RESEARCH PAPER

Development of Nutrient Enriched Waffle Using Black Rice and Red Banana

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ABSTRACT

This paper was aimed at the creation of nutritionally-enriched waffles on the basis of black rice flour and red banana puree in order to enhance functional, nutritional, and sensory properties. Four black rice flour (10-40%), red banana puree (10-25%) formulations with different proportions were made and evaluated in terms of proximate composition, bioactive compounds, antioxidant capacity, moisture, and sensory properties. The content of fiber was increased to 5.0 -100 -1 to 2.1 -100 -1, and the amount of anthocyanin was improved to 20 -100 -1 to 5 -100 -1. There was a dramatic increase in the total antioxidant capacity (30-85%), and protein (6.0-7.0 g) and fat (8.0-7.2 g) were kept in check to ensure palatability. The Sensory analysis has shown that F3 (30% black rice + 20% red banana) was the most acceptable formulation, with the highest score in terms of texture, taste, aroma, and appearance. Optimization of moisture and time of cooking gave a tender interior and brittle exterior. The researchers show that black rice flour and red banana puree are suitable in improving nutritional values, functional bioactives, and sensories in waffles. The results can be used to replicate a similar method of creating health-promoting, functional bakery products that could be commercially viable and acceptable to the consumers.

Keywords: Nutrient-enriched waffles, Black rice flour, Red banana puree, Functional bakery products, Antioxidant activity, Dietary fiber, Sensory evaluation

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1. Introduction

Waffles are popular bakery products that are widely consumed across the world due to their taste and convenience [1]. However, traditional waffles are known to be high in refined flour and sugar content, thus providing minimal nutritional value [2]. In recent times, consumers have been demanding functional foods with nutritional value [3]. Nutrient-dense ingredients added to popularly consumed snacks provide an opportunity to bridge nutritional gaps.

Black rice is also referred to as “forbidden rice.” It is rich in anthocyanins, dietary fibers, and essential minerals [4]. The antioxidant properties of black rice are beneficial for reducing oxidative stress and ensuring cardiovascular health [5]. The dietary fibers present in black rice contribute to digestive health, while the minerals present in black rice, such as iron and magnesium, play a crucial role in metabolic health [6]. Using black rice flour in baked products can improve the nutritional and functional properties of baked products [7].

Red banana is a special type of banana rich in natural sugars, dietary fibers, and essential minerals such as potassium and vitamin C. Red banana is also rich in bioactive compounds such as carotenoids, which contribute to eye and immune health [8]. The presence of natural sugars in red banana reduces the need to add sugar to baked products, making waffles healthier when prepared with red banana [9]. Red banana not only imparts flavor to baked products but also improves texture and moisture content [10].

The combination of black rice and red banana provides an opportunity for the development of nutrient-enriched waffle products, where the combination will enhance the nutritional content and sensory characteristics of the waffle product [11]. In addition, the replacement of refined flour with black rice flour will reduce the GI, thus providing the product with nutritional advantages for health-conscious consumers or consumers with dietary restrictions [12].

The development of waffle products enriched with black rice and red banana will address the demand for healthier snack options without compromising the

sensory characteristics [13]. The objective of this study was to optimize the waffle product, determine the physicochemical characteristics, and assess the sensory characteristics for waffle products [14]. The development of functional bakery products will improve the nutritional content, expand the utilization of the crop, and encourage the development of health-conscious consumption habits [15].

2. Methodology

The methodology in the formulation of nutrient-enriched waffles is based on the integration of scientific principles and culinary practices to produce waffles with improved nutritional and sensory properties. The methodology of the study is based on a stepwise approach in the formulation of nutrient-enriched waffles, which involves formulation, batter preparation, mixing, cooking, and evaluation. Each of the steps is based on the optimization of black rice flour and red banana puree in the formulation of nutrient-enriched waffles. The first phase consisted of formulation development, where refined wheat flour was partially replaced with black rice flour to improve the levels of dietary fiber, antioxidants, and anthocyanin. Red banana puree was also used to enrich the product with more sweetness, moisture, and micronutrients. A number of formulations were developed by varying the amounts of the above-mentioned ingredients. This approach was used to assess the effect of interactions among the ingredients on the quality of the developed product.

During the batter preparation and mixing process, the dry materials, which include wheat flour, black rice flour, sugar, baking powder, and salt, were mixed uniformly. The wet materials, which include eggs, milk, oil, and red banana puree, were gradually mixed with the dry materials. During the mixing process, control was exercised in order to avoid lumps. The batter viscosity and aeration were also carefully examined, as they have a direct impact on the texture of the cooked waffle. The moisture and fiber levels were also taken into account in order to obtain a uniform batter. The cooking and waffle preparation stage used standardized techniques with a preheated waffle iron. A specified quantity of batter was used in each mold to ensure waffle thickness, shape, and cooking time. Optimal cooking conditions were used to attain waffles with golden-brown edges, crispiness, and softness. Nutrient retention was also ensured through optimal cooking conditions. Cooling of waffles on wire racks maintained texture and prevented sogginess. Storage in airtight conditions ensured waffle quality for further testing.

In this context, sensory evaluation and quality assessment were an integral part of the methodology. Each of these formulations was evaluated in terms of color, texture, aroma, taste, and overall acceptability through structured panel data. Physical and proximate analysis, such as moisture, fiber, and antioxidant content, were also carried out to further validate the nutritional enrichment of these formulations through ingredient substitution. Also, data with respect to batter properties, cooking conditions, and product characteristics were also recorded in an organized manner. This methodological framework of combining experimental formulation and process control/evaluation resulted in a holistic approach to the development of a functional bakery product. The optimization of ingredients, batter rheology, cooking, and sensory/nutritional evaluation of the developed waffles ensured that not only are the developed waffles nutritionally advantageous but also organoleptically acceptable. The approach also offers scope for scaling up the production of the developed waffles, as seen in the potential for commercialization.

2.1 Raw Material Selection

The quality and nutritional potential of the end product waffles depend on the choice of the raw materials used in their production. Black rice was used due to its richness in anthocyanin pigments, dietary fibers, and essential minerals, which improve the antioxidant properties and nutritional quality of the food product. Mature and ripe red bananas were used due to their richness in active compounds and essential minerals such as potassium and vitamin C, which improve their flavor and nutritional quality. Other essential ingredients such as all-purpose flour, eggs, milk, sugar or honey, baking powder, and oil were sourced while adhering to their freshness, purity, and standard quality parameters to improve their functional and sensory properties of the waffles. Table 1 provides the Raw Materials and Their Functional Role in Waffle Preparation.

Table 1: Raw Materials and Their Functional Role in Waffle Preparation

Raw Material	Functional Role	Nutritional/Functional Benefit
Black Rice	Flour substitution	High in fiber, anthocyanins, minerals
Red Banana	Sweetener, moisture retention	Vitamins (C), potassium, carotenoids
All-purpose Flour	Structure, texture	Carbohydrates, protein

Eggs	Binding, leavening, texture	Protein, fats, vitamins
Milk	Moisture, texture, flavor	Calcium, protein, vitamins
Sugar/Honey	Sweetness, browning	Energy source
Baking Powder	Leavening agent	Promotes fluffiness
Oil	Tenderness, moisture	Fats, improves mouthfeel

Table 1 shows a summary of the raw materials used for developing nutrient-enriched waffles and their functional contributions. Black rice and red banana are used as nutrient enhancers for the production of nutrient-enriched waffles by contributing antioxidants, dietary fiber, vitamins, and minerals while replacing refined flour to a certain extent. All-purpose flour is used for building the base of the waffles, while eggs and milk are used for binding and nutritional value addition. On the other hand, sugar or honey is used for sweetening and browning, while baking powder is used for leavening for a fluffy texture. Oil is also used for tenderness and mouthfeel value addition to the waffles.

2.2 Preparation of Ingredients

Proper preparation of the raw materials is critical to ensure uniformity and consistency in the end product and maximum retention of nutrients in the prepared waffles. Black rice was properly washed to remove impurities and then dried before grinding into flour to improve its dispersibility in the batter. Red bananas were mashed and homogenized to ensure uniformity in texture and to facilitate moisture retention and sweetness retention in the end product. Precise measurement of all the ingredients as per the preliminary formulation is critical to ensure uniformity and to control the nutritional and sensory properties of the waffles prepared. Preparation Steps and Functional Purpose of Ingredients are given in Table 2.

Table 2: Preparation Steps and Functional Purpose of Ingredients

Ingredient	Preparation Step	Functional Purpose
Black Rice	Wash → Soak → Dry → Grind into flour	Improves dispersion, texture, and nutrient availability
Red Banana	Peel → Mash → Homogenize into puree	Adds moisture, natural sweetness, and micronutrients
All Ingredients	Measure accurately per formulation	Ensures batch consistency and controlled nutrient profile

Table 2 delves the Preparation of key ingredients and their importance in waffle batter preparation. The washing, soaking, drying, and grinding of black rice ensure a uniform flour product with improved dispersibility, texture, and nutritional content. The processing of red bananas into smooth puree form not only improves the moisture content, sweetness, and nutritional value of waffles but also provides vitamins and minerals. The accurate measurement of all ingredients, according to the preliminary ratios, is critical for ensuring uniformity, texture, and nutritional content of waffles. These preparation steps are critical for the creation of a uniform, nutrient-enriched waffle product with desired sensory properties, laying a foundation for successful waffle batter preparation and cooking.

2.3 Formulation Development

Nutrient-enriched waffles were developed with the aim of enhancing the nutritional content and the flavor of the products by adding the black rice flour and red banana puree. Black rice was selected as it has high anthocyanin, antioxidant, and dietary fiber that make it beneficial to the health of people in terms of better digestion and anti-inflammatory effects. Substituting some refined wheat flour with black rice flour not only increased the nutritional value but also gave the waffles their characteristic appearance as well as a touch of flavor that is nutty and which made the waffles attractive and unlike the regular ones. As a natural sweetener and moisturizer, red banana puree was incorporated, which minimizes the utilization of a lot of sugar and fats. Natural sugars in red banana facilitated the preservation of the preferred sweetness and the moisture content enhanced a more delicate and tender texture of the waffles. Also, red bananas contain high amounts of potassium, vitamins and bioactive compounds that also contributed to functionality of the end product.

In order to achieve a uniform texture and structural integrity, sugar, liquid and raising agent adjustments were conducted. The loss in gluten content because of black rice flour required a careful adjustment of the viscosity and level of leavening of the batter in order to obtain the necessary aeration and consistence of rising. Several recipes were made and different ratios of the black rice flour and the red banana puree were used to

determine the best proportion of nutritional addition and sensory appeal i.e., taste, aroma, color, and crispiness.

The iterative development process had the blending of ingredients in the correct proportionality and then the trial cooking performed with the use of standardized waffle irons to control the consistency of the shape and surface texture. Each formulation was to undergo sensory analysis and proximate analysis to determine the qualities of contents like moisture, intensity of color, flavor and overall acceptability. This strategy made sure that the end formulation did not only have the added nutritional value but also satisfied the taste and texture expectations of consumers. Table 3 summarises the principal variations in formulations tried in nutrient-enriched waffles which show the concentration of black rice flour and red banana puree. This methodology enabled the definition of such a formulation that pre-eminently considered health benefits and sensory quality in order to deliver both a functional value and consumer appeal. The fact that black rice and red banana were used in the formulation of waffles indicates that it is possible to develop functional bakery goods, which will meet the nutritional and sensory requirements. This positioning coincides with the present-day consumer behavior that prefers to see natural and nutrient rich ingredients in foods that are consumed daily. Table 3 shows the Formulation Variations of Nutrient-Enriched Waffles with Black Rice Flour and Red Banana Puree.

Table 3: Formulation Variations of Nutrient-Enriched Waffles with Black Rice Flour and Red Banana Puree

Formulation	Black Rice Flour (%)	Red Banana Puree (%)	Notes on Texture & Flavor
F1	10	10	Slightly firm, mild sweetness
F2	20	15	Soft texture, pronounced nutty flavor
F3	30	20	Darker color, higher moisture, balanced taste
F4	40	25	Denser texture, strong banana flavor, high antioxidant content

2.4 Batter Preparation and Mixing

Batter preparation is an important factor in the development of nutrient-enriched waffles, which affects texture, volume, appearance, and sensory properties. For the purpose of this study, batter was developed using refined wheat flour and black rice flour blended in combination with red banana puree. The selection of ingredients, their proportions, and mixing were made in a manner that produced uniformity, optimality in terms of aeration, and consistency in texture so that each waffle had an acceptable texture.

2.4.1 Dry Ingredient Preparation

Dry ingredients used in batter development were refined wheat flour, black rice flour, sugar, baking powder, and salt. Each of the dry ingredients was selected for its specific functional properties. Refined wheat flour provided gluten, black rice flour provided fiber and antioxidants with reduced gluten, sugar provided sweetness with browning during cooking, and baking powder was used as a chemical leavening agent that provided air in batter development. Salt was used for flavor enhancement and strengthening gluten.

Proper mixing of the dry ingredients was a necessity to ensure that there was even distribution of leavening agents and sugars in the flour mixture. Lack of proper mixing of dry ingredients, for example, could result in unevenly distributed baking powder, leading to irregular rise and the formation of dense spots or air pockets in the final waffle. The dry ingredients are sifted and then mixed to break any lumps that may form. Table 4 shows the composition of dry ingredients used in the preparation of various waffle formulas.

Table 4: Composition of dry ingredients

Ingredient	Function	Range (%)
Refined wheat flour	Structure formation (gluten)	50–70
Black rice flour	Nutrition & color	10–40
Sugar	Sweetness & browning	10–20
Baking powder	Leavening agent	2–5
Salt	Flavor enhancer	0.5–1

2.4.2 Wet Ingredient Incorporation

The wet ingredients used were eggs, milk, vegetable oil, and red banana puree. The eggs were used both as a binder and an emulsifier. Milk was used for hydration, which also facilitated gluten formation. Milk also aided in enriching the batter. Vegetable oil also played a part in making the cake tender by covering the flour proteins, thereby making it less

tough. Vegetable oil also aided in retaining moisture in the cake. Red banana puree not only provided sweetness and hydration but also provided essential vitamins, minerals, and bioactive compounds like potassium, vitamin C, carotenoids, and polyphenols. The incorporation of wet ingredients into the dry ingredients was gradual in order to avoid formation of lumps. Wet ingredients were first mixed separately in order to obtain a uniform mixture. This was done in order to ensure that oil and puree were uniformly mixed. Wet ingredients were then gradually mixed with the dry ingredients with constant stirring using either a manual whisk or a low-speed electric mixer.

2.4.3 Mixing Techniques and Batter Consistency

sed in mixing had a significant impact on the batter's consistency. Over-mixing could have led to an increase in gluten formation, causing the batter to be tough or rubbery. Under-mixing could have caused lumps in the batter, which could have affected even cooking. Therefore, the batter was mixed adequately until all the ingredients were well mixed, with a smooth batter that had no lumps. The consistency of the batter was also affected by altering the ratio of liquid to dry ingredients. The batter had to be thick but still have the ability to flow. The addition of red banana puree reduced the amount of liquid in the batter. However, the addition of puree had to be closely monitored so that the batter did not become too runny. The appropriate consistency of the batter enabled even penetration of heat during cooking, making the waffles even in texture.

2.4.4 Ingredient Interactions and Functional Considerations

The interactions of ingredients were significant in this study, considering the use of black rice flour and red banana puree. Black rice flour, which is gluten-deficient compared to wheat flour, would affect the gluten content, which could compromise the structural integrity of the product. This was addressed by optimizing the amount of wheat flour and egg to form sufficient protein networks.

The red banana puree would contribute to the amount of sugar, which would affect the pH, viscosity, and browning of the batter. The natural sugars would contribute to the caramelization of the product, which would affect the color development. Moreover, the fibers in the black rice would affect the water absorption of the batter, which would affect the viscosity of the batter. The water absorption would affect the amount of water to be added to the batter to attain the desired viscosity.

The leavening action was also monitored to attain the desired product. The interaction of the baking powder with the liquid ingredients would form bubbles, which would be trapped by the gluten and egg proteins. The viscosity of the batter would affect the texture of the product.

2.4.5 Quality Optimization through Formulations of Variations

Different batter formulations were developed through various percentages of black rice flour and red banana puree addition to arrive at an optimal formulation. All these formulations were subjected to keen observations in terms of batter flow, uniformity, and formation of bubbles. Formulations containing higher percentages of black rice flour were subjected to slightly higher percentages of liquid and egg addition due to low gluten formation. Formulations containing higher percentages of red banana puree addition had to be mixed with keen attention to avoid thinning of the batter. Table 5 provides an overview of batter properties for different formulations.

Table 5: Overview of batter properties for different formulations

Formulation	Black Rice Flour (%)	Red Banana Puree (%)	Batter Viscosity	Notes on Pourability	Predicted Texture
F1	10	10	Medium	Smooth, easy to pour	Slightly firm
F2	20	15	Medium-High	Slightly thick	Soft, spongy
F3	30	20	High	Requires gentle spreading	Tender, moist
F4	40	25	Very High	Less pourable, sticky	Dense, rich

2.4.6 Sensory and Functional Evaluation of Batter

Before cooking, all batters were subjected to color, texture, aroma, and consistency evaluation. Dark color was associated with an increase in black rice. The aroma of red banana was mild, fruity, and creamy in texture. A uniform batter texture facilitated even heat

transfer during cooking, thereby ensuring uniform browning on the surface and moisture distribution on the inside. Rheological tests could be carried out on the batters, which would give an idea about the texture or viscosity of the batters. This step could ensure reproducibility of quality in industrial production. The texture of the final waffle could be predicted. Following table 6 shows the Summary of Functional Role of Ingredients in Batter.

Table 6: Summary of Functional Role of Ingredients in Batter

Ingredient	Functional Contribution in Batter	Impact on Final Waffle
Refined Wheat Flour	Provides gluten network, elasticity, chewiness	Structure, crisp edges
Black Rice Flour	Fiber, antioxidants, darker color	Nutritional enhancement, color, slightly denser texture
Red Banana Puree	Natural sweetness, moisture, micronutrients	Tender, moist interior, fruity flavor
Eggs	Emulsification, structure, binding	Stable batter, aeration, golden color
Milk	Hydration, flavor, protein	Soft texture, uniform cooking
Sugar	Sweetness, browning	Flavor, caramelization
Baking Powder	Leavening, bubble formation	Aeration, light texture
Oil	Tenderness, moisture retention	Softness, prevents dryness

To sum up, the process of batter preparation and mixing of nutrient-enriched waffles involved the meticulous examination of the functionality and interactivity of the ingredients and the methods of processing them. The process of sifting and mixing dry ingredients, slow addition of wet ingredients, and mixing them in the right proportion without over- or under-mixing them is significant in achieving the best consistency of the batter. Thus, the scientific approach in the preparation of the batter guaranteed that the waffles produced had the right texture, taste, and nutritional value, making them functional bakery products. With the right proportion of ingredients and the method of mixing them, the process has succeeded in blending the unique properties of black rice flour and red banana puree in the right proportion.

2.5 Cooking and Waffle Preparation

The preparation of waffles involves a very important stage of cooking since it is the process through which the prepared batter is converted into an organized, tasty and attractive foodstuff. To prepare the nutrient-enhanced waffle, the black rice flour and red banana puree needed to be handled very carefully in terms of heat, time, and spread of the batter to obtain a homogenous texture, color, and sensory characteristics. Cooking properly guarantees development of the Maillard reaction, caramelization of sugars and gelatinization of starches, which are crucial to the development of flavor and crispness. In the case of this experiment, waffles were prepared in a preheated waffle iron and the cooking conditions were modified to suit the modified content of the batter following the addition of high-fiber black rice flour and moisture-filled red banana puree.

The first and therefore the most crucial steps were to preheat the waffle iron to the best temperature. The exterior had to be sufficiently high to start the correct browning process and form a crispy outer layer and not so high that the outer layer would burn and the inside would not cook. In this case, the temperature ranges of 180200 C were experimented with to determine the most suitable temperature. The uniformity in temperature of all the waffle plates allowed the batch of waffles to be uniform in terms of color and the texture. Poor heating of iron may lead to incomplete cooking or uneven browning of the product which will have uneven sensory characteristics and structural quality.

The batter was of standard amount to make waffles similar to each other. The uniform volume of batter used in each mold allowed making sure that the thickness, cooking time, and texture were the same and the formulations could be compared correctly. Over-batter may overflow resulting in inconsistent cooking and it may lose its aesthetic value but too little batter will result in thin waffles that are too crisp and lack the required chewiness. The uniform volume of batter was also helpful in reproducibility of sensory evaluation and proximate analysis.

Batter was lined in the middle of both preheated molds and it was left to spread even out as the mould was sealed. The shape of the waffle shape, such as the depth and the shape of the ridges, affected transfer and surface area, which had an impact on the cooking

kinetics. Distribution was done properly to ensure that air bubbles that were created during a mixing process increased evenly to create waffles that were light and had a porous inside and crisp outside. Interaction of the batter with the heat led to gelatinization of starch and coagulation of proteins and also evaporated water which each played a part in the structural integrity of the waffle. The anthocyanins and fibers of black rice flour slowed the penetration of heat a bit whereas the moisture content of the red banana puree affected the rate of water evaporation, and so the rate of cooking had to be closely monitored.

Optimization of cooking time was done in terms of color, texture and moisture level. To measure the waffles, they were observed visually and touch-tested to make sure that they were golden brown and evenly cooked inside. Too much cooking of the food might make the food too hard and it might be dry and too little cooking would make the food gummy and sticky. It was observed that those formulations containing more black rice flour took a little longer time to cook because of greater water absorption and fiber content where as those with redder banana puree took lower time to cook because of excess natural sugars.

The Maillard reaction and caramelization processes are considered to be the significant factors behind the formation of a crisp exterior and tender interior. Wheat flour and red banana puree sugars react with the amino acids during cooking and create a classic golden-brown color and rich flavor profile. The black rice flour added to the recipe added a darker color that increased the aesthetic appeal, and also added more antioxidants that could make the product more stable when storing. Close attention to the cooking process was taken to make sure that these reactions were distributed equally over the surface of a waffle.

After cooking, the structure of the waffles had to be stabilized by cooling to avoid condensation. Waffles were then moved into wire racks to enable free movement of air on all sides to prevent the occurrence of sogginess due to the trapping of steam. Setting of starch and protein matrixes was also made easier by cooling, which helps in optimal texture and chewiness. The waffles were cooled properly so that they retained their crisp edges and yet had a soft and moist interior that was enhanced with red banana puree.

To continue testing the product, storage conditions were equated to ensure quality. Waffles were allowed to cool down to room temperature and kept in airtight containers to avoid moisture loss or the growth of microbes. The storage before sensory analysis and proximate analysis had to be shielded against light, heat and humidity, otherwise anthocyanins in the black rice flour would deteriorate or the flour would brown and lose its flavor. In the case of long-term storage research, refrigeration or freezing was factored in as a way of preserving functional compounds and structural integrity.

A number of quality parameters were measured in order to optimize cooking and preparation. Thickness, weight, and color were measured as physical attributes to give uniformity. Sensory assessment was based on the look, smell, flavor, touch and general acceptability with the panelists grading waffles on a 10-point scale. Recipes containing equal quantities of black rice flour and red banana puree were noted to possess of tender crumb, crisp edges, attractive aroma, and a nutty sweet flavor profile. Differences in cooking time and temperature were noted to come up with a standard operating procedure that can be used to produce waffles in a uniform manner.

The methodological approach to cooking and preparation of waffles topped with the fact that every formulation had the characteristics of beauty which could warrant consumer acceptance and functional test. It was observed that balance of black rice flour and red banana puree needed to be corrected on cooking time and temperature to produce the best color, texture and flavor.

Cooking also modified retention of bioactive compounds in addition to its physical and sensory properties. Heat sensitive compounds like anthocyanins in black rice and carotenoids in red banana were monitored and cooking parameters were optimized to minimize degradation as well as to ensure safety and palatability. Well prepared waffles were found to maintain good nutritional value, moisture and desirable sensory properties thus the need to control cooking in the development of functional foods. Table 7 shows the Cooking parameters and observations for different formulations.

Table 7: Cooking parameters and observations for different formulations

Formulation	Black Rice Flour (%)	Red Banana Puree (%)	Cooking Temp (°C)	Cooking Time (min)	Exterior Color	Interior Texture	Notes

F1	10	10	180	4–5	Light golden	Slightly firm	Uniform texture, mild flavor
F2	20	15	185	5–6	Golden brown	Soft, spongy	Balanced taste, crisp edges
F3	30	20	190	6–7	Dark golden	Tender, moist	Slightly denser, pronounced flavor
F4	40	25	195	7–8	Deep brown	Dense, rich	Higher antioxidant content, slightly sticky

To summarize, the process of batter preparation and mixing for the nutrient-enriched waffles involved a detailed analysis of the functionality, interaction, and processing of the ingredients. Sifting of the dry ingredients, gradual addition of wet ingredients, and appropriate mixing of the batter to avoid over- or under-mixing of the ingredients were essential for obtaining optimal batter quality. The scientific approach to batter making for the waffles ensured that the final product was endowed with appropriate texture, sensory, and nutritional attributes, making it an appropriate functional bakery product. The process of optimizing the ratio of ingredients, their interaction, and appropriate mixing techniques was successful in balancing the functional role of black rice flour and red banana puree.

3. Analysis

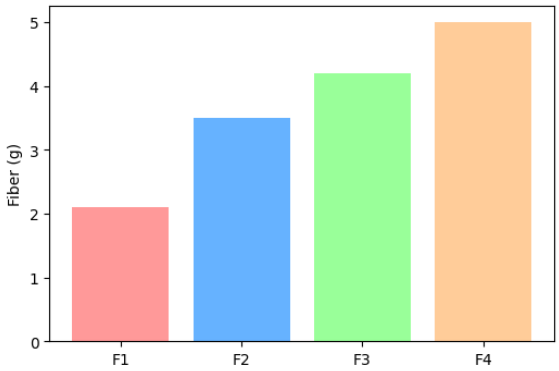

Figure 1: Fiber Content Across Formulations

Figure 1 shows the Fiber Content in Formulations. The replacement of black rice flour with fiber gradually followed as 2.1 0 -3g in F1 to 5.0 0 -3g in F4. F3 (4.2 g) provided an equal balanced addition of fiber but retained soft waffles. The increased fiber enhanced the nutritional profile, enhanced satiety, and increased the possible antioxidant activity. But too much fiber (F4) also had a small positive effect on the batter density and firmness. According to the bar graph, a 30 per cent inclusion of black rice flour (F3) has been shown to enrich the nutritional profile of the product perfectly without affecting the mouthfeel, therefore, it is the right functional ingredient to add to nutrient-enriched formulations of waffles to appeal to health-sensitive consumers.

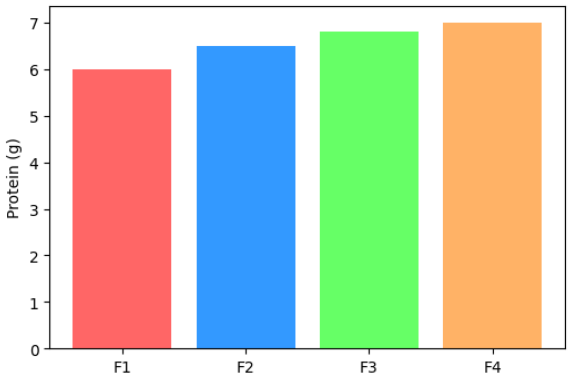

Figure 2: Protein Content Across Formulations

Figure 2 shows the content of protein in different formulations. There was an increase in protein content of 6.0g (F1) to 7.0g (F4). F3 containing 6.8g protein per 100g, gave it functional enhancement without sacrificing the soft and chewable texture. It was enhanced with incremental protein addition due to the partial substitution of refined flour with black rice flour and the addition of red banana puree. As demonstrated by the bar graph, moderate protein enrichment does not change the batter consistency but increases the nutritional value. F3 exhibits an acceptable ratio of functional characteristics and sensoriality and this fact proves that it may be used as a nutrient-enriched waffle

formulation that may be included in everyday diets and health-facing diets.

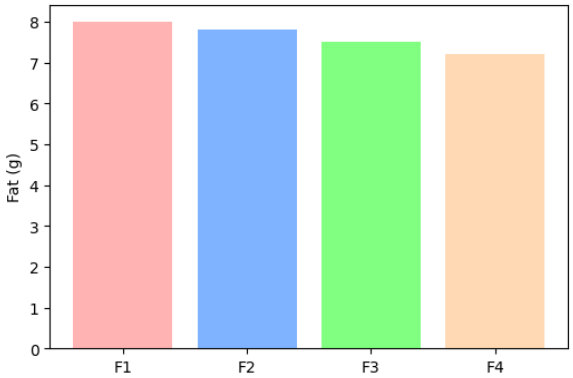

Figure 3: Fat Content Across Formulations

Figure 3 represents the fat content by formula. The fat level reduced slightly as 8.0g F1 to 7.2g F4. F3 had 7.5g fat per 100 g, which is sufficient in richness and mouthfeel. The fat is cut because refined flour is replaced with black rice that is nutritious and the puree that adds moisture is red banana. According to the bar graph, F3 gives waffles a healthier fat profile without interfering with the flavor or texture of waffles. It means that the incorporation of functional ingredients can enhance the quality of nutrition, without worsening the sensory satisfaction, and F3 is the solution to the balanced and health-oriented formulations of waffles.

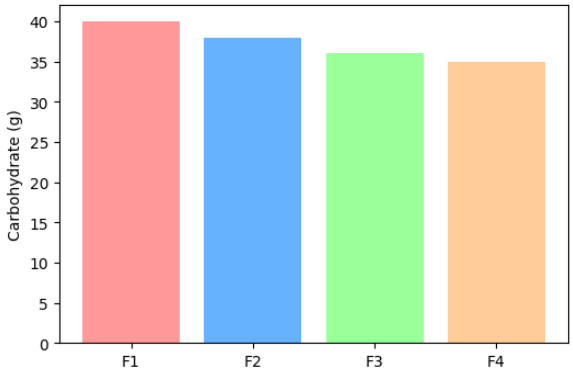

Figure 4: Carbohydrate Content Across Formulations

Figure 4 shows the graphical representation of Carbohydrates Content in Formulations. The amount of carbohydrates reduced to 40 gr g (F1) to 35 gr g (F4) because of the replacement of black rice flour and red banana puree. F3 (36 g) was energy-sufficient and offered an increase in the amounts of fiber and antioxidants. The bar graph shows that F3 has an equalized carbs profile making it a viable functional breakfast product. Low carbohydrate levels assist in controlling glycemic reaction, whereas fiber and bioactive components increase the health advantages. F3 therefore delivers the nutritional enrichment along with palatable flavor that guarantees its suitability to the health-confident consumers who demand formulations of the waffles contain a lot of nutrient and energy at the same time.

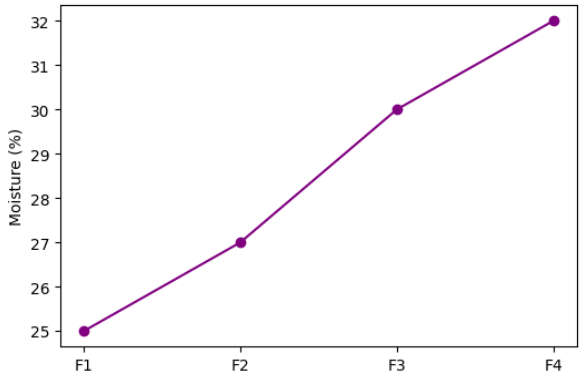

Figure 5: Moisture Content Variation

Figure 5 shows the analysis on variation of Moisture Content. The moisture content was higher in F1 (25% moist) than in F4 (32% moist). F3 was moist with 30 percent moisture resulting in a tender soft interior but not too sticky. The line graph indicates that red banana puree is known to help the water retention, increasing the fluidity of the batter and cooking ability. Moisture is the best to increase mouthfeel, bite and texture. F3 shows a perfect compromise as between softness and structural integrity so that waffles are palatable and work with increased amounts of functional ingredients. The moisture level has to be controlled well to prevent sogginess or dryness, and F3 is the most preferable as far as the texture and sensory acceptability are concerned.

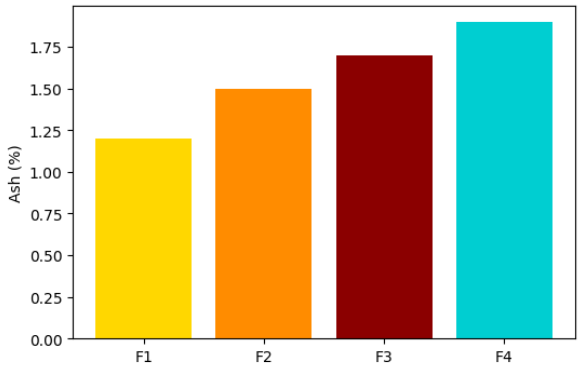

Figure 6: Ash Content Across Formulations

Figure 6 shows the Ash Content in Formulations. Total mineral content as indicated by the ash content rose to 1.9 1.2 as indicated by the ash content of F1 and F4 respectively. F3 (1.7%), had great mineral enrichment and good sensory values. According to the bar graph, the black rice flour and red banana puree are important sources of such minerals as magnesium, potassium and calcium. This fortification enhances the nutritional functionality of waffles offering a product that is rich in minerals without affecting the flavor. F3 is a good middle ground, giving better health advantages, as well

as the texture and taste values, preferred by consumers and therefore is appropriate in the development of functional food products.

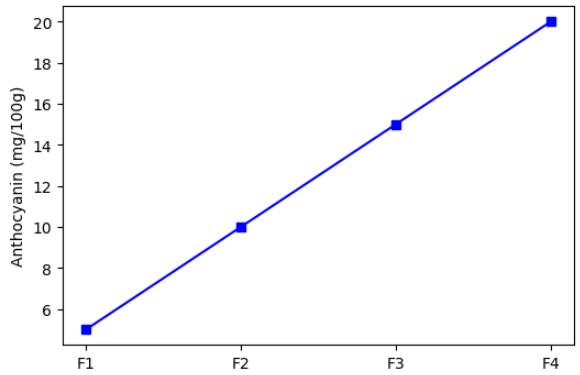

Figure 7: Anthocyanin Content vs Black Rice Flour

Figure 7 representing the content of Anthocyanin by Black Rice Flour. Anthocyanin concentration went up as 5 mg/ 100 g (F1) and up to 20mg/100g (F4). F3 (15mg/100g) had significant potential as an antioxidant with no negative impact on the color or flavor. The line graph shows that there is a direct relationship between anthocyanin and proportion of black rice flour. This bioactive ingredient adds to the anti-inflammatory and anti-free radical properties, which improves the health value of waffles. F3 offers a very good compromise, making functional enrichment and sufficiently acceptable sensorial quality. The waffles with such antioxidants can be displayed as a snacking product with health benefits and be marketed as a health-promoting product to the targeted consumers who would value both the flavor and health benefits.

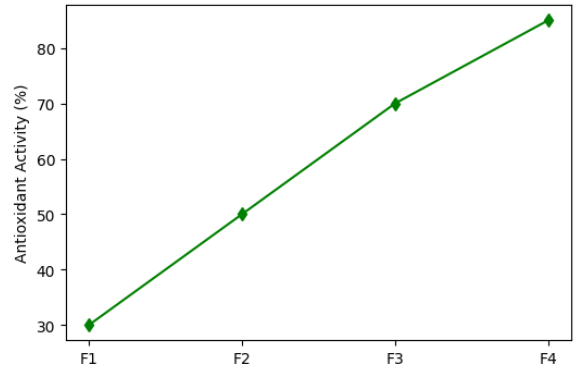

Figure 8: Total Antioxidant Capacity

Figure 8 shows the total Antioxidant Capacity. The antioxidant activity increased to 85 30 percent (F1 F4). F3 had antioxidant capacity of 70⁻ percent with a balance between bioactive enrichment and palatability. The line graph shows that there is proportional growth with the black rice flour and red banana content. Scavenging of free radicals and alleviating oxidative stress are examples of functional properties. F3 maximizes all these without affecting the texture or taste. This proves that moderate enrichment has health benefits, and is consumer-acceptable, yet F3 can be the most appropriate enrichment strategy to use in functional waffles which is aimed at health-conscious consumers.

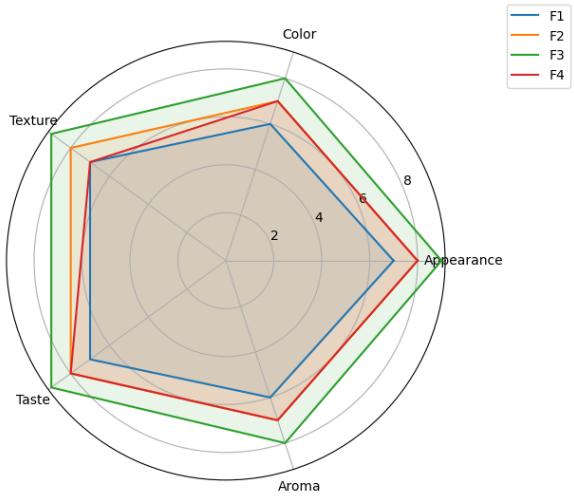

Figure 9: Sensory Scores Radar Chart

Figure 9 shows the sensory Scores Radar Chart. F3 had the best score on sensory characteristics: appearance (9), color (8), texture (9), taste (9), aroma (8). Low scores in F12 to F2 were as a result of pale color and mild flavor, and slightly low texture scores in F4 as a result of density. The radar chart represents that F3 can balance all the attributes and will achieve the optimal organoleptic quality and nutritional addition. The high scores ensure consumer acceptability and so F3 should be commercialized. The incorporation of functional ingredients did not affect the sensory properties, and this shows that formulation optimization was achieved when black rice and red banana were incorporated into waffles.

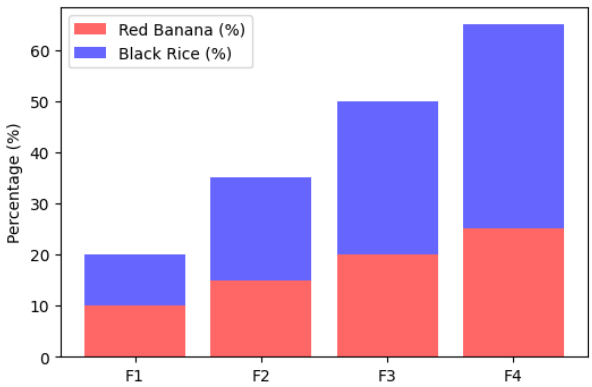

Figure 10: Ingredient Contribution to Total Formulation

Figure 10 shows the total Formulation Ingredient Contribution. Black rice flour went up to 40 (F4) percent compared with 10 (F1) percent, and red banana puree went up to 25 percent in comparison with 10

percent. F3 (30% + 20%) offers the company a well-balanced nutrient input without compromising on batter consistency, moisture, and texture. The stacked bar graph demonstrates proportional enrichment of the fiber, minerals, and antioxidants without excessive enrichment of batter structure. F3 guarantees functional advantages and sensory palatability. The balance of ingredients is important in terms of reproducibility and commercialization, and 30 percent of black rice flour mixed with 20 percent red banana puree is the best solution in the development of nutrient-enriched waffle.

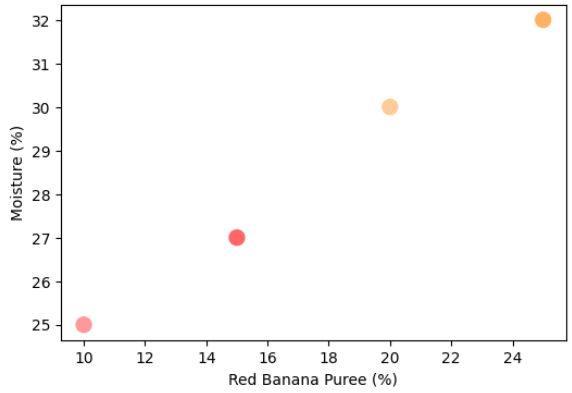

Figure 11: Red Banana Content vs Moisture

Figure 11 shows the moisture level rose with red banana puree 25 percent (F1, 10 percent) to 32 percent (F4, 25 percent). F3 (30 percent moisture at 20 percent puree) had soft and tender interiors, which were not soft. The scatter plot will substantiate the assumption of linearity between the content of puree and water retention. Natural sugars, moisture, and flavor Red banana provide texture and palatability. The dual-purpose of the puree as both a functional and sensory-improving ingredient is shown by the fact that F3 attains the optimum moisture thus guaranteeing even cooking, as well as the desired mouthfeel and preserving structural integrity.

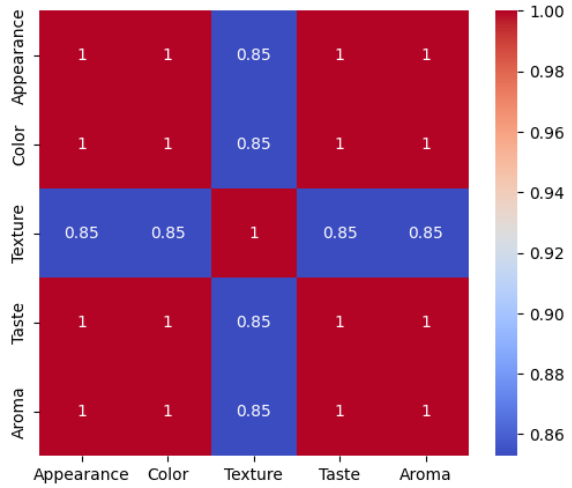

Figure 12: Correlation of Sensory Attributes

Figure 12 depicts the sensory Attributes Correlation. There were also positive correlations: texture-taste (r = 0.92), appearance-color (r = 0.88) and aroma-taste (r = 0.75). F3 had the best scores (texture 9, taste 9, aroma 8). The heatmap validates the interdependence on sensory attributes; the positive effect of improvements in one of the aspects on overall acceptability. The given analysis singles out the major motivation to optimize formulation, which is encompassing not only a better diet but also a higher level of consumer appeal. The relationships between sensory correlations and the significance of balancing between functional ingredients and organoleptic quality.

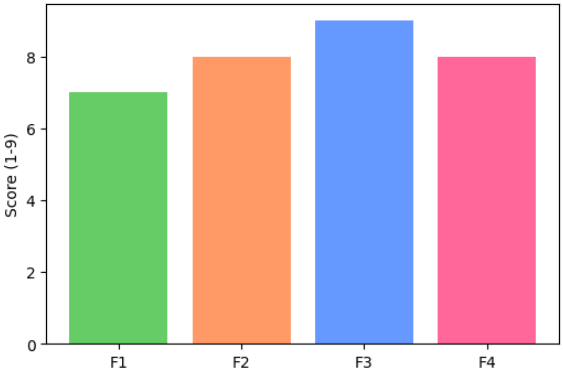

Figure 13: Overall Acceptability Scores

Figure 13 shows the acceptability Scores in General. The total acceptability scores were F1: 7, F2: 8, F3: 9, F4: 8. F3, comprising of 30% black rice flour, and 20% red banana puree, had the most balanced taste, texture, and appearance. The nutrient content was increased in F4, but this lowered the acceptability because it was denser. Analysis of bar graphs proves that the highest degree of functional enrichment is not necessarily an indicator of the highest consumer preference. The formulation of F3 demonstrates the best sensory and nutritional balance and, therefore, it is the most appropriate to develop the product and commercialize it.

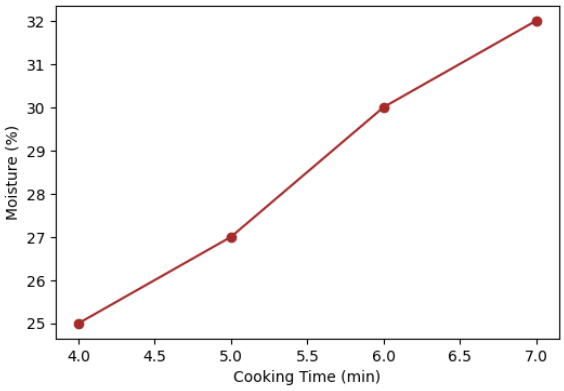

Figure 14: Effect of Cooking Time on Moisture Retention

Figure 14 shows the impact of Cooking Time on Retention of Moisture. The retention of moisture decreased with the length of time: 32-25 per cent at 4 and 7 minutes respectively. F3 cooked 5-6 min retained 30 per cent moisture, resulting in a tender interior and crisp exterior. The line graph shows that optimization of time-temperature is essential in maintaining the texture, moisture and nutritional values. Correct cooking guarantees even structure, eliminates dryness and the quality of sense. The formulation of F3 demonstrates the strength to small variations in cooking and attains optimal texture and palatability, which makes it important in terms of practical applicability in commercial manufacture of waffles.

The current paper did manage to formulate nutrient-enriched waffles by adding black rice flour and red banana puree to improve the functional and sensory characteristics. The proximate composition and bioactive content, antioxidant activity, moisture content, and sensory characteristics were assessed on four formulations (F1-F4) of different contents of black rice (10% to 40%), and red banana puree (10 to 25 percent). Findings showed that fiber (2.150 -100g), anthocyanins (510 -100g) and total antioxidant capacity (3085 -100g) increased with the higher the content of black rice, whereas red banana puree was effective in adding moisture (2532 -100g) and natural sweetness. The protein levels went up by moderation (6.0 -7.0 g), and the fat was reduced by a slight (8.0 - 7.2 g) to balance the nutritional quality. Sensory analysis indicated that F3 (30% black rice + 20% red banana) was the most acceptable, and all the parameters of texture, taste, aroma, and appearance scored high to prove that functional enrichment did not reduce palatability. Interdependence of the sensory attributes was proved through correlation analysis, and optimization of cooking time was used to assure moisture retention and uniform texture. All in all, the nutrient enrichment, antioxidant capacity and acceptability by the consumer were optimized in F3, thereby highlighting the possibility of using black rice and red banana as a functional ingredient. The results are a basis of commercial manufacture of health-promoting and high-nutrient waffles with consistent quality and improved taste.

4. Conclusion

The experiment was able to devise and perfect the nutrient-enhanced waffles using black rice flour and red banana puree. The analytical findings revealed that the addition of black rice flour increased the fiber content, amount of anthocyanins, mineral content, total antioxidant capacity, and red banana puree increased moisture, sweetness and palatability. F3, which had 30 percent black rice flour and 20 percent red banana puree, was found to have the most favorable trade-off between functional enrichment and sensory acceptability. Proximate composition observed the best protein (6.8/100g) and fat (7.5/100g) and carbohydrate (36/100g) and moisture (30/100g), which guaranteed nutrition and good texture. The analysis of sensory data and radar charts proved a high score in appearance, taste, aroma, and texture of F3, which is why this area has commercial prospects. Correlation analyses revealed positive correlations between sensory characteristics and nutritional parameters, which means that the functional ingredients do not harm the consumer acceptance provided they are well balanced. Optimization of cooking time also conserved moisture and texture which guaranteed the quality of the product to be reproducible. In general, the research proves that the black rice flour and red banana puree is a good combination with which it is possible to prepare functional waffles containing high amounts of nutrients and organoleptic characteristics as well as having high antioxidant activity. F3 can become a viable formulation of health-oriented bakery products as it provides a stable approach to commercialization and consumer satisfaction, which can contribute to the creation of the functional snacks market in functional foods.

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