Scientific Research Publishing

Journal of Agricultural Chemistry and Environment, 2024, 13, 169-181
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Study and Formulation of Composite Flours Based on Gluten Flour and Local Cereal Flours: Fonio, Millet and *Sorghum*

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How to cite this paper: Bah, L., Kourouma, K., Sakho, A.M., Diallo, A. and Sow, M.M. (2024) Study and Formulation of Composite Flours Based on Gluten Flour and Local Cereal Flours: Fonio, Millet and *Sorghum*. *Journal of Agricultural Chemistry and Environment*, **13**, 169-181.
https://doi.org/10.4236/jacen.2024.131011

Received: January 26, 2024
Accepted: February 24, 2024
Published: February 27, 2024

Abstract

This study makes it possible to establish baking flours of nutritional quality and technologically acceptable following the increase in their rheological parameters due to the insertion of gluten flour. The composite flours were obtained using the Philips mixer type (model HR2811). The nutritional qualities of the formulated flours were determined by the Kjeldahl, AOAC 985-29, UV-VIS spectrophotometry (DR 5000; HACH and LANGE, France) and Soxhlet gravimetric methods. The compounds obtained are respectively: Protein, carbohydrate, lipid, micronutrient and vitamin contents. Monitoring the analysis of functional properties (water and oil absorption capacity) as well as baking value.

Keywords

Cereal Flour, Gluten Flour, Bread Making, Biochemical and Rheological Properties

1. Introduction

The use bakery products made from wheat flour, particularly bread, in people's diets is now a major concern, and even non-wheat-producing countries today among the major demanders of this product. This important food product (wheat) is the exclusivity of the producing countries, which at the time of the economic crises, provoke an opportunistic increase in wheat prices like at marketing [1] [2] [3]. In 2022-2023, despite a bearish campaign on wheat prices, the price has remained unchanged, and even a rebound at €238/tons [4]. This situation is causing non-producing countries to devour huge amounts of foreign currency on wheat imports. The Republic of Guinea is a major importer of certain cereals such as rice and wheat, with almost: 544,135 and 532357.14 metric tons of rice and wheat flour per year, despite the presence in the country of two wheat flour processing units (Moulins d'Afrique and Grands Moulins de Conakry) which also import the raw material [5]. However, local agricultural production of all the country's species: fonio, millet, *sorghum*, rice, tubers and others is estimated at 7,309,844 tonnes, or approximately 8 million tons if other sources of breadmaking materials such as plantain are taken into account [6]. This trend could diminish if these available cereal and legume sources are processed into flours to partially or totally replace wheat flour in the baking industry [7]. To this end, various techniques for processing cereals (fonio, millet, *sorghum*, rice and tubers) in different forms and possible substitution of the wheat flour are growing gradually in Republic of Guinea and in many other African countries [1]. In the same order of ideas, numerous studies have been reported on techniques for formulating numerous types flours for cakes and breads in which part of the wheat flour is substituted by flours from local produce [8] [9] [10] [11] [12]. Indeed, taking the example of the cereals like as fonio, millet and *sorghum*, their chemical composition is similar to that of wheat flour, the only difference being that they do not contain gluten, the protein responsible for the breadmaking properties of all flours, which can be incorporated into these local flours to produce better-quality breads. This is why the strategy advocated by the FAO since 2008 encourages the use of these local resources available for partial or total substitution of flour of all kinds, with a view to reducing dependence on imports [4] [7]. The aim of this study is to continue the previous work carried out by our predecessors in the formulation of flours of all kinds from our local products, by formulating three different flours with the incorporation of 10% wheat flour in the flours of fonio, millet and *sorghum* (90%) for bread-making, follow up to carry out a physico-chemical analysis of the flours formulated and the breads produced. It should be noted these cereals used in this study, fonio is the least well known, but is one of the preferred crops of some West African countries. It is an herbaceous plant belonging to the grass family (*Poaceae*), with tiny seeds measuring around 1.5 mm and measure 80 cm in length. It is mainly consumed in certain regions of West Africa because of its ease of digestion and its tolerance for people allergic to gluten [13].

2. Materials and Methods

2.1. Materials

The composite flours produced from the cereals (Fonio, *Sorghum* and Millet) yeast and glutens flour used in this study were purchased from the locations indicated in (**Table 1**) and taken to the food technology laboratory of the Gamal Abdel Nasser University in Conakry (Republic of Guinea) (**Table 1**).

Table 1. Origin of local flours and gluten.

Designation	Guinée Maritime (GM)	Moyenne Guinée (MG)	Haute Guinée (HG)	Others
Gluten				My grocery France
Sorghum			Siguiri Market	
Fonio	Market Enco-5			
Millet		Mamou Market		

Equipment

- Péntrin
- Pastry cutter
- Thermometer
- Mechanical scale
- Oven (Fungand model topelec)
- Baker's blade
- Flour brush
- ChemDraw Ultra 7.0

2.2. Methods

2.2.1. Preparation of Cereal Flour

The cereal flours were produced in accordance with (**Diagram 1**).

Grain from the reception area undergoes the treatment shown in (**Diagram 1**). This is followed by polishing to remove the embryonic husk. The seeds are then soaked for an average of 3 to 12 hours. They are then drained and re-dried. This operation is immediately followed by milling, which extracts the flour. After sifting, the flour is roasted to further reduce its water content. The resulting flour is packaged in 1, 5, 10 or 50 kg packs, then sealed and packed in cartons or on pallets.

2.2.2. Formulation of Composite Flours

Composite flours are obtained by mixing gluten and flour from the cereals used in this study in the proportions: 90% flour: 10% gluten as shown in (**Table 2**). The mixture was homogenized using a Philips mixer (HR2811 model). The result is 100% wheat flour-based composite flours. The coloration of the composite flours is rectified by adding turmeric flour to each of the local flours.

2.2.3. Assessment of the Nutritional Quality of Composite Flours

Dry matter and ash contents were determined by oven-drying at 105˚C to constant weight using the NF V03-707 method [14]. Proteins were determined by the traditional Kjeldahl method [15]. Carbohydrates and fiber were determined by the AOAC 985-29 method. Micronutrients, iron and zinc were determined by UV-VIS spectrophotometry (DR 5000; HACH et LANGE, France). Lipids were determined using the Soxhlet gravimetric method. The gluten content of the composite flours was determined as described:

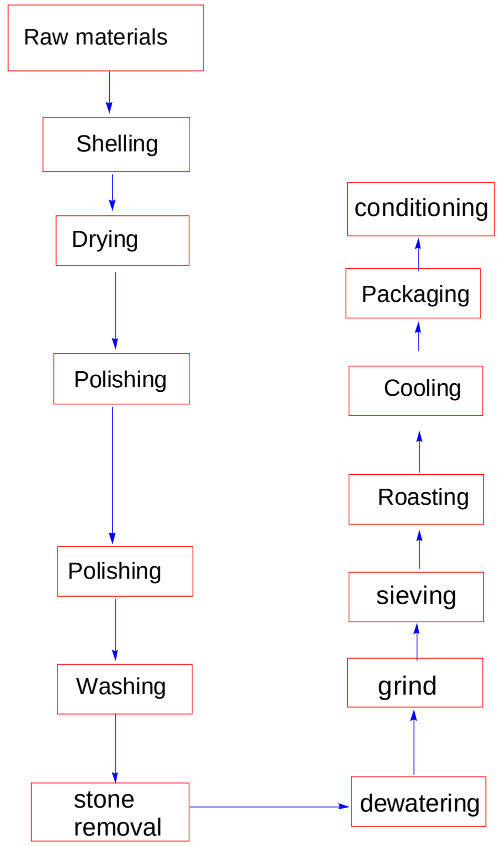

Diagram 1. Scheme of the flour preparation process of the cereals used in this study.

Table 2. Composite flour formulations.

Formulation	Local flours	Gluten
Sorghum flour (FS)	90%	10%
Fonio flour (FF)	90%	10%
Millet flour (FM)	90%	10%

Operating mode

Weigh 33.33 g of flour, mix with 17 ml of water (kneading the dough to form the dough piece) and the resulting 10 g flour dough piece was washed with a 2% NaCl solution. The resulting mass was wiped dry, weighed, oven-dried at 120˚C for 2 hours, cooled in a desiccator and then reweighed [16]. The mass of gluten obtained is determined by the formula:

$$MG = \frac{m}{10} * 100$$

Or *m*: weighed mass.

2.2.4. Analysis of Functional Properties

- **Water absorption capacity (WAC)**

It is determined according to method [17]. Which consists of: Take 1 g (m_0) of flour to disperse in 10 ml of distilled water. Shake for 30 minutes using a KS10 shaker, then centrifuge the mixture at 4500 rpm for 10 minutes. Weigh the wet pellet collected (m_2) and dry at 105˚C to constant weight (m_1). The water absorption capacity (WAC) was then determined using the formula:

$$\text{CAE} = \frac{m - m_0}{m} * 100$$

- **Oil absorption capacity (CAH)**

It is determined according to the method of [17] [18]. Which consists in taking 1 g (m_1) of flour to be dispersed in 7 ml of refined palm oil. Shake for 30 minutes using a KS10 shaker, and centrifuge the mixture at 4500 rpm for 10 minutes. Weigh the wet pellet collected (m_2) and dry at 105˚C to constant weight (m_3). The water absorption capacity (WAC) was then determined using the formula:

$$\text{CAH} = \frac{m_2 - m_1}{m_3} * 100$$

2.2.5. Determining the Baking Value

It represents all the plastic properties of doughs intended for bread-making, and is carried out using the CHOPIN alveograph. These tests are covered by standard NF ISO 5530-4: 2002.

- *Operating mode*

The method consists in gradually moving a fragment of mass dough in the form of a disk, under the influence of an air current, from the state to the natural limit of dough extension, where a break occurs. By recording a curve on a recording cylinder, it is possible to assess the flour's baking properties [17].

- *Analysis of dough behavior*

Add 2.5% salted water to 250 g flour. Knead the mixture (flour + water) for 2 minutes. Knead the resulting dough in the Chopin alveograph mixer (8 min, 60 rpm). Roll the dough back and forth on a glass plate using a roller. Lubricate dough with kerosene oil. Using a cookie cutter, cut the rolled dough into 5 pieces. Let dough pieces rest for 14 min, 25˚C in the alveograph relaxation chamber. Insert each dough piece between two metal plates to allow the open air valve to apply atmospheric pressure to the dough. Determine the paleographic parameters, notably the dough's toughness (P), extensibility (L), work of deformation (W) and balance between toughness and extensibility (P/L).

- *The energy value was determined using Coleman's empirical formula and the coefficients of Alwater and Rosa* [2] *as follows*:

E (calories) = 4(% Protein + % Carbohydrate) + (9 × % Lipids).

2.2.6. Statistical Analysis

Analyses are performed in triplicate and results are expressed on a dry matter basis. The data were then subjected to an analysis of variance (ANOVA) using StastSoft software (Tulsa, USA) to compare the means. In the event of a significant difference, the Newman-Keuls test was used to identify the means responsible for the observed difference at the 5% threshold.

3. Results

In this study, the provenance of the samples, schema of composite flour formulations, the formulation of composite flours based on cereals (fonio, *sorghum* and millet) and gluten in proportions of 90:10%, the composition and physico-chemical properties of local cereal flours before gluten insertion and flours after gluten insertion (gluten/local flours composites) are shown in the tables (**Tables 1-4**) flour preparation process in **Diagram 1**, the different flours obtained and the commercial gluten used are shown in **Figure 1**). This formulation gave us the following results: Proteins (fonio, millet and *sorghum*) from 1.1 to 0.2; 0.4 to 0; and 9.5 to 16.1 g%g respectively. Lipids from 7.2 to 14.01; from 7.1 to 13.9 and from 2.6 to 1.2 g%g. Carbohydrates from 71.6 to 65.5, 7.1 to 13.9, and from 66.2 to 54.6 g%g. Fiber from 2.6 to 2.0 g%g; from 2.7 to 1.9 and from 2.4 to 1.7 g%g respectively. Ash from 2.6 to 1.7; 2.8 to 2.1; and 3.1 to 2.2 g%g. Calories from 325.1 to 292.8; from 322.8 to 287.3; and from 326.2 to 280.7 Kcal. However, the values found: characteristics of pasta made from composite bread-making cereal flours, water and oil absorption capacity, the breads obtained and their characteristics, bread made from local cereal flours are shown in the tables and figure (**Tables 5-7** and **Figure 2**).

Table 3. Composition of cereal flours before gluten insertion.

Minerals and vitamins	Units	Fonio	Mil	*Sorghum*
Dry matter	g%g	84.9 ± 0.42	85.7 ± 0.37	83.8 ± 0.62
Proteins	g%g	7.2 ± 0.03	7.1 ± 0.05	9.5 ± 0.06
Lipids	g%g	1.1 ± 0.004	0.4 ± 0.002	2.6 ± 0.003
Carbohydrates	g%g	71.6 ± 0.60	72.7 ± 0.68	66.2 ± 0.39
Fibers	g%g	2.4 ± 0.04	2.7 ± 0.07	2.5 ± 0.05
Ashes	g%g	2.6 ± 0.04	2.8 ± 0.07	3.1 ± 0.05
Sodium	mg%g	55 ± 0.22	62 ± 0.25	58 ± 0.34
Potassium	mg%g	785 ± 2.59	912 ± 2.84	769 ± 3.51
Calcium	mg%g	110 ± 0.42	95 ± 0.85	130 ± 3.64
Phosphorus	mg%g	90 ± 0.22	117 ± 0.87	99 ± 0.51
Magnesium	mg%g	120 ± 0.41	93 ± 0.51	140 ± 0.95
Iron	mg%g	5.7 ± 0.007	4.8 ± 0.05	5.1 ± 0.09
Copper	mg%g	0.04 ± 0.001	0,03 ± 0.001	0.03 ± 0.001
Zinc	mg%g	0,05 ± 0.001	0.05 ± 0002	0.06 ± 0.002
β-carotene	µg%g	25 ± 0.13	40 ± 0.15	31 ± 0.12
Thiamin	mg%g	0.05 ± 0.002	0.07 ± 0.001	0.08 ± 0.003
Riboflavin	mg%g	0.05 ± 0.001	0.06 ± 0.001	0.08 ± 0.001
Niacin	mg%g	1.2 ± 0.005	2.1 ± 0.002	0,9 ±
Energy	Kcal	325.1 ± 5	322.8 ± 3	326.2 ± 6
	Kj	1358.9	1349.3	1363.5

Table 4. Composite gluten and local cereal flours after gluten insertion.

Nutrients	Units	(Fo + Gl)	(Mi + Gl)	(So + Gl)
MS	g%g	84.9 ± 0.72	85.7 ± 0.69	83.8 ± 0.71
Total proteins	g%g	14.25 ± 0.25	14.36 ± 0.40	15.35 ± 0.64
Gluten	g%g	7.2 ± 0.010	7.1 ± 0.09	9.5 ± 0.07
Lipids	g%g	0.7 ± 0.005	0.3 ± 0.008	2.3 ± 0.007
Carbohydrates	g%g	71.6 ± 0.82	72.7 ± 0.73	66.2 ± 0.65
Fibers	g%g	2.4 ± 007	2.3 ± 0.05	2.3 ± 0.04
Ashes	g%g	2.2 ± 0.8	2.2 ± 0.09	2.9 ± 0.07
Sodium	mg%g	55 ± 0.62	62 ± 0.53	58 ± 0.42
Potassium	mg%g	785 ± 4.25	912 ± 3.64	769 ± 4.35
Calcium	mg%g	105 ± 0.32	92 ± 0.38	121 ± 0.589
Magnesium	mg%g	85 ± 0.64	113 ± 0.70	88 ± 0.62
Phosphorus	mg%g	120 ± 0.22	93 ± 0.40	140 ± 0.35
Iron	mg%g	4.6 ± 0.05	3.7 ± 0.03	4.8 ± 0.07
Copper	mg%g	0.02 ± 0.001	0.01 ± 0.001	0.02 ± 0.001
Zinc	mg%g	0.03 ± 0.001	0.04 ± 0.002	0.04 ± 0.001
β-carotene	µg%g	27 ± 0.17	43 ± 0.15	35 ± 0.26
Thiamin	mg%g	0.04 ± 0.001	0.05 ± 0.002	0.05 ± 0.001
Riboflavin	mg%g	0.03 ± 0.001	0.04 ± 0.001	0.06 ± 0.001
Niacin	mg%g	0.6 ± 0.04	2.1 ± 0.02	0.7 ± 0.02
Energy	Kcal	92.14 ± 1.23	88.54 ± 31.18	120.1 ± 1.16
	Kj	1223.9	1200.9	1215.1

(Fo + Gl): fonio mixtures with gluten; millet with gluten (Mi + Gl) and *sorghum* with gluten (So + Gl).

Table 5. Characteristics of composite cereal bread flour pastes.

Parameters	units	(Fo + Gl)	(Mi + Gl)	(So + Gl)
Protein levels	g%	11.7 ± 0.42	11.9 ± 0.54	12.1 ± 0.54
Bakery strength (W)	J	162 ± 1.37	150 ± 1.16	155 ± 1.65
Extensibility (L)	mm	75.8 ± 0.52	76.7 ± 0.72	77.6 ± 063
Swelling index (G)	m^3	6.9 ± 0.65	17.60 ± 0.37	18.7 ± 034
Tenacity or Pressure (P)	mm	128 ± 0.11	132 ± 1.26	135 ± 1.27
Configuration report (P/L)	ND	1.69 ± 0.7	1.72 ± 0.27	1.74 ± 0.065

Table 6. Water and oil absorption capacity.

Parameters	Units	(Fo + Gl)	(Mi + Gl)	(So + Gl)
CAE	%	180.29 ± 1.46^a	115.62 ± 2.12^f	121.54 ± 1.49^e
CAH	%	104.38 ± 4.2^c	95.53 ± 2.19^d	98.30 ± 1.00^d

CAE: water absorption capacity; CAH: oil absorption capacity.

Table 7. Bread characteristics of local cereal flours.

Parameters	Units	(Fo + Gl)	(Mi + Gl)	(So + Gl)
Bread volume after 2H fermentation	2117	2075 ± 8.45	1661 ± 7.26	2003 ± 7.58
Bread weight after 2H fermentation	538	538 ± 3.57	388 ± 2.35	540 ± 3.16
Bread volume after 3H fermentation	2208	2121 ± 5.82	1715 ± 6.58	2076 ± 7.81
Bread weight after 3H fermentation	531	531 ± 1.56	352 ± 1.35	533 ± 1.57
Score out of 2 in Furnace	203/300	227/300	298/300	121/150

Figure 1. Showing flour of: millet, fonio, *sorghum* and wheat gluten.

Figure 2. Showing the three breads made from the flours of: millet, fonio, *sorghum* and wheat gluten.

The effect of adding gluten flour to cereal flours showed changes in paleographic parameters. At 10% insertion, led to different formulations with the following values (**Table 8**).

Table 8. Rheological characteristics.

Features	G + Fo (F1)	G + Mi (F2)	G + So (F3)
Bakery strength (W) (J)	160	150	155
Extensibility (mm)	75.8	76.7	77.6
Tenacity (P) (mm)	128	132	135
Swelling index (G) (m^3)	16.9	17.6	18.7
Rapport (P/L)	1.69	1.72	1.74

F1, F2 and F3 are the different formulations.

4. Discussion

Adding gluten flour to local cereal flours increases the total protein, lipid, fiber ash and energy content of composite flours. Protein contents before and after insertion vary from 7.2 to 14.25 g%g for fonio; from 7.1 to 14.36 for millet and from 9.5 to 15.35 g%g for *sorghum*. These protein contents for the millet and *sorghum* varieties used are higher than the millet and *sorghum* varieties used by [19], which are: 8 to 11.7 and 9.6 to 12.5 g%g respectively. Lipids from 1.1 to 0.7 g%g for fonio; from 0.4 to 0.3 for millet and from 2.6 to 2.3 g%g for *sorghum*. This protein content in the *sorghum* variety used in this formulation is higher than that used by [2] [12], which varies between 12.5%, 11% and 10.5% respectively. Carbohydrates from 71.6 to 71.6 for fonio, from 72.7 to 72.7 for millet and from 2.5 to 2.3 g%g for *sorghum*; fiber from 2.4 to 2.4 g%g for fonio, from 2.7 to 2.3 g%g for millet and from 2.5 to 2.3 g%g for *sorghum*; ash from 2. 6 to 2.2 g%g for fonio, 2.8 to 2.2 g%g for millet and 3.1 to 2.2 g%g for *sorghum*; calories: 325.1 to 92.14 Kcal%g for fonio; 322.8 to 88.54 Kcal for millet and 326.2 to 280. 120.1 Kcal for *sorghum*. This is probably due to the low carbohydrate and lipid content of gluten. However, the mineral elements in local cereal flours and composite flours. This is higher than in composite flours with a mass difference of 5.0, 1.1, 0.02, and 0.02 calcium, iron, copper and zinc respectively (**Table 3** and **Table 4**). Vitamin contents in local cereal flours and their composites also vary with the insertion of gluten: β-carotene 25 to 27 mg%g; 40 to 43 mg%g and 31 to 35 mg%g respectively. However, the other vitamins—thiamine, riboflavin and niacin—are present, albeit at low levels. According to [20], traditional hulling by friction, for example, to obtain cereal grains, can influence the content of certain nutrients such as iron by 10% to 12%. These protein and fiber contents in millet are higher than those found by [21] in the preparation of its infant flour formulated with local ingredients. The results obtained showed that mineral contents were as follows: Ca: 105; 92 and 121 mg%g; Mg: 85; 113 and 88 mg%g; Iron: 4.6; 3.7; and 4.8 mg%g; Cu: 0.02; 0.01; and 0.02 mg%g; Zinc: 0.03; 0.04 and 0.04 mg%g respectively.

- *Functional properties of composite flours*

The dough characteristics of composite flours bread-making cereals (**Table 5**) show a protein growth rate, and extensibility. The swelling index of (Fo + Gl) is significantly lower than that of the other formulated flours. Toughness and ratio of configuration of the three different formulations increase progressively, but with an average difference of 0.03 to 0.05 (**Table 5**). However, the bakery strength (F1) value (Fo + Gl) is higher than the others. However, all three values are appreciable, as they are greater than or equal to 150 as the limit value for bread-making [22]. The water absorption capacities of local fonio, millet and *sorghum* flours are respectively 180.29% for fonio flour, 115.62% for millet flour and 121.54% for *sorghum* flour. With regard to oil absorption capacity, their values are 104.38% for fonio flour, 95.53% for millet flour and 98.30% for *sorghum* flour (**Table 6**). **Table 7** shows the characteristics of bread made from local cereal flours and wheat gluten. We note an increase in bread weight after: 2 to 3 hours of fermentation: 538 to 531 and 388 to 352 for (Fo + Gl) and (Mil + Gl). This is probably due to the escape of air from the bread. However, this value decreases for the (So + Gl) mixture to 540 to 533. Also, bread volume increases after: 2 to 3 hours of fermentation for all combinations (Fo + Gl); (Mil + Gl) and (So + Gl). Baker's strength (W) is the deformability of the dough made by a flour. It is characterized by two parameters: elasticity and extensibility. The first is the dough's capacity to stretch and return to its original shape after an applied effort, while the second expresses its ability to be stretched without being torn. In terms of rheological characteristics, the baking strength values of formulated flours are given in **Table 8**. These values oscillate around 150 (G + Mi (F2); 155 (G + So) (F3) and 160 (G + Fo) (F1). These values are higher than 150, as a value below 150 is not suitable for bread-making [22] [23]. With regard to the extensibility of formulated flours, we note a slight difference of 0.8 to 1.8 mm with the highest value (G + So) (F3) at: 77.6. Toughness P and the P/L ratio increased with the insertion rate. The F3 formulation had the highest values for toughness and extensibility, at: 77.6 and 135 mm. Baking strength was highest with F1 (G + Fo), followed by F2 and F3 respectively. The swelling index is higher with F3 than the other two. An excellent study was made by [12] in a process for formulating composite flour (*sorghum* and wheat flours) with different incorporations: water absorption capacity 58%; tenacity 110%; extensibility 70%; with good bolting strength (W) 260% versus 121.54%; 135%; 77.6% and 155% respectively (**Table 6** and **Table 8**). This difference can probably be linked to the following parameters: variety, chemical composition of the growing medium (soil). According to [23], between 150 and 180 is the average for bread-making. For an extension, we carried out a chemical study to determine the lipid, carbohydrate, trace element and vitamin contents before and after formulation for all the flours formulated, including *sorghum* flour and gluten (So + Gl) (**Table 3** and **Table 4**), and the bread characteristics of the flours.

5. Conclusion

Cereals (fonio, *sorghum* and millet) are widely used for human consumption in many countries in Africa and elsewhere. For economic and health reasons, a formulation of cereal-based flours was developed in this work as a method of preparing flour for bread-making with the incorporation of gluten flour in local cereal flours (fonio, *sorghum* and millet) up to 10%, which will reduce wheat flour imports by at least 50%. In addition, the production of low-cost ready-to-use therapeutic foods (breads, cakes and gluten flour, cookies) based on composite flours made from local cereal flours will considerably reduce malnutrition among children under five. To this end, post-formulation studies were carried out to assess the nutritional quality of the composite flours (dry matter, protein, lipid, carbohydrate, ash and micronutrient contents), as well as their functional properties (water and oil absorption capacity) and baking value. The flours formulated had an appreciable baking strength of 150 Joule. Further studies are recommended, as these flours could be an alternative to make up for the shortfall in imported flours.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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