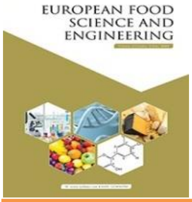

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Evaluation of the effect of coconut flour addition on the physicochemical and functional properties of wheat flour

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ABSTRACT

The use of wheat flour alone in the formulation of many products in Africa not only causes a large deficit in the balance of trade, but also nutritional problems, as it is poor in many nutrients. Thus, the present article concern the physico-chemical and functional properties of flours formulated from coconut and wheat. Coconut pulp was used to formulate the flours in association with wheat flour. Using the two-factor centered mixture design, we generated five formulations (F1 to F5) and then the physico-chemical and functional properties were performed. Physico-chemical and functional properties revealed a variation in the various parameters with the substitution percentage. In fact, fiber, lipid, protein, and ash content, as well as energy density, increased with the percentage of coconut flour. The same phenomenon was observed with minerals. All the functional and physical properties were significantly ($P<0.05$) improved by substitution. Principal component analysis showed small-group correlation between some samples overall. These results show the need to partial substitute wheat with foods from other classes in order to improve the nutritional values and functional properties of derived products. In addition, they offer a way out for African policies to reduce wheat imports and thus retain foreign currency.

1. Introduction

Coconut is a proteo-oleaginous fruit that grows mainly in the world's coastal areas (Srivastava, 2011). The coconut comes from the coconut tree (*Cocos nucifera*), one of the representatives of the Araceae or Palmaceae family. Often referred to as the "tree of life", the coconut palm probably originated in the Indo-Malaysian region: Fossil coconuts, dating back millions of years, have been found in New Zealand and India and it's now acclimatized in most tropical countries. It is highly prized for its richness in simple sugars, lipids, proteins, fat-soluble vitamins and essential fatty acids, making it a basic raw material for many industries (Trinidad et al., 2006). This composition makes the plant a basic ingredient in many formulations aimed at reducing malnutrition (Gunathilake et al., 2009). The fresh coconut contains a very complete food: the immature almond. Coconut water is rich in mineral salts and sugars. The nutritional value of 100 g of coconut corresponds to 353 kilocalories. On 100 grams, there are on average 3.4 grams of protein, 5.9 grams of carbohydrates, 35.1 grams of fat and 9.5 grams of fiber (Moore, 1986). Thus, the use of coconut flour in all these formulations or products would convey the many nutrients that compose it in order to fight malnutrition in all its forms, metabolic disorder diseases such as diabetes and obesity (Hossain et al., 2016). The use of coconut flour in human and animal food as well as cosmetics is increasingly continuously in Africa given all the properties it has. Indeed, coconut oil is widely used in India for its scalp regenerating properties, attributed to the presence of a high proportion of the essential fatty acids such as linoleic and linolenic acids (Trinidad et al., 2006). In addition, its supply of essential amino acids makes this fruit an indispensable ingredient in the fight against nutritional deficiencies, especially for vegetarians (Trinidad et al., 2006). Coconut proteins are essentially made up of three classes: albumins, glutelins and globulins, which are recognized for their exceptional emulsifying, foaming and gelling properties (Kwon et al., 1996). It's also important to note that coconut is very rich in insoluble fiber (more than 50% of its fiber content), which makes this matrix a highly digestible food. In view of these properties, the incorporation of coconut flour as a substitute in numerous formulations such as cakes, breads and complementary flours becoming very important (Yalegama et al., 2013). Partial replacing many cereals with this fruit would not only improve their nutritional, sensory and biological properties, but also make them suitable for a wide range of formulations (Fife, 2011).

Wheat is the world's most widely grown and used cereal for both human and animal consumption (Akhtar et al., 2008). The

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whole wheat kernel is an essential source of B vitamins, minerals such as phosphorus, fiber, starch and protein, the main one being gluten which gives wheat its much sought-after properties in formulations and applications in the baking industry for the production (Bakke & Vickers, 2007; Akhtar et al., 2008). Despite its important properties, many governments in wheat-importing countries such as Cameroon are increasingly recommending reducing dependence on this cereal by using local products. Moreover, cereals are deficient in Lysine, Threonine, Calcium and Iron, and a combination with other nutritional sources like coconut is highly recommended (Adeoti et al., 2023). To this end, the determination of substitution proportions in order to fully benefit from both nutritional and techno-functional properties (i.e ability to be used in bakery) becomes a matter of some urgency and concern.

The composite flours introduced in 1964 by the FAO are the result of combining several ingredients from different classes to overcome the shortcomings of each matrix (Jisha et al., 2008; Hasmadi et al., 2020). This has not only helped to reduce malnutrition, but also poverty (Hasmadi et al., 2020). Furthermore to the nutritional and economic benefits, it should be noted that the supplementation of coconut flour with cereals tends to reduce their specific volume and improve their texture, given their high content in reducing sugar which is responsible for the maillard reaction that is essential for the product's acceptability (Adeoti et al., 2023). The work of Nilufer et al. (2008) showed that the properties of flours made from wheat and soy were much better than those of 100% wheat. Therefore, this work aimed to evaluate the physico-chemical and functional properties of mixture flours made up from wheat and coconuts.

2. Materials and methods

2.1. Research design

The research carried out for this study was experimental and quantitative (Trochim, 2005). It consisted in collecting quantitative data from the analysis of various samples.

2.2. Materials

The material used in this work was coconut and wheat flour, which was purchased from traders at Market B in the town of Dschang (Menoua division, West Region of Cameroon). Once collected, these were transported to the Research Unit of Biochemistry of Medicinal Plants, Food Science and Nutrition where they underwent various transformations prior to analysis.

2.3. Data source location

The coconuts and wheat flour were purchased from Market B in the town of Dschang (Altitude: 1350 m; 5°26.6382′ North, 10°3.1992′ East), West Cameroon Region while coconut flour and the various formulations were produced at the Research Unit of Biochemistry of Medicinal Plants, Food Science and Nutrition of the Department of Biochemistry, Faculty of Science, University of Dschang (Altitude 1500 m; 5°27′ North, 10°04′ East). The various analyzes were carried out both at the Soil Science Research Unit of the Faculty of Agronomy and Agricultural Sciences and at the Medicinal Plants, Food Science and Nutrition Biochemistry Research Unit of the Biochemistry Department of the Faculty of Science at the University of Dschang.

2.4. Methods

Production of the coconut flour

Coconut endosperm after the removal of shell and paring, was shredded, grated and oven dried at 50 °C for 24 h in a hot air oven (model QUB 305010G, Gallenkamp, UK), milled using mill (model MXAC2105, Panasonic, Japan) to obtain coconut flour. The flour obtained was packaged in polyethylene bag before use.

Formulation of composite flour

A centered mixture design was applied to obtain the different proportion of flour. The design was carried out using software from Minitab® (version 18.1 Minitab Inc). According to mixture design, the coconut flour has been incorporated at 7.50%, 0.00%, 15.00%, 22.50% and 30.00% into the wheat flour. The formulations obtained were labelled F1, F2, F3, F4 and F5 (Table 1).

Table 1. Formulation of composite flour

Formulations	Wheat flour (%)	Coconut flour (%)
F1	92.50	7.50
F2	100.00	0.00
F3	85.00	15.00
F4	77.50	22.50
F5	70.00	30.00

Evaluation of functional properties of composite flour

The different functional parameters like water retention capacity (CRE), oil retention capacity (CRH), swelling power (TG) and ratio between CRH and CRE were evaluated according to Lin et al. (1974) method partially modified by Tambo et al. (2019a,b). One gram (1 g) of each sample was respectively mixed with 10 mL of sunflower oil or distilled water and incubated in a water bath at 30 °C for 30 min. The mixture was centrifuged at 4500 *xg* for 15 min. The volume of water or oil absorbed was measured. The CRE and CRH were calculated as follows (Eq. 1):

$$CRE/CRH\ (\%) = \frac{V0-V1}{V0} \times 100 \quad (1)$$

where V_0, initial volume of oil (mL); V_1: sedimented volume after centrifugation (mL); CRE, water retention capacity; CRH, oil retention capacity

The swelling power (TG) was deduced by difference between the mass of the sample having retained the water (M_1) and that of the start (M_0). The swelling power is given by the Eq. 2:

$$Swelling\ power\ (\%) = \frac{[(M_1-M_0)\times 100]}{M1} \quad (2)$$

where M_1, mass of the pellet or mass after water intake (g); M_0, mass of the test sample (g)

Determination of physical properties

The physical properties like loose bulk density (LB), packed bulk density (PB), Porosity and hausner ratio (HR) were determined according to the method described by Okaka et al. (1991). In fact, an empty crucible of known volume was filled with flour (100 g) and weighed before and after packed one hundred times. The results obtained were expressed as follows (Eq. 3, 4 and 5):

$$\text{Losse bulk and Tapped density } \left(\frac{g}{mL}\right) = \frac{\text{weight of sample (g)}}{\text{volume occupied by the sample}} \quad (3)$$

$$Hausner\ ratio = \frac{\text{Tapped density}}{\text{Loose bulk density}} \quad (4)$$

$$Porosity\ (\%) = \frac{\text{Tapped density} - \text{Loose bulk density}}{\text{Tapped density}} * 100 \quad (5)$$

The standard method developed by AOAC (1990) was used to assessed the pH. In fact, one g of sample of each flour was weighed into centrifuge tubes and mixed with 10 mL of distilled water. The suspension obtained was stirred using a "Barnstead/Thermolyne" brand vortexer for 30 min and then centrifuged at 4000 rpm for 5 min with a refrigerated "Heraeus" brand centrifuge. The pH of the aqueous phase was measured using a calibrated pH meter, at 25.03±0.22 °C.

Chemical composition of the formulations

The formulations produced as described above were subjected to different chemical analyses. The proximate chemical composition (moisture, crude protein, crude fiber, total digestible carbohydrate, and energy calorie) was carried out according to the standard methods described by AOAC (1990). The soxhlet extraction method using hexane as solvent was used to quantify lipids in the formulations (IUPAC, 1979). The Kjeldahl method, which converts organic nitrogen into ammoniacal nitrogen in the presence of concentrated sulfuric acid, was used to determine total nitrogen. Proteins were deduced by multiplying the rate of nitrogen release by a factor of 6.25. Total digestible carbohydrates content was obtained by difference with moisture, ash, lipid, fiber and protein content (AOAC, 1990) according to Eq. 6:

$$\%\text{Total digestible carbohydrates} = \%\text{Dry matter} - \%\text{Proteins} - \%\text{Lipids} - \%\text{Ashes} - \%\text{Fibers} \quad (6)$$

The total metabolizable calorific energy (expressed in kcal/100 g) in 100 g of each formulation was obtained after multiplying the quantities of carbohydrates, lipids and proteins by the coefficients of Atwater & Rosa (1899), which are 4, 9 and 4 respectively (Eq. 7):

$$\text{Calorific energy (kcal/100 g)} = (4 \times (\%\text{carbohydrates})) + (9 \times (\%\text{lipids})) + (4 \times (\%\text{proteins})) \quad (7)$$

Starch and amylose contents were determined using the methods described by Jarvis & Walker (1993), and Chrastyl (1987) respectively. In the case of starch, after extraction in a mixture of potassium hydroxide (KOH) and hydrochloric acid (HCl), an iodine-iodide solution (I_2/KI) of lugol was used to determine the content in the various samples. Amylose content was determined using the same procedure, plus defatting. Amylopectin content was obtained by the difference between starch and amylose percentage.

The ash was determined after total destruction of the organic matter by incineration in a muffle furnace (Perkin Elmer, USA) at 560 °C under oxidizing atmosphere according to the protocol described by AOAC (1990). The same ashes were used to quantify the minerals (Ca, Mg, Na, K, Fe, Zn and Cu) after pre-digestion in a liquid HNO_3/HCl mixture prior to reading with an atomic absorption spectrophotometer (BIOBASE BK-D590, spectrophotometer) at different wavelengths (AOAC, 1990).

2.5. Statistical analyzes

The experimental data, reported as means±standard deviation was calculated using Excel 2016 software (Microsoft Inc). The graphs were draw using the same software. The Analysis of Variance (ANOVA) was used to establish the difference between the samples. When the difference was found, the Fisher test was applied at the 5% probability level to compare these means using MINITAB (version 18.1 Minitab Inc). The Principal Component Analysis between chemical, physical and functional properties of different formulations were done using XLSTAT® 2014 for IBM STATISTICS (add-in for Excel) and allowed us to correlate the different parameters (variables and observations).

3. Results and Discussion

3.1. Proximate chemical composition

The physico-chemical and functional property data for the formulations presented in this work are intended to demonstrate the importance of substituting wheat flour with coconut flour. The proximate chemical analysis presented in Table 2 shows that the moisture content of composite flours does not change statistically. The level of substitution does not significantly (P=0.355) affect by the moisture level. The moisture content is an indicator of a product's storage and transport stability, and is highly dependent on the nature of the product's constituents, drying time and temperature (Kumarakuru et al., 2024). The values obtained are less than 14%, which then make the flours suitable for the production of long shelf life foods, more stable or resistant to chemical-microbial deterioration during storage or transport (Ndangui, 2015; Ajjata et al., 2016). Lipids are responsible for food flavor but also for rapid degradation on the effect of oxidation (Muyanja et al., 2014; Shams et al., 2022). Lipid content fluctuated significantly (P=0.000) with the proportion of substitution and this is related to the contribution of coconut flour, which is an oil-rich matrix. The contents obtained are similar to those of Klang et al. (2019a) on corn-, soy- and moringa-based formulations. The addition of coconut flour enabled us to obtain flours with contents covering more than 100% of the recommended daily intake of this nutrient (FAO/WHO, 2006). The protein content is range from 15.05 (F4) to 16.80 (F2). It was significantly (P=0.004) reduced by supplementation, which is contrary to the observations of many authors (Klang et al., 2019a; Onipe et al., 2024). This may be due to the quantification method used. Onipe et al. (2024) obtained protein contents 11 times lower than those of this study in millet- and fruit-based formulations, proving that these flours would be suitable as complementary foods to fight against protein-energy malnutrition in children aged 6 to 59 months. Ash refers to the presence of minerals in a food (Sukainah et al., 2023). This parameter varied significantly (P=0.000) with the percentage of nutmeal intake, with values ranging from 1.05 (F5) to 9.10% (F4). The values obtained are not consistent with the substitution rate, probably due to the analysis technique or calcination time, or to losses suffered by the last sample during processing. The values obtained are higher than those of Aini et al. (2010) but similar to those of Klang et al. (2019a). The increase in ash content in all formulations with the exception of formulation 5 is in line with the work of Kohajdova et al. (2012), who reported an improvement in this parameter with the level of carrot powders in different formulations.

Table 2. Proximate chemical composition of different flours

Samples	F1	F2	F3	F4	F5	*p-value*
Moisture content (%)	6.44±0.14^{a}	6.38±0.12^{a}	6.21±0.06^{a}	6.24±0.09^{a}	6.28±0.16^{a}	0.355
Lipids content (%)	7.08±0.27^{d}	2.58±0.00^{e}	11.11±0.34^{c}	15.76±0.03^{b}	20.42±0.42^{a}	0.000
Proteins content (%)	16.19±0.25^{a}	16.80±0.25^{a}	15.49±0.25^{b}	15.05±0.25^{b}	15.31±0.25^{b}	0.004
Ash content (%)	3.10±0.14^{b}	2.05±0.07^{c}	2.15±0.21^{c}	9.10±0.14^{a}	1.05±0.07^{d}	0.000
Fibers content (%)	2.84±0.25^{c}	3.04±0.22^{c}	1.41±0.25^{d}	4.02±0.25^{b}	5.67±0.25^{a}	0.000
Glucids content (%)	64.51±0.53^{b}	69.15±0.42^{a}	63.63±0.31^{b}	49.84±0.57^{c}	51.11±1.12^{c}	0.000
Energy value (kcal/100 g)	386.51±3.55^{d}	367.08±0.63^{e}	416.48±3.33^{b}	401.39±1.04^{c}	449.46±0.31^{a}	0.000
Starch content (%)	46.94±2.87^{b}	52.42±1.48^{a}	33.06±1.64^{d}	37.50±1.14^{c}	31.72±1.14^{d}	0.000
Amylose content (%)	12.92±0.79^{c}	13.81±0.42^{bc}	14.45±1.11^{b}	15.87±0.45^{a}	16.07±0.54^{a}	0.001
Amylopectin content (%)	87.08±0.79^{a}	86.19±0.42^{ab}	85.55±1.11^{b}	84.13±0.45^{c}	83.93±0.54^{c}	0.001
Ratio amylose/amylopectin	0.15±0.01^{c}	0.16±0.00^{bc}	0.17±0.01^{b}	0.19±0.01^{a}	0.19±0.01^{a}	0.001

F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour.

These ash contents show that these formulations could be recommended in the preparation of cookies and cakes for the elderly or diabetics, as well as for children suffering from hidden hunger. The fiber plays a major role in the health of our organism, particularly the colon, ensuring good transit and, above all, preventing cancer, diabetes and obesity (Sheikh et al., 2019). The fiber content increases significantly (P=0.000) with the substitution rate (except F3), ranging from 1.41 (F3) to 5.67% (F5). The reduction observed with formulation F3 is thought to be due to partial digestion of the fibres in this formulation, resulting in poor quantification. These variations concur with the observations of Malomo et al. (2011), who observed a positive evolution of fiber in bread with the substitution rate of the fruit formulation. The use of these formulated flours, in addition to their energy and nutritional values, would also have significant health benefits due to their fiber content. This positive trend in fiber content is testimony to the contribution of coconut flour, as demonstrated by Yalegama et al. (2013). The levels obtained are higher than those of Onipe et al. (2024), which ranged from 0.24 to 3.15%. The carbohydrates are the main form of energy that can be directly metabolized by the body and serve as the brain's energy raw material (Tambo et al., 2019a,b).

Furthermore, they determine the functional properties, color (particularly through non-enzymatic browning), texture and flavor of the products (Sukainah et al., 2023). This parameter decreased with the substitution rate from 69.15% (F2 or wheat flour) to 49.84% (F4). Coconut is a low-carbohydrate protein-oleaginous plant, although it is a source of simple sugars, and this would explain these results (Sukainah et al., 2023). Bello & Esin (2023) also reported a drop in carbohydrate content in a formulation based on corn, cowpea and coconut when the proportions of the last two ingredients were increased. Moreover, this parameter is negatively (r=-0.9305; P<0.05) correlated with lipids, as shown by the results in Table 8. The values obtained are lower than those of Bello & Esin (2023), which ranged from 76.08 to 78.36. Calorific energy, which is related to nutritional composition, also increased with coconut content, while the opposite was observed for starch content. This parameter was significantly (P=0.000) boosted by the addition of coconut flour, as shown in Table 2. Indeed, the energy density of the flours increased from 367.08 kcal (F2) to 449.46 kcal (F5). This contribution is in line with the high lipid content provided by coconut, and thus concurs with the work of Bello & Esin (2023) who observed a positive evolution of the flours formulated when the coconut flour substitution rate increased. Furthermore, these results are confirmed by the positive correlation (r=0.9089; P<0.05) between lipids content and energy density (Table 8). The energy values reported are similar to those of Bello & Esin (2023), which ranged from 404.97 to 413 kcal. The results obtained also show that the consumption or use of these flours in the formulation of products intended for supplemental feeding would make it possible to meet a deficit of more than 70% of their daily requirements for a 100 g portion (FAO/WHO, 2006; Klang et al. 2019a,b). Starch, amylose, amylopectin and the amylose/amylopectin ratio are parameters that significantly influence the various techno-functional properties of a flour, such as water retention capacity and physical stability (Klang et al., 2019b; Dongmo et al., 2020). One example is the positive correlation between starch content and swelling rate (r=0.1648; P>0.05). Starch and amylopectin contents decreased substantially with the coconut flour substitution rate, while amylose content, which is responsible for the retrogradation and hence thermal instability of starch, increased with substitution. Cisse et al. (2023) also observed a decrease in starch content with the rate of substitution of attiéké by legumes. Coconut is low in starch, which would explain its negative effect on starch content. These results are also confirmed by the negative correlation (r=-0.8821; P<0.05) between the lipid content of coconut and starch content (see Table 8). The results obtained for starch content are lower than those of Cisse et al. (2023), which ranged from 69.79 to 77.91% in flour formulations based on Attieke & Voandzou. These results also demonstrate the need for other cereal sources to benefit from starch properties. The amylose/amylopectin ratios of the various formulations are positively related with the substitution rates, but remained below 1, demonstrating that these flours will retrograde little and consequently maintain the techno-functional properties of starch. The data obtained are in the same range as those of Dongmo et al. (2020), which varied between 0.13 and 0.26 for corn flours subjected to different treatments.

3.2. Proximate mineral composition in different blending flours

The influence of the substitution percentage on the mineral composition of formulations is shown in Table 3. The minerals are so essential for the proper functioning of the organism, participating in homeostasis, enzymatic activity, muscle contraction, cell growth and activity, as well as the techno-functional properties of flours (Klang et al., 2019a,b; Dongmo et al., 2020; Tambo et al., 2023). With regard to functional properties, the work of Tambo et al. (2019a,b) revealed a positive correlation between Ca and water retention capacity. The same applies to this study, where a positive correlation (r=0.7682; P<0.05) was found between the two parameters. In this study, seven minerals were evaluated, of which four are major (Ca, Mg, Na and K) and three are microelements (Fe, Cu and Zn). With the exception of K, all ions show a negative trend with coconut content. These observations does not concur with those of Klang et al. (2019a). These results can be explained by the composition of the ash used to quantify the minerals. Poor mineralisation and the presence of organic matter in certain formulations, particularly F5, are thought to be responsible for these variations. In addition, the presence of phytates and oxalates (complexing agents for divalent cations) in coconuts could explain a drop in these elements with substitution. All the micro and macro elements were significantly ($P<0.05$) affected by the percentage of substitution, and this can be explained by the significant contribution of coconut flour. The Calcium levels contributed over 50% of the recommended daily requirement (2 g/day) for the F1 formulation, and 26% for the F5 formulation. These values are much higher than the 3.5% obtained by Diallo et al. (2024) with Bambara groundnuts. The contribution of magnesium ranged from 26% to 36%, while that of copper (1 mg/day) was over 300%. These results suggest that the consumption of these formulated flours should be recommended for athletes, pregnant women, the elderly and children (Omotoso, 2006). Iron is an important element in hemoglobin synthesis and oxygen transport in the body (Omotoso, 2006). These activities make iron an indispensable mineral for women. Iron intake decreases with supplementation, but remains above 100% of daily contribution for the F1 formulation. The levels of these minerals were higher than those of Botella-Martinez et al. (2023), with the exception of zinc. Calcium and sodium availability can be assessed by determining Ca/Mg and Na/K ratios. These ratios show that supplementation reduces Ca availability from 11.18 Mg (F1) to 4.33 Mg (F5), and Na availability from 0.22 K (F1) to 0.01 K (F5). Although these results are decreasing, they nevertheless demonstrate that consumption of the different blending would provide a large quantity of available and therefore bioavailable Calcium, and would also be safe for hypertensive patients, given the low availability of Na (Tambo et al., 2019a,b).

3.3. Influence of blending ratio on functional properties of flours

The functional properties were evaluated and results are presented in Table 4. The water absorption capacity is a parameter highly dependent on flour composition, in particular protein, starch, amylose and amylopectin content, but also on the conformational structure of these molecules (Onipe et al., 2024). This parameter represents a flour's ability to bind water molecules under stress conditions and form a more or less stable gel consistency (Bajo et al., 2021). The water retention decreased with substitution and is lesser than those of wheat flour. These observations are contrary to those of Adeoti et al. (2023), who observed an improvement in water retention capacity with increasing substitution by cocoa powder. This is the consequence of a reduction in the hydrophilic group content by lowering the starch content. Indeed, substitution with coconut flour increases the lipid and protein content, which forms complexes on the starch surface and with amylose, thus hindering hydrophilic interactions (Bajo et al., 2021). It would also be linked to an increase in the amylose content of formulated flours and a complexification of the starch structure. Unlike amylopectin, amylose is less soluble, as it interacts with insoluble molecules such as lipids (Adeoti et al., 2023). The negative correlation ($r=-0.3692$) with amylose content confirms these observations (Dongmo et al., 2020). These results suggest the use of these flours in the formulation of foods that do not require dough elasticity, such as cookies.

The swelling capacity depends both on intrinsic factors such as molecular composition and organization, and extrinsic factors such as culinary treatments and water stress (Onipe et al., 2024). It measures a flour's ability to form a consistent and stable gel with water molecules. The analysis of this table shows that this parameter was significantly ($P=0.025$) influenced by the substitution rate, and decreased with it. The values ranged from 53.70 (F4) to 65.36 (F1).

Table 3. Proximate mineral composition of different flours

Samples	F1	F2	F3	F4	F5	*p-value*
Ca (mg/100 g)	1360.16±0.22^{a}	720.16±0.22^{c}	640.17±0.23^{d}	800.18±0.25^{b}	400.15±0.21^{e}	0.000
Mg (mg/100 g)	121.68±0.25^{b}	102.21±0.21^{d}	111.96±0.25^{c}	131.40±0.25^{a}	92.52±0.25^{e}	0.000
Cu (mg/100 g)	3.56±0.22^{a}	1.07±0.17^{b}	1.12±0.37^{b}	1.19±0.21^{b}	1.59±0.67^{b}	0.005
Fe (mg/100 g)	14.11±0.00^{a}	0.99±0.00^{c}	3.22±0.00^{b}	0.96±0.00^{d}	0.13±0.00^{e}	0.000
Zn (mg/100 g)	15.15±0.22^{a}	0.37±0.06^{c}	0.35±0.00^{c}	0.30±0.00^{c}	1.74±0.00^{b}	0.000
Na (mg/100 g)	36.82±0.22^{c}	50.15±0.21^{b}	65.17±0.23^{a}	25.18±0.25^{d}	25.18±0.25^{d}	0.000
K (mg/100 g)	167.85±0.22^{c}	1237.65±599.80^{b}	1431.23±325.56^{b}	1200.82±0.21^{b}	2421.84±319.20^{a}	0.010
Ca/Mg	11.18±0.02^{a}	7.04±0.01^{b}	5.71±0.01^{d}	6.09±0.01^{c}	4.33±0.01^{e}	0.000
Na/K	0.22±0.001^{a}	0.05±0.02^{b}	0.05±0.01^{b}	0.02±0.00^{bc}	0.01±0.001^{c}	0.000

F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour.

Table 4. Functional properties of different flours

Samples	WRC (%)	SP (%)	OHC (%)	Ratio OHC/WRC
F1	22.00±0.00^{a}	65.36±1.53^{a}	63.52±0.79^{a}	2.89±0.04^{a}
F2	27.00±4.24^{a}	65.16±0.53^{a}	63.76±0.74^{a}	2.39±0.40^{a}
F3	22.00±2.83^{a}	54.02±6.39^{b}	60.46±0.43^{b}	2.77±0.38^{a}
F4	21.00±1.41^{a}	53.70±0.61^{b}	60.31±0.66^{b}	2.88±0.16^{a}
F5	22.00±2.83^{a}	61.38±1.05^{ab}	61.00±0.33^{b}	2.80±0.37^{a}
p-value	0.310	0.025	0.005	0.540

WRC: Water retention Capacity; SP: Swelling power; OHC: Oil holding capacity. F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour.

In fact, the addition of a small quantity of coconut not only provides polar amino acids in the proteins, but also limits molecular saturation, which facilitates interactions between polar molecules and water (Tambo et al., 2023). These results are contrary to those of many authors who have demonstrated that the presence of fibres improves water retention capacity and consequently swelling rate (Fida et al., 2020; Onipe et al., 2024). This suggests that coconut fibers are mainly insoluble and would therefore be recommended for people suffering from diabetes and obesity. In addition, the richness of minerals such as Ca and Mg capable of forming strong and stable ionic bonds with the water molecules would also explain these results. In addition, a positive correlation ($r=0.6356$; $P<0.05$) was observed between swelling power and water retention capacity, indicating the high solubility of these flours. Furthermore, these observations reveal that partial substitution at 7.5% rate with coconut flour would be beneficial to manufacturers in terms of swelling power.

The oil retention capacity, on the other hand, decreased significantly ($P=0.005$) with the substitution percentage, thus showing the interest of substitution in reducing oil intake, since coconut is already a source of lipid. Indeed, the richness of polar amino acids in coconut flours and a molecular arrangement orienting these towards the interior of the chain would be the consequence of weak hydrophobic interactions with the hydrocarbon chains of fatty acids (Mubaiwa et al., 2018). Similarly, an increased intake of coconut flour would lead to saturation of amylose-lipid interactions, thus reducing interactions with additional fats (Chandra et al., 2015). The capacities obtained are lower than the 69-92% range obtained by Yusufu & Ejeh (2018) in different wheat- and bambara-based flour formulations. This therefore suggests that the use of different formulations would limit the absorption of oil, which could be a danger to the product's shelf life or preservation. Indeed, oils are subject to oxidation, responsible for the formation of rancid odors and toxic compounds, thus limiting storage. In addition, these results also show that the use of these flours would be beneficial for private individuals, as they would limit expenditure on the purchase of oil and, above all, energy, as they would take less time to cook.

The OHC/WRC ratio, like emulsifying capacity, provides information on the ability of matrix constituents to form table mixtures by modifying the interfacial tensions of the heterogeneous mixture constituents (Matidza et al., 2023). This ratio was not affected ($P=0.540$) by the substitution rate, although the highest values were found with formulated flours. Indeed, Matidza et al (2023) demonstrated that the addition of oil-rich matrices would facilitate the stability of the mixture, as these lipids would play an amphiphilic role. The results obtained show that these flours are suitable for the formulation of cakes and breads, as they promote interactions between the hydrophobic zones of the gluten and the starch of the flours, thus contributing to the creation of a more compact and stable molecular network (Thakaeng et al., 2021). Furthermore, these results show that substitution with coconut flour would improve the flavor and taste of foods in view of the higher ratios.

3.4. Influence of blending ratio on physical properties of flours

The physical properties are presented in Table 5. The physical properties are also among the parameters governing a flour's applicability. The table shows that pH varied between 7.07 (F4) and 7.35 (F2). It was not significantly influenced ($P= 0.122$) by the rate of substitution by coconut flour, although the substituted flours presented the lowest values. The richness of coconut in acidic amino acids would be responsible for these observations (Owusu-Kwarteng et al., 2022). These results would also explain the data on water retention capacity. Indeed, Tambo et al. (2019a) reported that a reduction in pH due to the presence of organic acids lowers the water-holding capacity of a flour. The values obtained are all above 7, demonstrating that there is no need to use acidity-correcting agents during formulation, and that these macronutrients are readily accepted and, above all, digestible. In addition, products formulated from these flours are more stable (as they are less conducive to microbial growth) and easier to store (Matidza et al., 2023). The results obtained are superior to those of Matidza et al. (2023), which ranged from 5.27 to 5.79 for banana- and wheat-based flours.

The porosity measures the interstices that can be found in a heterogeneous mix, and is related to macronutrient composition. Indeed, the richer a mixture is in macronutrients such as proteins and starch, the less porous it is. Indeed, proteins and starch, being high molecular weight macromolecules, will not more rationally occupy all the spaces, thus facilitating the passage of air and favoring packaging (Jha & Sit, 2024). These observations are confirmed by the negative correlation between porosity and protein ($r=-0.3949$) and starch ($r=-0.5996$; $P<0.05$) contents respectively. The porosity ranged from 50 (F2) to 36.97% (F3). It was significantly ($P=0.000$) reduced by the coconut flour substitution rate. In fact, coconut substitution increases the lipid content, which promotes cohesion of the molecules by acting as a binder, thus reducing particle dispersion and making them resistant to any flow movement (Jha & Sit, 2024).

The values obtained are higher than those of Jha & Sit (2024), which ranged from 7 to 18% in a mixture of zein and corn starch. These results show that substituting coconut flour for 7.5% would result in a product that would not pose any packaging problems. In fact, these data provide further evidence that the addition of coconut produces flours suitable for bread-making (Djikeng et al., 2022).

The bulk densities depend on particle size, nutrient composition (especially protein) and pellet shape (Dongmo et al., 2020; Djikeng et al., 2022; Tambo et al., 2023). They influence food intake, preservation, transport and packaging (Dongmo et al., 2020). Indeed, Jha & Sit (2024) reported that a flour with a high bulk density would be beneficial as it would occupy less pace during packaging.

Table 5. Physical properties of different flours

Samples	F1	F2	F3	F4	F5	*p-value*
pH	7.32±0.06^{a}	7.35±0.04^{a}	7.26±0.10^{ab}	7.07±0.01^{b}	7.21±0.16^{ab}	0.122
Porosity (%)	46.67±0.00^{b}	50.00±0.00^{a}	36.97±2.10^{c}	38.08±1.39^{c}	37.98±0.68^{c}	0.000
Loose bulk density (g/mL)	0.40±0.00^{c}	0.43±0.00^{b}	0.47±0.01^{a}	0.48±0.01^{a}	0.47±0.00^{a}	0.001
Packed bulk density (g/mL)	0.75±0.00^{c}	0.86±0.00^{a}	0.75±0.32^{c}	0.77±0.00^{b}	0.75±0.00^{c}	0.000
Hausner ratio	1.47±0.02^{c}	1.71±0.00^{b}	1.93±0.00^{a}	1.71±0.00^{b}	1.77±0.08^{b}	0.001

F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour.

The Loose bulk density varied between 0.48 (F4) and 0.43 g/mL (F2) and was significantly (P=0.001) improved by coconut substitution rate, while the opposite effect was observed with the tapped bulk density. In fact, the higher lipid content with coconut flour substitution led to particle aggregation, making them denser and less porous. There was also an inverse variation between loose bulk density and tapped bulk density, contrary to the observations of Djikeng et al. (2022). This observation is confirmed by the negative correlation with porosity (r=-0.7421; P<0.05). Onipe et al (2024) also reported an improvement in bulk density with the percentage of *Parinari curatellifolia* flour. The values obtained are respectively lower for the loose bulk and tapped bulk densities than those of Onipe et al. (2024), which ranged from 0.82 to 0.85 g/mL, and those of Bello & Esin (2023), which varied from 0.72 to 0.96 g/mL. These results demonstrate that these flours are suitable for the preparation of supplementary feeds with adequate viscosity, easy digestibility and high energy density (Tambo et al., 2022).

The evaluation of compression and compaction resulting from intermolecular friction between the constituents of a blend are possible through to the determination of the Hausner ratio (Shumaila et al., 2015). Indeed, compared to the control (F2), coconut substitution increased significantly (P<0.05) with 15% substitution. This parameter was unaffected by the 22.5% and 30% substitution, while it dropped significantly (P<0.05) at 7.5% to reach a value of 1.47 (F1).

Overall, this parameter was affected by substitution (P=0.001). These ratios are higher than the range of 1.10 to 1.40 obtained by Djikeng et al. (2022) on snail meal. In fact, the difference is due to a difference in composition directly linked to the coconut flour content. All these values are higher than 1, which has been defined as the value of excellence for judging good flowability, tenderness and above all resistance to shearing phenomena (Jha & Sit, 2024). These results demonstrate the need to control the percentage of wheat substitution by legumes in order to benefit from all their techno-functional properties.

3.5. Principal component analysis between the nutritional, physical and functional properties of the different blending flours

The correlation between the various physico-chemical and functional parameters was assessed using principal component analysis. This multivariate analysis was also used to classify the formulations according to their similarities. This analysis showed that variables and observations are correlated in small groups. Formulations F1, F4 and F5 form the F1 axis, while formulations F2 and F3 form the F2 axis (Table 6).

Table 6. Contributions and squared cosines of variables

Parameters	Variables contributions (%)			Variables Squares Cosines		
	F1	F2	F3	F1	F2	F3
Water retention capacity (WRC)	2.1140	4.3247	4.1673	0.3240	**0.3353**	0.1338
Swelling power	0.9163	10.2316	0.1005	0.1404	**0.7933**	0.0032
Oil retention capacity (ORC)	5.1324	0.6011	4.7631	**0.7866**	0.0466	0.1529
ORC/WRC	0.3247	11.2853	1.4370	0.0498	**0.8750**	0.0461
pH	0.5842	8.7194	7.2477	0.0895	**0.6760**	0.2326
Moisture	4.6583	0.3884	0.1087	**0.7140**	0.0301	0.0035
Lipids	3.7227	3.9318	3.5351	**0.5706**	0.3048	0.1135
Porosity	4.0724	4.2909	0.5607	**0.6242**	0.3327	0.0180
Loose bulk	5.5518	0.1325	4.2975	**0.8509**	0.0103	0.1379
Packed bulk	0.0074	6.4742	13.8317	0.0011	**0.5020**	0.4440
Hausner ratio	3.6493	4.6029	1.2684	**0.5593**	0.3569	0.0407
Starch	3.5381	0.4873	8.8737	**0.5423**	0.0378	0.2848
Amylose	5.8621	1.2822	0.0630	**0.8985**	0.0994	0.0020
Amylopectin	5.8621	1.2822	0.0630	**0.8985**	0.0994	0.0020
Amylose/Amylopectin	5.8306	1.3482	0.0549	**0.8936**	0.1045	0.0018
Proteins	3.1317	2.6799	1.4076	**0.4800**	0.2078	0.0452
Glucids	3.2220	6.2787	0.0000	**0.4938**	0.4868	0.0000
Fibers	1.5432	5.6699	0.0270	0.2365	**0.4396**	0.0009
Energy	3.0668	1.1755	13.6669	**0.4700**	0.0911	0.4387
Ashes	0.1500	2.5369	14.3365	0.0230	0.1967	**0.4602**
Na	0.3301	10.8523	1.1966	0.0506	**0.8414**	0.0384
K	5.1856	0.1101	2.0562	**0.7948**	0.0085	0.0660
Ca	5.3337	1.1797	0.4975	**0.8175**	0.0915	0.0160
Mg	0.5868	1.4546	6.0919	0.0899	0.1128	**0.1955**
Cu	3.9745	3.5562	3.5828	**0.6092**	0.2757	0.1150
Fe	5.1780	1.0437	2.5200	**0.7936**	0.0809	0.0809
Zn	4.5544	2.7464	2.7547	**0.6980**	0.2129	0.0884
Ca/Mg	6.1640	0.5284	0.1294	**0.9447**	0.0410	0.0042
Na/K	5.7528	0.8049	1.3606	**0.8817**	0.0624	0.0437

Values in bold for each variable correspond to the factor for which the cosine squared is the greatest.

Table 7. Contributions and squared cosines of observations

	F1	F2	F3	F1	F2	F3
F1	61.2316	13.8567	4.4906	**0.8841**	0.1012	0.0136
F2	2.7104	26.8649	23.1719	0.1044	**0.5233**	0.1868
F3	1.8798	32.9740	16.6136	0.0694	**0.6159**	0.1285
F4	10.3839	16.2203	35.0907	**0.3559**	0.2812	0.2519
F5	23.7944	10.0841	20.6332	**0.6308**	0.1352	0.1145

Values in bold for each observation correspond to the factor for which the cosine squared is the greatest. F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour.

Axis F3 is not formed by any of the observations. The formation of these different axes by variables and observations is confirmed by biplots (Figure 1). The dendograms (Figure 2) used to link formulations on the basis of their physico-chemical properties revealed that formulations F2, F3 and F4 belong to one class or have the same properties, while formulations F1 and F5 form two respective classes. These results show that formulations F3 and F4 can be used as an alternative to 100% wheat. Classification of the variables (Figure 2) revealed the existence of 6 classes. The first class is made up of Cu, Fe, Zn, Ca/Mg, Na/K, CRE/CRH and amylose/amylopectin ratios, amylose, fiber, protein, ash, water content, water retention capacity (CRE), and physical properties such as mass density and Hausner ratio. The second class is made up of swelling ratio, oil retention capacity (ORC), porosity, carbohydrate, starch and Na contents.

Classes 3, 4, 5 and 6 are respectively formed by amylose and amylopectin content, energy value, K content and Ca content. The negative correlation (r=-0.369) between amylose content and water retention capacity (Table 8) is in line with the work of Tambo et al. (2019a,b), who demonstrated that amylose retrogrades more rapidly, leading to a reduction in water retention capacity. The positive correlation (r=0.5293) between Loose bulk density and protein content is in line with that of Tambo et al. (2019a,b). This multivariate analysis shows that the choice of formulation must take into account both its chemical and functional properties, for greater efficiency.

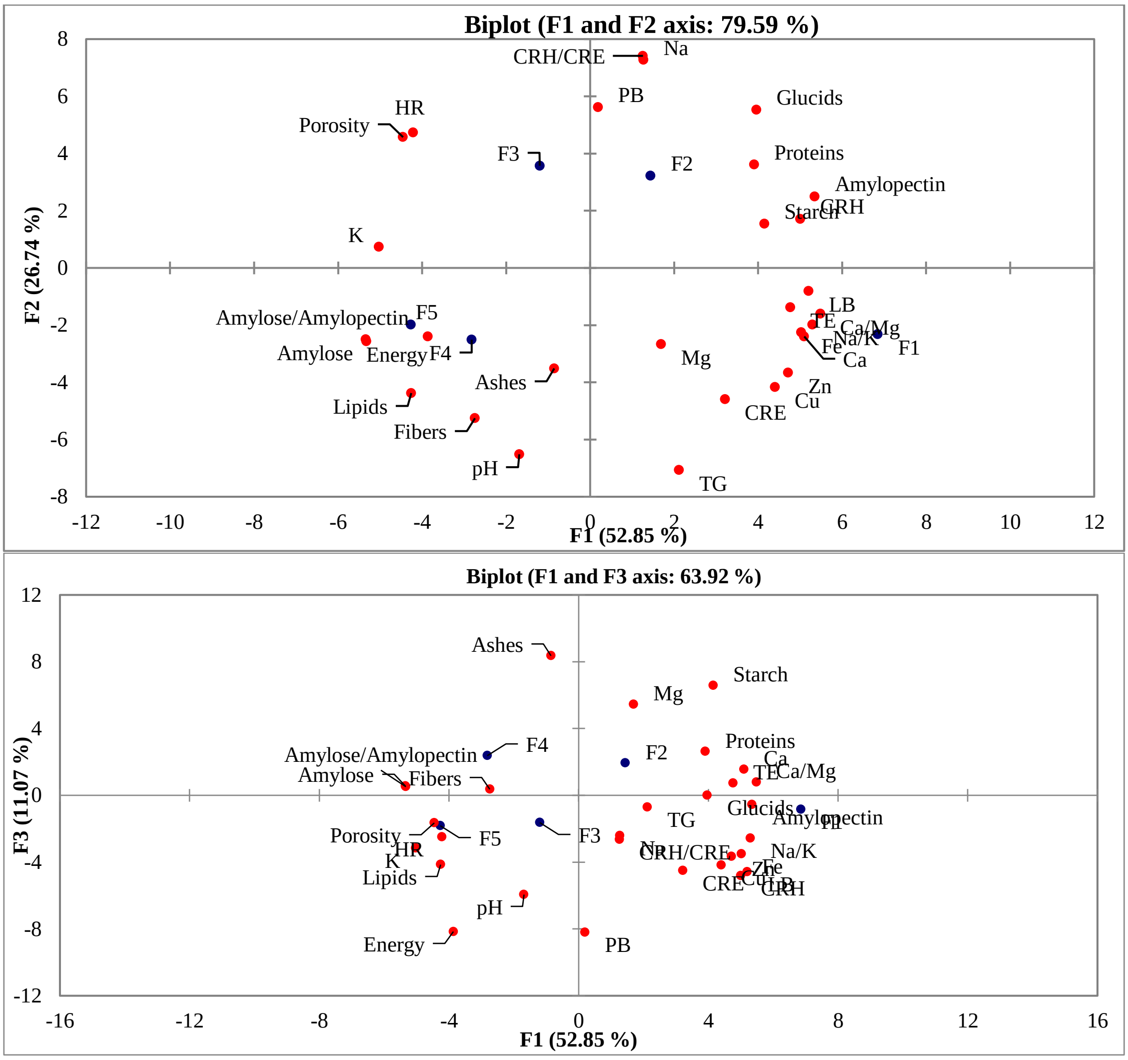

Figure 1. Biplot of correlation between contributions and variables (F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour. CRE: Water retention capacity; TG: Swelling power; CRH: Oil retention capacity; TE: Moisture content; LB: Loose bulk; PB: Packed bulk; HR: Hausner ratio.)

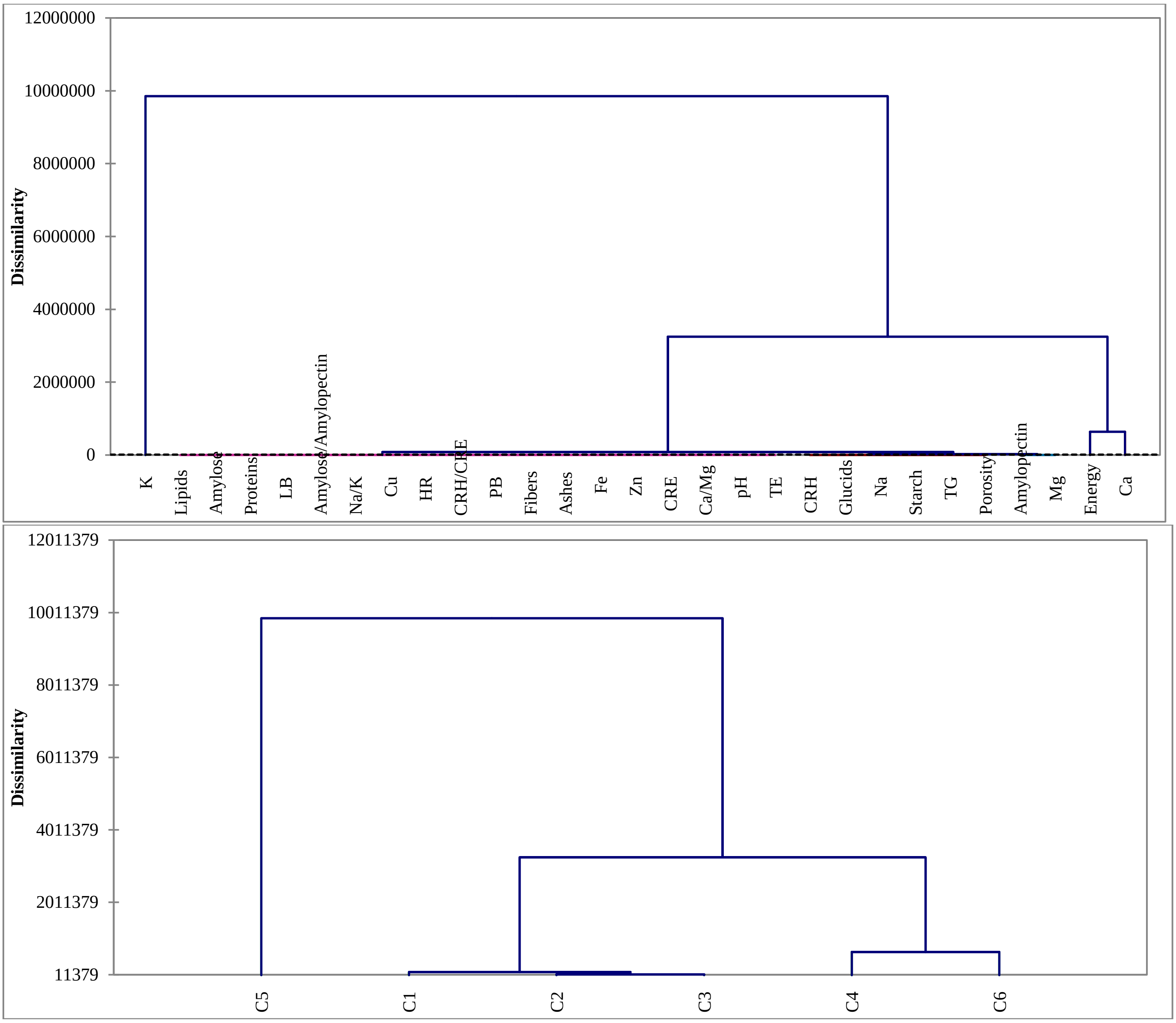

Figure 2. Dendogram that show the different classes of variables (CRE: Water retention capacity; TG: Swelling power; CRH: Oil retention capacity; TE: Moisture content; LB: Loose bulk; PB: Packed bulk; HR: Hausner ratio)

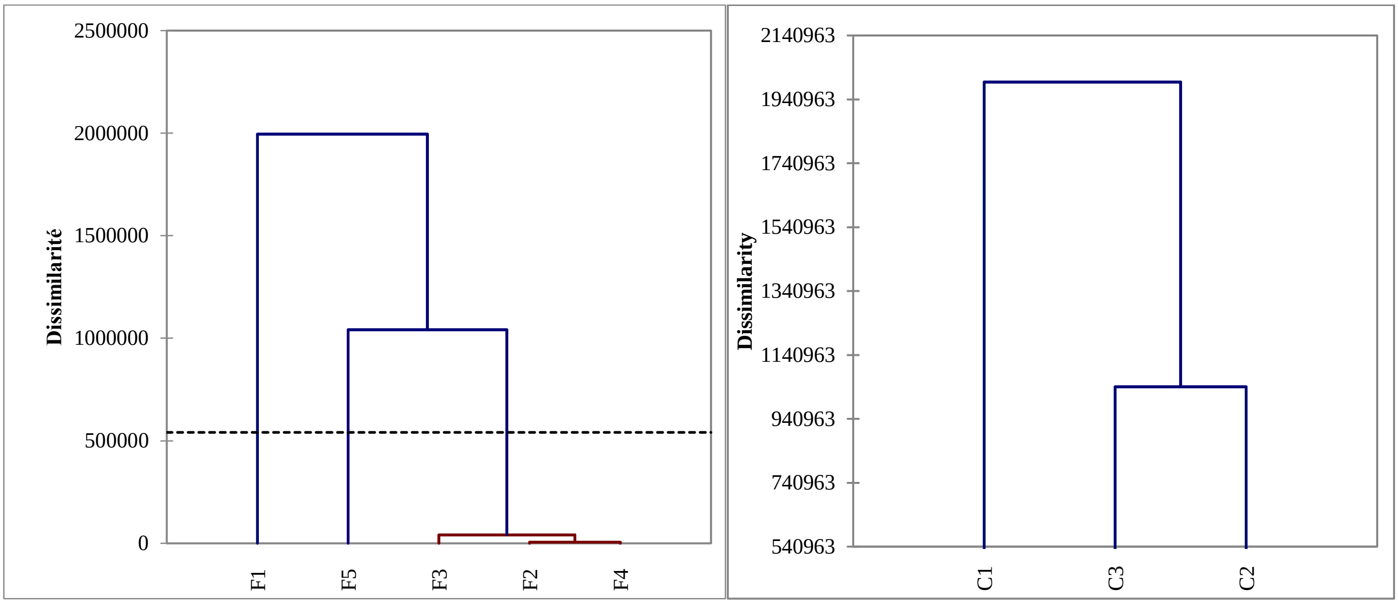

Figure 3. Dendogram that show the different classes of observations (F1= 92.5% wheat flour + 7.5% coconut flour; F2= 100% wheat flour; F3= 85% wheat flour +15% coconut flour; F4= 77.5% wheat flour + 22.5% coconut flour; F5= 70% wheat flour + 30% coconut flour)

Table 8. Pearson correlation matrix of variables

Variables	CRE	TG	CRH	CRH/ CRE	pH	TE	Lipids	Porosity	LB	PB	HR	Starch	Amyl	Amyp	Amyl/ Amyp	Proteins	Glucids	Fibers	Energy	Ashes	Na	K	Ca	Mg	Cu	Fe	Zn	Ca/ Mg	Na/ K
CRE	**1**																												
TG	**0.635**	**1**																											
CRH	0.469	0.192	**1**																										
CRH/ CRE	-0.259	**-0.780**	0.464	**1**																									
pH	0.463	**0.658**	-0.249	**-0.739**	**1**																								
TE	0.331	**0.594**	0.748	-0.072	-0.117	**1**																							
Lipids	0.061	0.201	**-0.669**	**-0.595**	**0.838**	**-0.615**	**1**																						
Porosity	**-0.663**	**-0.842**	**-0.542**	0.419	-0.179	**-0.855**	0.340	**1**																					
LB	**0.706**	0.465	**0.945**	0.186	-0.012	**0.790**	**-0.519**	**-0.742**	**1**																				
PB	-0.043	**-0.638**	0.416	**0.853**	-0.281	-0.249	-0.168	**0.508**	0.199	**1**																			
HR	**-0.603**	**-0.853**	-0.479	0.471	-0.179	**-0.852**	0.325	**0.995**	**-0.682**	**0.580**	**1**																		
Starch	-0.056	0.165	**0.529**	0.169	**-0.622**	**0.805**	**-0.882**	**-0.599**	0.472	-0.278	**-0.619**	**1**																	
Amyl	-0.369	-0.079	**-0.927**	**-0.514**	**0.521**	**-0.748**	**0.876**	**0.563**	**-0.859**	-0.283	**0.514**	**-0.739**	**1**																
Amyp	0.369	0.079	**0.927**	**0.514**	**-0.521**	**0.748**	**-0.876**	**-0.563**	**0.859**	0.283	**-0.514**	**0.739**	**-1.000**	**1**															
Amyl/ Amyp	-0.362	-0.071	**-0.926**	**-0.521**	**0.528**	**-0.745**	**0.879**	**0.556**	**-0.855**	-0.287	**0.507**	**-0.739**	**1.000**	**-1.000**	**1**														
Proteins	-0.182	-0.029	**0.691**	0.447	**-0.663**	**0.778**	**-0.901**	-0.395	**0.529**	0.086	-0.396	**0.902**	-0.796	**0.796**	**-0.798**	**1**													
Glucids	-0.067	-0.323	**0.791**	**0.786**	**-0.778**	**0.543**	**-0.931**	-0.175	**0.582**	0.486	-0.137	**0.704**	**-0.888**	**0.888**	**-0.891**	**0.877**	**1**												
Fibers	-0.162	0.549	**-0.519**	**-0.832**	**0.701**	-0.009	**0.664**	-0.092	-0.375	**-0.636**	-0.156	-0.262	**0.666**	**-0.666**	**0.670**	-0.339	**-0.725**	**1**											
Energy	0.032	0.047	-0.416	-0.291	**0.772**	**-0.572**	**0.909**	0.458	-0.356	0.207	0.468	**-0.921**	**0.715**	**-0.715**	**0.718**	**-0.759**	**-0.694**	**0.507**	**1**										
Ashes	0.178	0.158	**-0.562**	-0.498	0.059	-0.295	0.191	-0.137	-0.364	**-0.641**	-0.171	-0.044	0.319	-0.319	0.320	-0.455	-0.495	0.066	-0.205	**1**									
Na	-0.212	**-0.788**	0.443	**0.995**	**-0.738**	-0.113	**-0.583**	0.419	0.179	**0.849**	0.474	0.142	**-0.509**	0.509	**-0.515**	0.396	**0.762**	**-0.873**	-0.298	-0.425	**1**								
K	**-0.634**	-0.311	**-0.628**	-0.119	0.330	**-0.603**	**0.671**	**0.735**	**-0.726**	0.124	**0.699**	**-0.643**	**0.801**	**-0.801**	**0.799**	-0.443	**-0.512**	**0.570**	**0.749**	-0.285	-0.161	**1**							
Ca	**0.768**	**0.532**	**0.655**	-0.062	-0.094	**0.686**	**-0.529**	**-0.862**	**0.809**	-0.205	**-0.825**	**0.574**	**-0.753**	**0.753**	**-0.749**	0.374	0.386	-0.391	**-0.609**	0.238	-0.026	**-0.965**	**1**						
Mg	**0.556**	0.192	-0.071	-0.209	-0.059	-0.052	-0.108	-0.367	0.123	-0.344	-0.353	0.106	-0.151	0.151	-0.149	-0.252	-0.132	-0.351	-0.388	**0.842**	-0.123	**-0.692**	**0.641**	**1**					
Cu	**0.868**	**0.782**	**0.713**	-0.246	0.362	**0.736**	-0.186	**-0.876**	**0.899**	-0.122	**-0.831**	0.296	**-0.589**	**0.589**	**-0.582**	0.235	0.184	-0.035	-0.152	-0.121	-0.242	**-0.653**	**0.819**	0.252	**1**				
Fe	**0.872**	**0.550**	**0.815**	0.029	0.096	**0.679**	-0.398	**-0.796**	**0.949**	0.066	**-0.735**	0.371	**-0.765**	**0.765**	**-0.760**	0.318	0.398	-0.373	-0.334	-0.082	0.051	**-0.824**	**0.913**	0.401	**0.939**	**1**			
Zn	**0.863**	**0.735**	**0.755**	-0.177	0.272	**0.756**	-0.273	**-0.882**	**0.927**	-0.095	**-0.835**	0.358	**-0.659**	**0.659**	**-0.653**	0.293	0.262	-0.123	-0.236	-0.110	-0.171	**-0.720**	**0.864**	0.293	**0.995**	**0.965**	**1**		
Ca/Mg	**0.693**	**0.516**	**0.783**	0.031	-0.159	**0.809**	**-0.634**	**-0.877**	**0.890**	-0.131	**-0.839**	**0.674**	**-0.854**	**0.854**	**-0.850**	**0.543**	**0.528**	-0.394	**-0.647**	0.043	0.047	**-0.938**	**0.976**	0.466	**0.842**	**0.926**	**0.889**	**1**	
Na/K	**0.806**	**0.559**	**0.848**	0.039	0.021	**0.769**	-0.489	**-0.840**	**0.966**	0.019	**-0.786**	0.491	**-0.819**	**0.819**	**-0.815**	0.435	0.470	-0.360	-0.429	-0.111	0.052	**-0.847**	**0.928**	0.359	**0.934**	**0.990**	**0.965**	**0.961**	**1**

Pearson coefficients in bold are those that are significant at the 5% level. Amyl: Amylose; Amyp : Amylopectine; CRE: Water retention capacity; TG: Swelling power; CRH: Oil retention capacity; TE: Moisture content; LB: Loose bulk; PB: Packed bulk; HR: Hausner ratio

4. Conclusions

At the end of this work, which aimed to highlight the influence of substituting wheat flour by coconut flour on the nutritional and techno-functional properties of blends, it was found that substitution did not affect water and protein content. It positively improves lipid and fiber content. The energy density increased with the percentage of coconut flour added. With the exception of potassium, the 7.5% coconut flour substitution resulted in the best mineral profile and calcium availability. The functional properties (swelling rate, OHC/WRC ratio, water and oil retention capacities) were better when coconut flour was incorporated at 7.5%. In terms of physical properties, pH was similar in all flours. The porosity decreased with coconut flour percentage, while the opposite effect was observed with loose bulk density and Hausner ratio. The tapped bulk density was higher with 100% wheat flour, and the addition of coconut flour had no effect on this parameter. The principal Component Analysis (PCA) revealed a similarity between the F2, F3 and F4 formulations, while the F1 formulation was more correlated with minerals and functional properties. These results thus demonstrate the contribution of coconut flour as a substitution agent on the physico-chemical and functional properties of the resulting products.

Limitations

Data on the amino acid composition, rheological properties and texture of the flours obtained should be completed.

Data on breadmaking trials with these flours should also be completed.

Ethics statements

The authors have read and followed the ethical requirements for publication and confirm that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

Author' contributions

Stephano Tambo Tene: Conceptualization, Methodology, Software, Writing- Original draft preparation.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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