texture (5)	Overall acceptance (5)	Average (5)
Ripe banana flour cookies	4.5	4	3.2	3	3	3.5

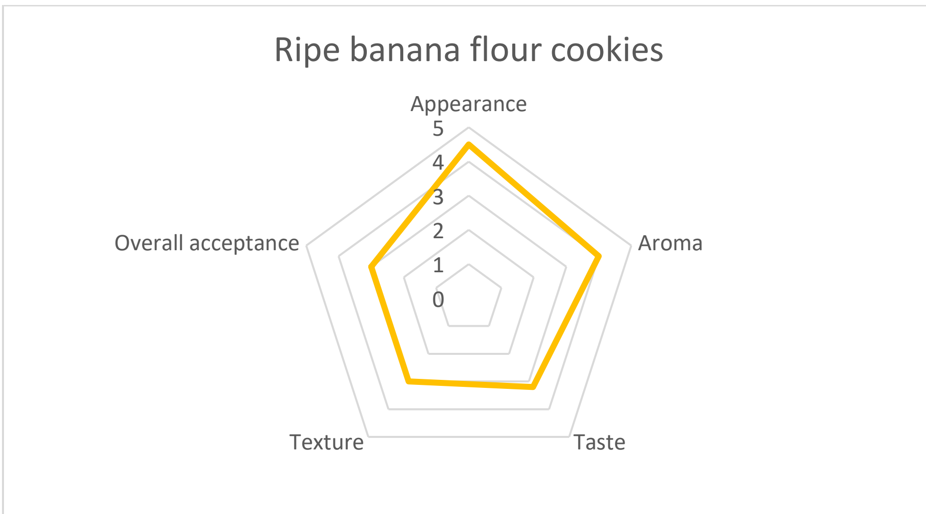


Fig 4.29 – Sensory attributes of ripe banana flour cookies after 45 days

Sensory evaluation of cookies after 45 days received a score of 4.5 for appearance, 4 for aroma, 3.2 for taste, and 3 for texture, along with an overall acceptance score of 3. The cookies showed slight changes in texture and flavor over the storage period. The crispiness was slightly reduced, and there was a mild increase in hardness. However, the overall acceptability remained satisfactory, with no significant off-flavors detected.

Microbial assessment after 45 days of storage

The microbial load was analyzed after 45 days of storage to assess the safety and shelf life of the product. Table 4.34 shows the microbial load of ripe banana flour cookies after 45 days of storage.

Table 4.34 – Microbial assessment of cookies after 45 days

Sample	Total plate count (cfu/ml)	Coli forms	Asperigillus	Yeast
Ripe banana flour cookies	152 X 10^2	Absent	Absent	Present

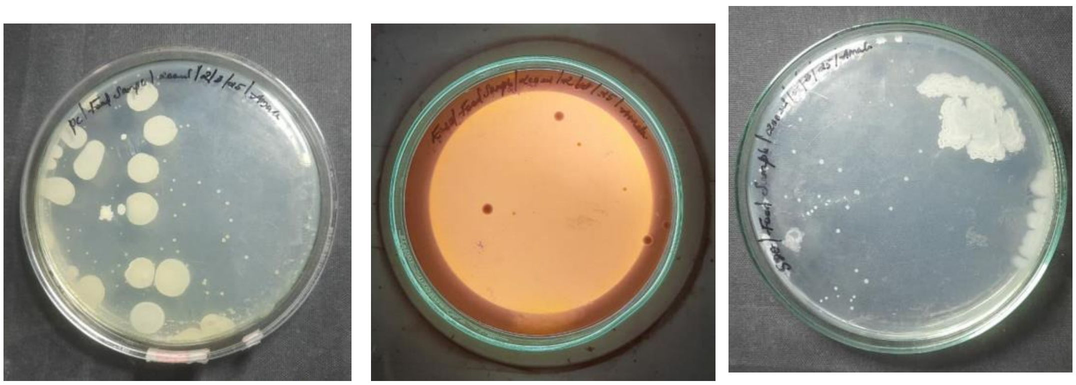


Plate 4.7 – Microbiological assessment of ripe banana flour cookies after 45 days

The microbial analysis of ripe banana flour cookies on the 45th day of storage revealed a total plate count of 15,200 cfu/ml (152 × 10^2 cfu/ml), which exceeds the permissible limit of 10^4 cfu/ml (10,000 cfu/ml). This indicates microbial growth beyond the acceptable safety threshold. Coliforms and Aspergillus species were absent, confirming the absence of pathogenic contamination. However, yeast was detected, suggesting potential spoilage. Although no visible mold growth was observed, the elevated microbial load indicates a decline in shelf stability, making the product unsuitable for extended storage beyond this period.

CHAPTER – 5

SUMMARY & CONCLUSION

This study investigated the proximate composition, functional properties, and pasting properties of flour from Musa paradisiaca at different maturity stages – tender, mature, and ripe – and its application in developing value – added products. The result that emerged from the study are summarized as below:

Phase 1: Comparative study of Banana Flour

- Flour Yield: The highest yield was in the mature stage (20.8%), followed by the tender (15.5%) and ripe (15%) stages. The lower yield in the ripe stages was due to higher moisture content and prolonged drying time (20 hours).

Proximate Composition:

- Ash content increased with ripening, peaking at 2.22% in the ripe stage.
- Moisture content was higher in ripe flour (6%) due to water retention during ripening.
- Protein content increased significantly in the ripe stage (6 g/100g), compared to tender (3.7g/100g) and mature (2.9 g/100g) stages.
- Carbohydrate content remained stable, but reducing sugars increased dramatically in the ripe stage (22.4 g/100g), enhancing natural sweetness.
- Fat content was highest in the ripe stage (0.796 g/100g), slightly increasing from tender and mature stages.
- Crude fiber was highest in the mature stage (0.651 g/100g) and lowest in the ripe stage.

Mineral Composition:

- Iron content was highest in the mature stage (6.39 mg/100g) but decreased in the ripe stage (1.28 mg/100g).
- Sodium content declined with ripening, while potassium levels peaked at 159.2 mg/100g in the ripe stage.
- Calcium content decreased slightly across stages.

Functional Properties:

- Water absorption capacity (WAC) was highest in ripe flour (72.7%), enhancing moisture retention in food applications.
- Oil absorption capacity (OAC) was highest in tender flour (77.1%) and decreased with ripening.
- Foam capacity was highest in mature flour (17.07%), while swelling capacity peaked in mature flour (160%) but dropped significantly in ripe flour (20%).
- Bulk density was higher in tender and mature flours, while ripe flour had better flowaility (Hausner Ratio = 1.1).
- Gelatinized temperature decreased with ripening (Tender – 57.1^{o}C, Ripe – 54.8^{o}C), making ripe flour more suitable for baking.

Pasting Properties:

- Viscosity declined in ripe flour, suggesting reduced pasting ability due to starch hydrolysis.

Phase 2: Development of Cookies

Product Formulation:

- Cookies were developed using banana flour from tender, mature, and ripe, stages, mixed with ragi flour.

Sensory Evaluation:

- Ripe banana flour cookies had the highest acceptability (4.5/5) due to natural sweetness, pleasant aroma, and desirable texture.
- Tender flour cookies had moderate acceptance (4.12/5), while mature flour cookies received the lowest score (3.71/5).

Nutritional Composition of Ripe Flour Cookies:

- The cookies contain 373 kcal/100g energy, 35.6g/100g of carbohydrate, 3.44g/100g of protein and 24.1 g/100g of fat.

Shelf – Life Assessment:

- Day 30: Cookies remained sensory acceptable and microbiologically safe within FSSAI limits.
- Day 45: Microbial growth exceeded the permissible limit (15,200 CFU/ mL), and yeast was detected, making the product unsafe for prolonged storage.

CONCLUSION

The study on Musa paradisiaca flour at different maturity stages highlights its nutritional, functional, and pasting properties, demonstrating its potential as a value – added ingredient in food applications. The finding indicate that mature banana flour had the highest yield, iron, and fiber content, making it suitable for fibre – enriched foods, while ripe banana flour exhibited higher sugar content, better flowability, and superior sensory properties, making it ideal for baking applications. Among the developed products, ripe banana flour cookies emerged as the best, offering natural sweetness, reduced added sugar, and good consumer acceptability. Shelf – life evaluation confirmed that the cookies remained microbiologically safe for 30 days but it showed microbial growth beyond acceptable limits after 45 days, indicating the need for improved storage strategies. The study underscores banana flour's potential for food sustainability and waste reduction, and future research could explore commercialization, gluten – free applications, and extended shelf life techniques to enhance its viability in the food industry.

CHAPTER – 6

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