



Research Article

Impact of Soaking and Drying Mango Kernels Flour (*Mangifera Indica*.) on the Physicochemical Properties of Biscuits

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Abstract

The objective of this study was to produce biscuits using composite flours derived from wheat and mango kernels, with the aim of determining their physicochemical characteristics. The mango kernel was soaked and dried in order to produce flour. The flours were produced from both untreated and treated mango kernels. The produced flour was used to substitute wheat flour at varying rates (10%, 20%, 30%, 40%, and 50%). The chemical composition and functional properties of the flours were determined in accordance with the established standard methods. The study's findings revealed that the incorporation of mango kernels resulted in an increase of ash, lipid, fiber, and energy contents within the flour. There was a decline in phenolic compound content, accompanied by an increase in protein content. The water absorption capacity of the flours exhibited an increase with both substitution and treatment, while the oil absorption capacity demonstrated a decrease. The sensory evaluation revealed that biscuits prepared with 10% mango kernels exhibited a sensory score that was comparable to those produced with pure wheat flour. The biscuits containing 10% processed mango kernel flour (FAMT) exhibited the greatest degree of crispness, accompanied by an increase in lipid, ash, and fiber contents, and a reduction in sugars and proteins. The 10% substitution was identified as the optimal solution.

Keywords

Biscuit, Mango Kernel, Composite Flour, Treatment, Sensory Test

1. Introduction

The issue of food security persists as a substantial challenge in numerous developing countries, where the pressing imperative to augment food production in a substantial manner is particularly acute. This is driven by the projected demand of a rapidly expanding population, estimated to reach approximately 9 billion by the

year 2050 [1]. This population shift is driving changes in dietary patterns, characterized by increased consumption of wheat-based products, such as bread and biscuits, across all social strata and age groups in both urban and rural areas [2]. The importation of

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wheat is a costly endeavor with the potential to disrupt the equilibrium of trade for nations where agriculture represents a primary economic activity [3]. Consequently, the rising demand for wheat has led to its use in the production of local flours. Substituting local cereals and tubers for wheat flour has the potential to conserve foreign currency [4]. This approach is a focal point of the Food and Agriculture Organization (FAO), which, in 1964, popularized the term "composite flour" with the objective of promoting research in the domain of local cereals and tubers from the perspectives of technology, economics, and nutrition. Beyond the aforementioned sources of local flour, there are also a number of oilseeds and kernels of certain fruits that can be used for this purpose.

Fruit constitutes a substantial agricultural product in developing countries. Examples of these fruits include bananas, mangoes, and oranges. The current high consumption of these fruits, coupled with the considerable waste they generate, has prompted researchers to investigate methods of transforming fruit waste into either food or non-food by-products [5]. The mango, a tropical fruit, is primarily cultivated for its edible pulp, which is consumed in various forms, including juice, dessert fruit, and nectar [6]. Mango is the eighth most widely cultivated fruit globally, with an annual yield of approximately 43 million tons [7].

In Cameroon, mango is the second most produced fruit after banana, with the majority of production concentrated in the Far North, Littoral, and Centre regions [8]. As Torres-Leon et al. [9] have previously indicated, the kernels constitute a substantial proportion of the fruit, ranging from 20% to 60% of its total weight. The biochemical composition of mango kernels is analogous to that of cereals, with values of 10.06% for protein, 70.12% for carbohydrates, 14.8% for lipids, and 2.40% for fiber [9]. Mango kernels are a valuable source of protein, exhibiting an amino acid profile that encompasses nearly seven essential amino acids, including lysine, which is a limiting amino acid in cereals. Furthermore, the kernels are a substantial source of vitamins, essential fatty acids, and minerals, which are frequently deficient in cereals. This nutritional potential could be a valuable resource for the food sector.

The chemical composition of mango kernels renders them a viable source of raw materials for the formulation of compound flours, which have the potential to be incorporated into a wide range of food products, including biscuits [10, 11]. Numerous studies have demonstrated that defatted mango flour can be incorporated at levels ranging from 25 to 30% in biscuit formulations [11, 12]. The utilization of mango kernel seed oil and the undefatted and defatted mango kernel seed flour has been a focal point of research. However, it is imperative to acknowledge the presence of antinutritional factors, such as

tannins, in mango seed kernels. To address this challenge, the present study sought to examine the composition and characteristics of Cameroonian mango seed kernel flours through the application of soaking and drying. The objective of this study is to investigate the effect of treated kernels mango flour on the final quality of biscuits.

2. Materials and Methods

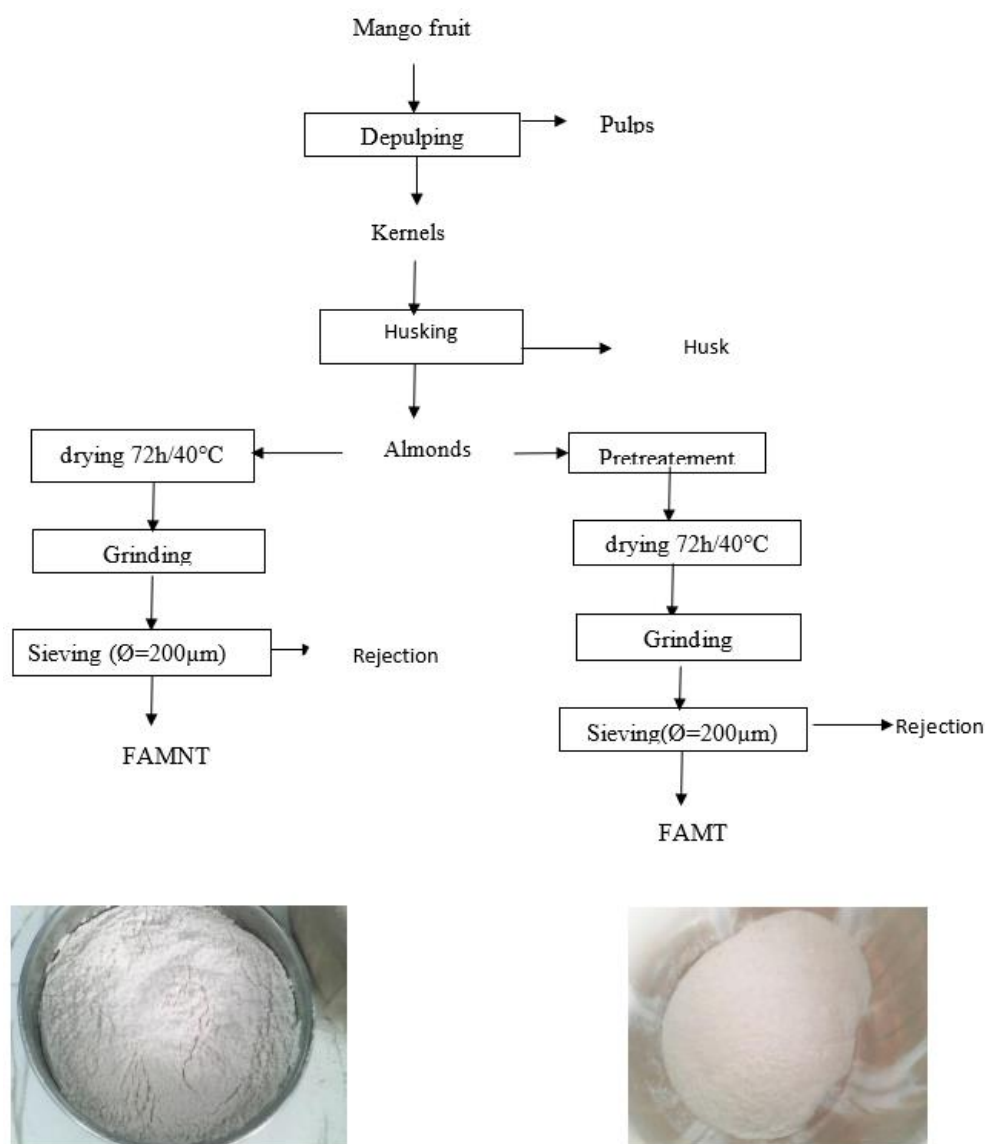
2.1. Materials

The plant material employed in this study is the local mango variety, designated as Tcheodeh. This variety was selected due to its greater regional availability and higher proportion of kernels in comparison to the improved varieties, which are commonly referred to as "grafted mangoes." The fruit samples were obtained at the point of physiological maturity and subsequently consumed in the orchard of the Jacques de Bernon College, located in the Far North region of Cameroon, Diamare department, Maroua 1 district. Subsequently, the specimens were transferred to the Biosciences laboratory of the Institut Supérieur du Sahel for further analysis.

2.2. Production and Physicochemical Properties of Flours

2.2.1. Production of Mango Kernel Flour (*Mangifera Indica* L.)

The mango fruit was obtained at the point of optimal ripeness and edibility. It was then manually pitted using stainless steel knives, and the kernels obtained were divided into two batches. The initial batch was subjected to a 72-hour drying process at 40 °C using a bespoke electric dryer. The second batch was subjected to a 48-hour soaking period at 50 °C, followed by boiling at 100 °C for 30 minutes and subsequent drying under identical conditions as the first batch, in accordance with the modified Legesse and Emire [12] protocol. This was done to remove anti-nutritional factors from the mango kernel flours. The dried mango kernels were subsequently ground using a hammer mill and sieved using 200 µm diameter sieves. The resulting flours were then stored in high-density polyethylene (HDPE) plastics to prevent moisture exchange until such time as they could be analyzed and used. The untreated mango kernel flour was designated "FAMNT," while the pre-treated mango kernel flour was designated "FAMT." The process diagram for the production of mango kernel flour is presented in Figure 1.



FAMNT: Untreated Mango Kernel Flour; FAMT: Treated Mango Kernel Flour.

Figure 1. Mango kernel flour production process.

2.2.2. Characterisation of Mango Kernel Flour, Wheat Flour and Composite Wheat-mango Kernel Flour

(i). Preparation of Composite Wheat-mango Almond Flours

Prior to the characterization of the composite wheat-mango kernel flours, the mango kernel flours were blended with wheat flour. The substitution of wheat flour by mango kernel flour was conducted in accordance with a ratio of 500 grams of flour to be kneaded in increments of ten, with the percentage of mango kernel flour varying between 0%, 10%, 20%, 30%, 40%, and 50% (w/w). The experimental design was formulated using Design Expert 13 (Table 1).

Table 1. Mixture design of wheat and mango kernel flour.

W/W substitution of mixed flour	100/0	90/10	80/20	70/30	60/40	50/50
FAM	0	50	100	150	200	250
FB	500	450	400	350	300	250

W/W substitution of mixed flour	100/0	90/10	80/20	70/30	60/40	50/50
Total (g)	500	500	500	500	500	500

FAM: Mango kernel flours. FB: Wheat flour.

(ii). Determination of the Chemical Composition of Mango Kernel Flour, Wheat Flour and Wheat-mango Kernel Composite Flour

a) Proximate analyses of flour mixtures.

The physicochemical properties of both the untreated and treated mango kernel flour were determined according to the AOAC 2000 method. This encompassed the assessment of moisture content, crude protein (Method 920.87), total lipid (Method 996.06), total ash (Method 972.15), crude fiber (Method 993.21), and total sugars (Zucco et al., 2011).

b) Total phenolic compound and tannin content.

The total phenolic compounds and tannins were determined using the method described by Georgiev et al. [13].

(iii). Evaluation of the Functional Parameters of Flours

The functional properties of flours, including their swelling capacity, water absorption capacity (WAC), and oil absorption capacity (OAC), were determined in accordance with the methodologies outlined by Arepally et al. [14]. The water absorption capacity was calculated as:

$$\text{water absorption capacity, \%} = \frac{\text{Water absorbed (g)}}{\text{Flour weight (g)}} \times 100$$

The oil absorption capacity was calculated as:

$$\text{water absorption capacity, \%} = \frac{\text{Oil absorbed by flour (g)}}{\text{Flour weight (g)}} \times 100$$

The swelling capacity was calculated as:

$$\text{Swelling capacity} = \frac{\text{Sediment weight}}{\text{Dry sample weight} - \text{dried supernatant weight}}$$

2.2.3. Production of Biscuits Based on Composite Wheat-mango Almond Flours and Determination of Their Physical Characteristics

The present study utilized both untreated and treated mango kernel flour, with the wheat flour employed being the BIJOU MAMMY brand, produced by OLAMCAM S. A. in Douala, Cameroon. The margarine used in this study was procured from the Jadida company, and the sugar utilized was produced

by the Societe des Sucres du Cameroun (SOSUCAM). The eggs used in this study were obtained from commercial establishments in Ngaoundere. The iodized salt, marketed under the brand name Diamant Blanc, was obtained from a local market and is produced by SOCAPURSEL S. A. The vanilla used by confectioners is a commercial variety, and the yeast used is a commercially available baking powder.

2.2.4. Production of the Biscuits

In the production of whole wheat/untreated and treated mango kernel flour biscuits, the methodology outlined by Agu et al. [15] was employed.

2.2.5. Physical Characterisation of Biscuits

Subsequent to the fabrication of the biscuits, a series of physical parameters, including mass, thickness, diameter, and expandability, were determined using the method described by Duarte et al. [16].

2.2.6. Sensory Quality and Chemical Composition of Biscuits Made from Composite Wheat-mango Almond Flours

(i). Evaluation of the Sensory Quality of Biscuits

A sensory analysis was conducted in the ENSAI sensory analysis laboratory at the University of Ngaoundere. The sensory analysis included a tasting test, in which thirty individuals participated. The panel comprised 11 women and 19 men, aged between 22 and 28, all of whom were students at the University of Ngaoundere. The panel was presented with a set of eleven biscuits. Of the eleven biscuits, five were produced using untreated composite wheat-mango kernel flour, one was made with treated composite wheat-mango kernel flour, and one was prepared with pure wheat flour, which served as the control. The panelists were tasked with evaluating a series of attributes, including surface color, interior color, surface appearance, texture, taste, flavor, crispness in the mouth, and overall acceptability of the biscuit. In order to assess the relative merits of each sample, panelists were asked to indicate their preferred sample and least preferred sample, providing a rationale for their choice. The scale employed for the assessment ranged from 1 to 9, with 1 representing an extremely unfavorable rating, 2 indicating a very unfavorable rating, 3 signifying an unfavorable rating, 4 denoting a slightly unfavorable rating, 5 indicating a neutral rating, 6 representing a

slightly favorable rating, 7 signifying a favorable rating, 8 indicating a very favorable rating, and 9 reflecting an extremely favorable rating.

(ii). Determination of the Chemical Composition of Biscuits

The content of water, crude protein, sugars, lipids, total ash, crude fiber, phenolic compounds, and the energy value of the biscuits were determined in accordance with the methodologies employed for the chemical composition of the flours.

2.2.7. Statistical Analysis

The results are presented as the mean $\pm$ standard deviation. The statistical analyses were conducted using SPSS software, version 16.0. The analysis of variance (ANOVA) test was employed to facilitate comparisons between multiple means, while the Duncan test was utilized to conduct two-by-two comparisons of means. It is imperative to note that all statistical tests were conducted with a probability level of $P < 0.05$.

3. Results and Discussion

3.1. Different Mango Kernel Flours Produced

The production of mango kernel flour yielded several distinct forms. The untreated mango kernel flour (FAMNT) was observed to be white in color, whereas the treated mango almond flour (FAMT) exhibited a slight brown hue. This discrepancy in coloration can be attributed to the impact of the elevated temperature (100 °C) employed during the thermal treatment of the almond, which prompted non-enzymatic browning reactions, culminating in the formation of brown flours subsequent to drying and grinding.

3.2. Chemical Composition of Mango Kernel Flour, Wheat Flour and Wheat-mango Kernel Composite Flours

Table 2 presents the proximal composition and energy value of mango kernel flour, wheat flour, and wheat-mango kernel composite flours. Wheat flour contains 12.28% water, 0.86% ash, 1.20% total lipids, 73.78% total sugars, 52.70% available sugars, 2.58% soluble sugars, 0.56% crude fiber, and 349.62 kcal of energy. The FAMNT sample contains 8.73% water, 2.79% ash, 7.21% crude protein, 9.94% total lipids, 72.41% total sugars, 67.95% available sugars, 2.39% soluble sugars, 2.06% crude fiber, and 407.97 kcal of energy. The FAMT sample contains 9.02% water, 1.50% ash, 7.67% protein, and 10.68% untreated mango kernel flour (FAMNT). The processed mango kernel flour (FAMT) was found to contain lipids, 71.13% total sugars, 56.54% available sugars, 2.65% soluble sugars, 2.64% fiber, and 411.30% energy.

The ash content of FB (0.86%) exceeds the values reported

by Duarte et al. [16]. This discrepancy may be attributed to the varying extraction rates of the flours employed, as the extraction rate offers insight into the mineral composition and, consequently, the ash content. The crude protein content of wheat flour (10.93%) is lower than that reported by Agu et al. [15], which is 11.87%, but greater than the 10.12% reported by Legesse and Emire [12].

The contents of water, protein, and soluble sugar exhibited a notable decline ($P < 0.05$) with substitution, yet demonstrated an increase with treatment. Conversely, the total ash and available sugar contents demonstrated a significant increase ($P < 0.05$) with substitution, yet a decrease with treatment. The values of the flour lipid, crude fiber, and energy exhibited a significant increase ($P < 0.05$) in response to both substitution and treatment, while the total sugar content demonstrated a significant decrease ($P < 0.05$) in both cases.

The water, ash, fiber, and protein contents reported in this study are consistent with those reported by Legesse and Emire [12]. However, the findings regarding sugar, lipid, and energy contents differ from those reported by the aforementioned authors. Specifically, the former indicated a decrease in these parameters with treatment, which was not observed in the present study.

The water content of foodstuffs is a crucial parameter in the process of food preservation. It is imperative to be cognizant of the water content of flours to ensure their optimal preservation. This necessity arises from the inherent hygroscopic tendency of flours, which necessitates a reduction in water content to varying levels, ranging from 14% to 7%, contingent upon the designated application. The water content of wheat flour (12.28%) was found to be in agreement with that previously reported by Ndangui [17], which was 12.4%. These values are notably higher than those observed for untreated mango kernels and treated mango kernels, which were found to be 8.73% and 9.02%, respectively. A significant decrease was observed with substitution, from 12.24% to 9.65%. These findings suggest that mango kernel flour may be more effective and durable than wheat flour in terms of preservation.

The reduction in ash content observed following treatment can be attributed to the leaching effect of the soluble mineral fractions of the mango kernels into the soaking and boiling water. The observed increase in protein content is consistent with the findings of Legesse and Emire [12], who reported a significant elevation in protein content in mango kernels following soaking and autoclaving. The hypothesis that this increase is due to the elimination of antinutrients, such as tannins, which complex proteins and render them unavailable in FAMNTs, is postulated.

The observed reduction in sugar content can be attributed to two factors: the low sugar content of the kernel and the solubilization of the sugar in water during the soaking and boiling processes. Furthermore, the hydrolysis and solubilization of the amylose may also contribute to this reduction (FAMT). The increase in these parameters observed in composite wheat-mango kernel flours is likely attributable to the inherent lipid, ash, and fiber content of the mango kernel flour. The comparatively lower

sugar and protein contents of the mango kernel flour relative to those of wheat flour suggest that the reduction in these nutrients

when wheat flour is substituted with mango kernel flour is likely attributable to the former's influence.

Table 2. Proximal and energy composition of different flours.

Types of flour	Water (g/100g MF)	Ash (g/100 g DM)	Protein (g/100 g DM)	Fat (g/100 g DM)	Total sugars (g/100 g DM)
FB	12.28 ±0.05e	0.86 ±0.28a	10.93 ±0.18c	1.20 ±0.10a	73.78 ±0.29b
FSNT10	12.24 ±0.45e	1.13 ±0.28ab	10.55 ±0.14bc	1.33 ±0.11a	73.74 ±0.30b
FSNT30	10.86 ±0.11cd	1.52 ±0.27b	10.49 ±0.29bc	3.25 ±0.64b	72.88 ±0.76ab
FSNT50	9.66 ±0.15b	2.76 ±0.28d	10.39 ±0.66b	5.12 ±0.70c	71.22 ±1.35a
FAMNT	8.73 ±1.02a	2.79 ±0.44d	7.21 ±0.16a	9.94 ±0.18d	72.41 ±0.68ab
FST10	11.41 ±0.36d	0.75 ±0.16a	10.88 ±0.29bc	1.89 ±0.09a	73.69 ±0.05b
FST30	11.04 ±0.30cd	1.47 ±0.11b	10.82 ±0.17bc	3.59 ±0.19b	71.76 ±0.27a
FST50	10.41 ±0.16 c	2.14 ±0.59c	10.76 ±0.17bc	5.19 ±0.38c	71.40 ±1.94a
FAMT	9.02 ±0.37ab	1.50 ±0.29b	7.67 ±0.03a	10.68 ±0.70a	71.13 ±0.96a

Types of flour	available sugar (g/100 g DM)	Soluble sugars (g/100 g DM)	Crude fiber (g/100 g DM)	Energy (Kcal/100g DM)
FB	52.70 ±0.49a	2.58 ±0.23ef	0.57 ±0.00a	349.62 ±1.75a
FSNT10	54.57 ±0.49ab	1.43 ±0.09c	0.95 ±0.16ab	349.10 ±2.63a
FSNT30	66.06 ±2.59d	1.22 ±0.05b	1.69 ±0.00bc	362.75 ±3.08b
FSNT50	66.11 ±1.93d	0.88 ±0.03a	1.84 ±0.16bc	372.38 ±7.21c
FAMNT	67.95 ±2.09d	2.39 ±0.12de	2.06 ±0.04c	407.97 ±1.60d
FST10	60.80 ±0.49c	2.25 ±0.09d	1.79 ±0.65bc	355.24 ±1.99ab
FST30	60.53 ±2.81c	1.43 ±0.08c	2.13 ±1.28c	362.56 ±0.99b
FST50	67.25 ±2.06d	1.00 ±0.12a	2.60 ±0.04c	375.35 ±8.86c
FAMT	56.54 ±0.61b	2.65 ±0.01f	2.64 ±0.45c	411.30 ±2.52d

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$).

MF: Fresh Matter DM: Dry Matter; FB: Wheat Flour; FSNT10: Flour substituted with 10% Untreated Mango kernel flour; FSNT30: Flour substituted with 30% Untreated Mango kernel flour; FSNT50: Flour substituted with 50% Untreated Mango kernel flour; FAMNT: Untreated Mango kernel flour. FST10: Flour substituted with 10% Processed Mango Kernel; FST30: Flour substituted with 30% Processed Mango Kernel; FST50: Flour substituted with 50% Processed Mango Kernel; FAMT: Mango Kernel Flour Processed by boiling soaking (soaked at 50 °C for 48h; boiled at 100 °C/30min and dried at 40 °C/72h in an electric dryer).

The total phenolic compound and tannin contents of the mango kernel flour, wheat flour, and wheat–mango kernel composite flours are variable (Table 3). The data in the table demonstrate that the total phenolic compound and tannin contents exhibited notable variation ($P < 0.05$) in response to the degree of substitution and the treatment applied. The concentration of phenolic compounds in the flours exhibited a positive correlation with increasing substitution and a negative correlation with increasing treatment. The phenolic compound content of FB was found to be 0.19%, with a tannin content of 0.10%. The contents of phenolic compounds and tannins in

mango kernel flours were found to be significantly ($P < 0.05$) greater than those of flours. Furthermore, the contents of phenolic compounds (7.56%) and tannins (6.14%) in FAMNT were found to be significantly higher ($P < 0.05$) compared to those in FAMT (5.10% for phenolic compounds and 3.52% for tannins). A significant decrease ($P < 0.05$) in these parameters was observed with treatment. These findings contradict those reported by Legesse and Emire [12] (2012), who, following the treatment of mango kernels, demonstrated that tannins could only be present in trace amounts. However, Dakare

et al. [18] reported that tannins cannot be completely eliminated by various treatments. The significantly higher phenolic compound and tannin contents of mango almond flour compared to wheat flour suggest that mango almond flour may be a contributing factor to the observed increase in phenolic compounds and tannins in the wheat–mango almond composite flour. Tannins are classified into two categories: hydrolysis-resistant condensed tannins and easily hydrolysable water-soluble tannins. The objective of the study was to eliminate as many tannins as possible. The residual tannin levels in the flours imply that they are condensed tannins. Alternatively, these levels could be attributable to the efficacy of the treatments, which vary on both sides, or to the mango varieties, which are known to be more tannin-rich.

Table 3. Phenolic compounds in different flours (g/100g DM).

Type of flour	Total phenolic compounds	Tannins
FB	0,19 ± 0,01a	0,10 ± 0,01a
FSNT10	1,55 ± 0,11c	0,93 ± 0,10c
FSNT30	2,16 ± 0,06d	1,64 ± 0,05d
FSNT50	3,35 ± 0,12f	2,68 ± 0,12e
FAMNT	7,56 ± 0,30h	6,14 ± 0,30g
FST10	0,96 ± 0,09b	0,57 ± 0,06b
FST30	1,96 ± 0,10d	1,77 ± 0,08d
FST50	2,85 ± 0,28e	2,47 ± 0,26e
FAMT	5,10 ± 0,22g	3,52 ± 0,21

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$).

DM: Dry Matter; FB: Wheat Flour; FSNT10: Flour substituted with 10% Untreated Mango Kernel; FSNT30: Flour substituted with 30% Untreated Mango Kernel; FSNT50: Flour substituted with 50% Untreated Mango Kernel; FAMNT: Untreated Mango Kernel Flour; FST10: Flour substituted with 10% Processed Mango Kernel; FST30: Flour substituted with 30% Processed Mango Kernel; FST50: Flour substituted with 50% Processed Mango Kernel; FAMT: Mango Kernel Flour Processed by boiling soaking (soaked at 50 °C for 48h; boiled at 100 °C/30min and dried at 40 °C/72h in an electric dryer).

3.3. Functional Properties of the Flours

Statistically significant ($P < 0.05$) disparities were identified in the bulk density, WACa, WACr, EA, and SI of the flours. Conversely, no statistically significant ($P > 0.05$) disparities were observed in the OAC (Table 4). The bulk density of FB (0.60 g/ml) was found to be significantly ($P < 0.05$) greater than that of FAMNT (0.58 g/ml), yet significantly ($P < 0.05$) lower than that of FAMT (0.66 g/ml).

The substitution of FB with NTAMF resulted in a notable

reduction in bulk density, while the use of NTAMF led to a considerable increase in this parameter ($P < 0.05$). These findings are consistent with those reported by Legesse and Emire [12], who observed an increase in the bulk density of wheat–almond composite flours from treated mango. The observed decrease in density for the flours composed of wheat and untreated mango kernels is consistent with the findings of Duarte et al. [16], who reported that the substitution of wheat flour with local flour could result in a reduction in density.

It was observed that the apparent and real water absorption capacities of the flours exhibited a notable increase ($P < 0.05$) with the progression of substitution and treatment. For wheat, the WACa (75%) and WACr (121.52%) were found to be significantly lower than those of FAMNT and FAMT, which were 147.33% and 252%, respectively, for WACa and 235.33% and 327.39%, respectively, for WACr. These findings are consistent with those reported by Himeda et al. [19], who observed an increase in WAC with elevated substitution rates in composite flours comprising wheat flour and white taro flour. The observed increase in WAC is hypothesized to be attributable to the presence of hydrophilic carbohydrates and protein functional groups in the flour, which are likely to form hydrogen bonds with water. The water absorption capacity (WAC) is contingent upon the affinity of the flour for water. Affinity for water has been demonstrated to be positively correlated with WAC. This phenomenon was observed in the present study with FAMT. During the boiling process, the starch in the flour underwent gelatinization, resulting in a change in its conformation and the availability of hydroxyl groups capable of forming hydrogen bonds with water. The high fiber content of mango kernel flour suggests that the absorption of water by the fibers is the primary factor contributing to the observed increase in the WAC of the composite flours. An additional hypothesis is that the removal of antinutrients may have resulted in the exposure of certain proteins with functional groups capable of forming hydrogen bonds with water. The capacity to absorb water is a crucial property of flours employed in pastry production. This property enables pastry chefs to incorporate a substantial quantity of water into the dough, facilitating its manipulation and preserving the freshness of the finished products.

The oil absorption capacity of the flours exhibited no statistically significant difference ($P > 0.05$). The OAC of FB (92.37%) was not found to be significantly greater than that of FAMNT (88.85%) and FAMT (87.27%) ($P > 0.05$). However, a decline in OAC was observed with increasing substitution and treatment levels. These findings are consistent with those reported by Himeda et al. [19], who observed a correlation between a reduction in oil absorption capacity (OAC) and a decline in flour protein content. The present study's findings support this correlation, demonstrating a decline in protein content of the flours concomitant with the introduction of substitutions. The variation in oil absorption capacity observed in flours is also associated with the presence of non-polar chains. The results of this study suggest that the processing of mango

kernels may have led to the presence of polar chains in FAMT, which could account for the relatively low OAC observed in FAMT. This property is of particular significance in the context of biscuit production, given its role in determining the quality of the final product. The substitution of wheat flour at a high rate, therefore, has the potential to adversely affect the characteristics of biscuits, as oil is a crucial precursor of biscuit flavor and taste.

The emulsifying activity of the flours utilized in this study exhibited a significant decline ($P < 0.05$) with substitution, yet demonstrated an increase with treatment. The respective values are 12.57% for FB, 7.37% for FAMNT, and 7.46% for FAMT. The incorporation of mango kernel meal resulted in a statistically significant reduction ($P < 0.05$) in the AE. However, the findings indicate that flours derived from treated mango kernels display enhanced emulsifying capabilities compared to those derived from untreated mango kernels. Legesse and Emire [12] previously observed, the EA of flours increases in conjunction with an increase in protein content and decreases in response to an increase in fibre content. This phenomenon could provide a plausible explanation for the ob-

servations made in this study, where a decrease in protein content was noted with substitution and an increase in fiber content was observed with treatment. It can be hypothesized that the significantly elevated AE in flours derived from treated mango kernels, as compared to those produced from untreated kernels, can be attributed to the augmented protein content resulting from the treatment process.

The solubility index of the flours demonstrated a significant variation ($P < 0.05$) in response to substitution and treatment. The respective values are 22.06% for FB, 27.78% for FAMNT, and 18.93% for FAMT. The SI exhibited an increase with the incorporation of FAMT and a decrease with that of FAMT. These findings contradict the results reported by Himeda et al. [19], who demonstrated that an increase in the SI could be attributed to starch cooking in water, which would induce gelatinization and solubilization of the amylose, thus increasing the soluble fraction of the flour. In this instance, however, the SI was observed to decrease with boiling. This observation suggests that the process of boiling water may have induced hydrolysis and leaching of the soluble matter. This outcome suggests that the incorporation of FAMT into wheat flour leads to a reduction in the solubility index.

Table 4. Effect of treatment on functional properties of different flours.

Type of flour	BD (g/ml)	WACa (g/100g)	WACr (g/100g)	OAC (g/100g)	EA (V/V)	SI (g/g)
FB	0,60 ±0,00 ^b	75,00 ±4,00 ^a	121,52 ±4,39 ^a	92,37 ±4,36 ^a	12,56 ±1,32 ^c	22,06 ±0,49 ^b
FSNT10	0,60 ±0,01 ^b	87,00 ±9,00 ^{ab}	148,71 ±8,86 ^b	92,19 ±2,49 ^a	11,57 ±0,80 ^{bc}	22,55 ±0,98 ^{bc}
FSNT30	0,60 ±0,00 ^b	117,33 ±6,50 ^c	178,84 ±9,09 ^c	86,99 ±4,81 ^a	10,00 ±1,42 ^b	24,68 ±0,44 ^{cd}
FSNT50	0,58 ±0,00 ^a	135,00 ±3,00 ^d	188,94 ±2,04 ^c	88,04 ±3,80 ^a	9,50 ±1,60 ^{ab}	25,38 ±0,60 ^{de}
FAMNT	0,58 ±0,01 ^a	147,33 ±2,30 ^e	235,83 ±7,04 ^d	88,85 ±9,26 ^a	7,37 ±0,57 ^a	27,78 ±1,49 ^e
FST10	0,64 ±0,00 ^c	92,33 ±2,88 ^b	134,64 ±4,21 ^{ab}	92,32 ±6,00 ^a	12,46 ±0,87 ^c	20,96 ±2,61 ^{ab}
FST30	0,65 ±0,00 ^{cd}	140,00 ±3,00 ^{de}	190,54 ±11,58 ^c	86,27 ±1,18 ^a	10,81 ±0,81 ^{bc}	19,37 ±2,19 ^a
FST50	0,66 ±0,01 ^d	185,33 ±8,05 ^f	246,88 ±18,02 ^d	85,77 ±3,65 ^a	9,87 ±2,30 ^b	19,14 ±0,04 ^a
FAMT	0,66 ±0 ^d	256,00 ±9,64 ^g	327,39 ±17,75 ^e	87,27 ±2,84 ^a	7,46 ±0,83 ^a	18,93 ±1,45 ^a

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$).

BD, bulk density; WACa: apparent water absorption capacity; WACr: real water absorption capacity; OAC, oil absorption capacity; EA Emulsion Activity; FB: wheat flour; FSNT10: Flour substituted with 10% Untreated Mango Kernel; FSNT30: Flour substituted with 30% Untreated Mango Kernel; FSNT50: Flour substituted with 50% Untreated Mango Kernel; FAMNT: Untreated Mango Kernel Flour. FST10: Flour substituted with 10% Processed Mango Kernel; FST30: Flour substituted with 30% Processed Mango Kernel; FST50: Flour substituted with 50% Processed Mango Kernel; FAMT: Mango Kernel Flour Processed by boiling soaking (soaked at 50 °C for 48h; boiled at 100 °C/30min and dried at 40 °C/72h in an electric dryer). SI: solubility index.

3.4. Physical Characteristics of Biscuits

Figure 2 show the image of biscuits made with mango kernel and wheat flours. The production of biscuits entails the amalgamation of wheat flour with a composite wheat-mango almond flour

(*Mangifera indica* L.). The manufacturing process utilized unprocessed mango wheat almond flour. It is evident that as the proportion of mango wheat almond flour is augmented in the biscuit recipe, the volume of the biscuits is diminished, and the color of the biscuits made with wheat flour and FAMNT becomes more intense than that of the biscuits made with wheat flour and FAMT.

Table 5. Effect of treatment of the mango kernel flour on physical characteristics of the various biscuits.

Types of biscuit	mass (g)	diameter (mm)	thickness (mm)	Expansibility
BFB	29,47±0,98 ^d	62,95±1,64 ^c	19,32±0,46 ^d	3,26±0,16 ^a
BSNT10	20,33±0,05 ^{bc}	56,35±0,93 ^{ab}	18,30±1,43 ^d	3,09±0,26 ^a
BSNT30	18,20±1,60 ^a	56,08±0,69 ^{ab}	11,53±0,01 ^b	4,86±0,06 ^c
BSNT50	18,10±0,30 ^a	55,67±0,18 ^{ab}	9,65±0,016 ^a	5,77±0,10 ^d
BST10	21,23±0,25 ^c	55,89±0,25 ^{ab}	14,39±0,19 ^c	3,88±0,05 ^b
BST30	19,73±1,19 ^{abc}	54,67±0,08 ^{ab}	14,13±0,32 ^c	3,87±0,08 ^b
BST50	18,97±0,61 ^{ab}	54,50±1,29 ^a	9,76±0,86 ^a	5,61±0,42 ^d

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$). BFB : Wheat Biscuit ; BSNT10 : Biscuit substituted with 10% Untreated Mango kernel flour ; BSNT30 : Biscuit substituted with 30% Untreated Mango kernel flour ; BSNT50 : Biscuit substituted with 50% Untreated Mango kernel flour ; BST10 : Biscuit substituted with 10% Processed Mango kernel flour ; BST30 : Biscuit substituted with 30% Processed Mango kernel flour ; BST50 : Biscuit substituted with 50% Processed Mango kernel flour.

The physical characteristics of the biscuits manufactured from composite wheat, mango, and almond flours is shown in Table 5. The physical parameters measured in the biscuits were statistically significant ($P < 0.05$). The substitution resulted in a reduction of biscuit mass, diameter, and thickness, while expandability increased. In contrast, the treatment resulted in an increase in biscuit mass and expandability, while thickness and diameter were reduced. The wheat flour biscuits had a mass of 29.47 g, a diameter of 62.95 mm, a thickness of 19.32 mm, and an expandability of 3.26%. The incorporation of mango almond flour led to a substantial decrease in biscuit mass, diameter, and thickness, while expandability exhibited a significant increase. These results are consistent with those reported by Ashoush and Gadallah [20], but contradict the findings of Legesse and Emire [12]. The latter researchers demonstrated that the width, thickness, and expandability of biscuits increase with the rate of incorporation of mango kernels. The reduction in biscuit mass with increasing incorporation rate can be attributed to the density of the composite flours. Density, defined as the weight of a specific volume of flour, is a pivotal factor in this study. The density of FB, which is 0.60 g/ml in this study, decreases with the incorporation of NTAMFs (0.60 to 0.58 g/ml) and increases with LTAMFs (0.60 to 0.66 g/ml). This phenomenon could provide a rationale for the observed discrepancy in biscuit mass between those composed of NTAMFs and those composed of LTAMFs.

The observed reduction in the thickness of biscuits made with wheat-mango almond flours can be attributed to a decline in gluten levels. Gluten, a protein, plays a crucial role in retaining gas within the dough. Its presence is essential for enabling the dough to rise and attain the requisite strength to prevent gas escape. The capacity of a dough to retain gas is contingent upon the gluten network, as demonstrated in prior studies. Consequently, the substitution of ingredients results in a reduction in protein content, which subsequently diminishes the strength of the dough.

It is hypothesized that the enhanced expandability of biscuits produced using composite flours can be attributed to the functional properties of the resulting flours. The expandability of biscuits is influenced by the competition between the ingredients for water. Akubor and Badifu [21] observed that the expandability of biscuits produced from composite flours (comprising wheat and *Treculia africana*) exhibited a slight increase in line with the rate of substitution of wheat flour. The same authors reported that the water absorption capacity of the flour increased considerably with the incorporation of *Treculia africana* flour.



Biscuits made with untreated wheat mango kernel flour.



Biscuits made with processed mango kernel wheat flour.

Figure 2. Biscuits made with mango kernel wheat flours.

3.5. Sensory Analysis and Chemical Composition of Biscuits

Figure 3 illustrates the findings of the sensory evaluation conducted on the biscuits. The biscuits containing 10% of the substitute were found to be more similar to the FB-based biscuit and exhibited notable differences in surface color, interior

color, texture, and flavor. With regard to the parameter of crispness, the 10% FAMT biscuit attained a score (8.36) that was not significantly ($P > 0.05$) higher than that of the FB-based biscuit (8.06). Regarding the parameters of taste, flavor, and general acceptability, biscuits produced with 10% FAMT, 10% FAMT and FB-based ingredients did not demonstrate statistically significant differences ($P > 0.05$). These findings contrast with those reported by Legesse and Emire [12], who, in a study conducted in Ethiopia, obtained the highest score of 30% for general acceptability by substituting wheat flour with FAMT. These discrepancies can be attributed to the variety of mango utilized, the specific recipes employed, and even the

treatments applied. The reduction in the taste score with the substitution of ingredients can be attributed to the presence of tannins in the flours, which were not fully removed.

The astringency of the ingredient in question would have exerted a significant influence on the sensory profile of the product. The observed coloration could be ascribed to the elevated phenolic compound content. Indeed, upon removal of the biscuits from the oven and subsequent observation, it was noted that the biscuits produced with FAMNT were darker in color. In a related study, Legesse and Emire [12] reported that the incorporation of mango almond flour into FB could lead to the development of dark coloration.

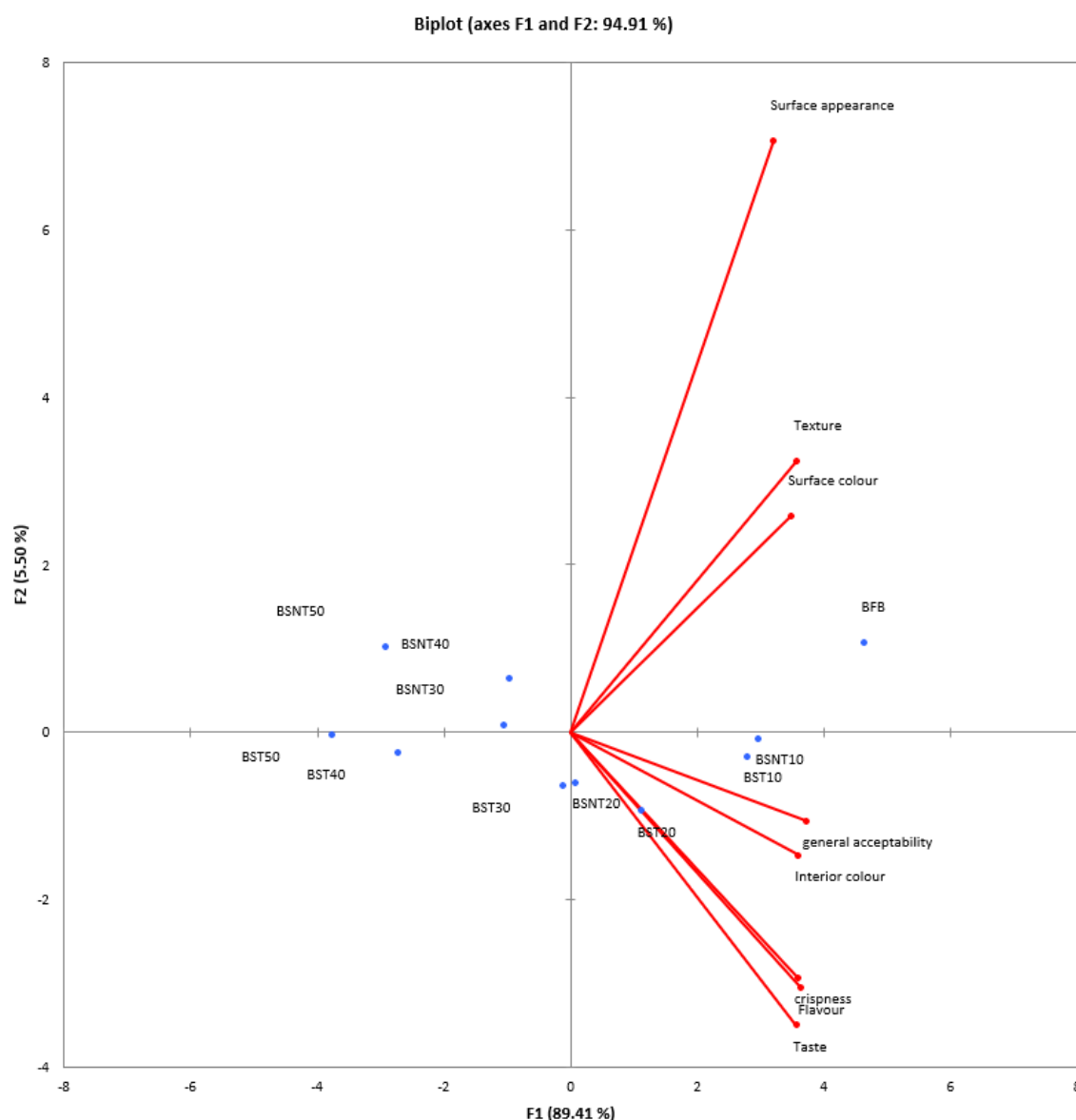


Figure 3. Effect of treatment of the mango kernel flour on the sensory analysis of different biscuits.

BFB: Wheat Biscuit; BSNT10: Biscuit substituted with 10% Untreated Mango kernel flour; BSNT30: Biscuit substituted with 30% Untreated Mango Almond; BSNT50: Biscuit substituted with 50% Untreated Mango Almond; BST10: Biscuit substituted with 10% Processed Mango Almond; BST30: Biscuit substituted with 30% Processed Mango Almond; BST50: Biscuit substituted with 50% Processed Mango Almond.

3.6. Chemical Composition of Biscuits

Table 6 illustrates the proximal composition and energy values of biscuits produced using wheat–mango almond composite flours. A significant variation ($P < 0.05$) was observed between the different biscuit parameters. The data presented in the table demonstrate that the water, ash, lipid, soluble sugar, and fiber contents of the biscuits exhibited a significant increase ($P < 0.05$) with substitution, whereas the protein, total sugar, available sugar, and energy contents demonstrated a significant decrease ($P < 0.05$) with substitution. Conversely, the treatment resulted in a reduction in the total sugar, energy, and ash content. Conversely, the protein, lipid, available sugar, soluble sugar, and fiber contents exhibited an increase. The observed variation in water, sugar, ash, lipid, fiber, and energy contents is consistent with the findings of Aleem Zaker et al. [22] who incorporated defatted soy flour into biscuit manufacturing. However, the aforementioned authors reported a markedly elevated protein content, which they attributed to the soy, which is a natural source of protein.

The analysis of the biscuits produced using FB revealed the following composition: 8.80% water, 1% ash, 10.11% protein, 12.69% fat, 70.37% total sugars, 0.70% soluble sugars, 0.68% fiber, and 436.10 kcal of energy. The incorporation of mango almond flour resulted in a significant increase in water content, reaching a maximum value of 11.16% at 50% FAMT. The underlying hypothesis suggests that this increase can be attributed to the water absorption capacity of the utilized flours. The functional properties of the flours employed in this study demonstrated that, in comparison with FB, FAMT exhibits a markedly elevated capacity for water absorption. This observation may provide a rationale for the observed increase in water content. Water content is a pivotal factor in food preservation, and the incorporation of a substantial quantity of mango almond flour may potentially have a deleterious effect on biscuit preservation.

The ash content exhibited an increase from 1% to 2.02% in the biscuits produced using the FAMT ingredient, and from 1% to 1.45% in those produced using the FAMT ingredient. This phenomenon can be attributed to the fact that mango kernel flour is a rich source of minerals, which are the primary components of ash. The low ash content observed in the FAMT-based biscuits can be attributed to the leaching of the soluble

mineral fraction from the flours, as previously discussed in the context of their chemical composition. It is noteworthy that this ash content serves as an indicator of the mineral richness of the biscuits in question. The decrease in protein content is due to the naturally low protein levels in mango almond flour. However, the observed increase can be attributed to the continuous elimination of antinutrients under the elevated baking temperatures that are characteristic of biscuit production. At a FAMT level of 10%, the protein content of the biscuits was not found to be significantly higher than that of the control biscuits. Conversely, the lipid content exhibited an increase, reaching a plateau at 50% incorporation, with a content of 14.63%. This increase can be attributed to the flour used, which is inherently rich in lipids. The incorporation of this flour into the margarine utilized in the recipe resulted in an overall increase in the biscuit's lipid content.

The total sugar content was observed to decrease, while the soluble sugar content was noted to increase. The reduction in sugar content is believed to occur concurrently with that of proteins, which are implicated in non-enzymatic browning reactions and contribute to the brown color of biscuits. The hypothesis that the increase in soluble sugars is due to the addition of sugars during the manufacturing of the biscuits is postulated. The observed increase in fiber content can be attributed to the high fiber content of the mango kernel flour utilized in the manufacturing process, which is known to increase during the processing of the kernels. The energy value of the biscuits manufactured (418.98–436.10 kcal/100 g) is approximately equivalent to one-fifth of the daily energy requirement (200–2500 kcal/day). These findings contrast with those reported by Legesse and Emire [12], who observed no variation in the sugar, water, and energy values of biscuits made with mango kernel flours in Ethiopia as the substitution level increased.

It is noteworthy that at 10% substitution, the proximal and energy compositions of the biscuits were found to be similar to those of the control. The ash content of the biscuits, which represents the mineral, lipid, soluble sugar, available sugar, and fiber content, was greater than that of the control biscuits at this level of incorporation. Additionally, it was observed that the protein content of the biscuits fortified with 10% FAMT was higher than that of the control.

Table 6. Effect of treatment of the mango kernel flour on the proximal and energy composition of the various biscuits.

Types of flour	Water (g/100g MF)	Ash (g/100 g DM)	Protein (g/100 g DM)	Fat (g/100 g DM)	Total sugars (g/100 g DM)	Available sugars (g/100 g DM)	Soluble sugars (g/100 g DM)	Crude fibre (g/100g DM)	Energy (Kcal/100g DM)
BFB	8,80±0,28 ^a	1,00±0,41 ^a	10,11±0,49 ^d	12,69±0,06 ^a	70,37±3,54 ^c	21,56±1,24 ^{abc}	0,70±0,07 ^a	0,68±0,41 ^a	436,10±13,09 ^c
BSNT10	8,64±0,13 ^a	1,28±0,57 ^{ab}	7,81±0,00 ^b	13,25±0,17 ^b	68,86±0,71 ^b	22,12±1,15 ^{bc}	0,71±0,04 ^a	0,82±0,27 ^a	425,94±1,73 ^{abc}

Types of flour	Water (g/100g MF)	Ash (g/100 g DM)	Protein (g/100 g DM)	Fat (g/100 g DM)	Total sugars (g/100 g DM)	Available sugars (g/100 g DM)	Soluble sugars (g/100 g DM)	Crude fibre (g/100g DM)	Energy (Kcal/100g DM)
BSNT30	9,92 ±1,22 ^{ab}	1,28 ±0,66 ^{ab}	6,45 ±0,25 ^a	14,19 ±0,10 ^c	68,16 ±0,99 ^{ab}	19,81 ±0,59 ^{ab}	0,82 ±0,07 ^a	0,83 ±0,00 ^a	426,18 ±2,21 ^{abc}
BSNT50	10,02 ±1,92 ^{ab}	2,02 ±0,13 ^b	6,38 ±0,12 ^a	14,63 ±0,13 ^d	66,94 ±0,07 ^{ab}	18,39 ±3,63 ^a	0,95 ±0,37 ^a	1,11 ±0,00 ^{ab}	424,98 ±1,11 ^{ab}
BST10	9,47 ±0,25 ^{ab}	0,92 ±0,41 ^a	10,17 ±0,31 ^d	13,08 ±0,29 ^{ab}	66,56 ±0,26 ^{ab}	25,89 ±1,17 ^d	0,99 ±0,32 ^a	0,96 ±0,41 ^{ab}	424,64 ±0,69 ^{ab}
BST30	9,49 ±0,26 ^{ab}	1,01 ±0,42 ^a	9,46 ±0,15 ^c	14,64 ±0,36 ^d	65,83 ±0,18 ^a	25,77 ±0,80 ^d	1,89 ±0,02 ^b	1,10 ±0,55 ^{ab}	432,09 ±2,76 ^{bc}
BST50	11,16 ±0,01 ^b	1,45 ±0,12 ^{ab}	6,37 ±0,09 ^a	14,63 ±0,32 ^d	65,39 ±0,69 ^a	24,92 ±1,96 ^{cd}	1,85 ±0,13 ^b	1,54 ±0,42 ^b	418,78 ±3,95 ^a

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$).

MF: Fresh Matter DM: Dry Matter; BFB: Wheat Biscuit; BSNT10: Biscuit substituted with 10% Untreated Mango Almond; BSNT30: Biscuit substituted with 30% Untreated Mango Almond; BSNT50: Biscuit substituted with 50% Untreated Mango Almond; BST10: Biscuit substituted with 10% Treated Mango Almond; BST30: Biscuit substituted with 30% Treated Mango Almond; BST50: Biscuit substituted with 50% Treated Mango Almond.

Table 7. Effect of treatment of the mango kernel flour on phenolic compounds in different biscuits (g/100g DM).

Type of flour	Total phenolic compounds	Tannins
BFB	0,08 ±0,00 ^a	0,07 ±0,00 ^a
BSNT10	0,93 ±0,33 ^c	0,81 ±0,35 ^b
BSNT30	1,38 ±0,03 ^d	1,00 ±0,063 ^{bc}
BSNT50	2,20 ±0,00 ^f	1,62 ±0,02 ^d
BST10	0,45 ±0,00 ^b	0,20 ±0,02 ^a
BST30	1,13 ±0,08 ^c	0,77 ±0,03 ^b
BST50	1,70 ±0,04 ^e	1,14 ±0,00 ^c

Means with different superscript letters in the same column are significantly different at the threshold ($P < 0.05$).

BFB: Wheat Biscuit; BSNT10: Biscuit substituted with 10% Untreated Mango kernel flour; BSNT30: Biscuit substituted with 30% Untreated Mango kernel flour; BSNT50: Biscuit enriched with 50% Untreated Mango kernel flour; BST10: Biscuit enriched with 10% Processed Mango kernel flour; BST30: Biscuit substituted with 30% Processed Mango kernel flour; BST50: Biscuit substituted with 50% Processed Mango kernel flour.

The total phenolic compound and tannin compositions of biscuits produced using wheat-mango almond composite flours were examined (Table 7). The analysis revealed a statistically significant increase in the total phenolic compound and tannin content of the biscuits with increasing mango almond flour incorporation ($P < 0.05$). The biscuits produced using FB exhibited the lowest levels of phenolic compounds. The corresponding values were 0.08% for CPT and 0.07% for tannins. The incorporation of

mango almond flour has been observed to result in a notable increase in the content of phenolic compounds. The highest levels of phenolic compounds were observed in biscuits produced using the FAMNT composite flour, with values ranging from 0.08 to 2.20%. Conversely, the lowest levels of phenolic compounds were exhibited by biscuits made with FAMT, ranging from 0.08 to 1.70%. This finding indicates a substantial decrease in phenolic compounds resulting from the treatment applied to the almonds. A parallel decline is evident in tannins, which are the primary anti-nutritional factor in mango almond flour. The substantial decline in phenolic compounds can be attributed to the impact of the baking temperature of the biscuits. This provides a rationale for the reduced content of phenolic compounds in the biscuits with 10% incorporation of NTMFs and the significant decrease in these compounds in the biscuits with 10% incorporation of TMFs.

4. Conclusion

The objective of this study was to prepare biscuits using composite wheat and mango kernel flours and to determine their physicochemical characteristics. The study revealed that the water, protein, and soluble sugar contents of the flours decreased with substitution and increased with treatment. Conversely, the ash and available sugar contents exhibited an increase with substitution and treatment, while the lipids, crude fiber, and energy contents demonstrated a similar trend. Conversely, the total sugar content exhibited a decrease with substitution and treatment, while the phenolic compound content demonstrated an increase with substitution but a considerable decrease with treatment. Furthermore, the water and oil absorption capacities increased with substitution and treatment, respectively, while the emulsifying activity decreased with substitution and increased with treatment. Substitution led to a decline in the physical parameters of the biscuits, while expandability exhibited an increase. The most favorable out-

comes were observed with the 10% substitution, which resulted in the highest protein content and physicochemical composition, approaching that of the control.

We strongly recommend the use of treated mango kernel flour to substitute the wheat flour in the production of biscuit.

Abbreviations

ENSAI Ecole Nationale Supérieure Agro-Industrielle

Author Contributions

Gaston Zomegni: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Writing – original draft

Panyoo Akdowa Emmanuel: Data curation, Writing – review & editing

Saidou Clement: Project administration, Supervision, Validation

Ponka Roger: Funding acquisition, Project administration, Supervision, Writing – review & editing

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Data Availability Statement

The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files.

Conflicts of Interest

The authors do not have any conflict of interest.

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