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Comparative Study of the Physicochemical Characteristics of High-Protein Gruels Adapted to the Nutritional Management of Malnourished Patients with or without Fistula

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Abstract

Malnutrition constitutes a major public health problem, particularly among hospitalized patients presenting complex conditions such as digestive fistulas. The objective of this study was to formulate and characterize two high-protein gruels (F1 and F2) based on local resources: maize, soybean, rice, pumpkin seeds, and caterpillars (*Imbrasia truncata*), suited to the nutritional management of malnourished patients with or without fistula. The raw materials were purchased in the markets of Brazzaville. The composite flours were produced by blending base flours obtained through established technological processes, then subjected to physicochemical analyses (moisture, protein, lipids, carbohydrates, ash, fiber, energy value, pH, titratable acidity, fat acidity, water activity) and functional analyses (water absorption capacity, oil absorption capacity, solubility index, swelling capacity, density, viscosity). The results show that both formulations exhibit high protein contents (39.66% ± 0.93% for F1 and 37.85% ± 0.06% for F2), high lipid contents (11.52% ± 0.60% for F1 and 17.80% ± 0.33% for F2), and energy values (421.67 ± 0.46 kcal/100g for F1 and 443.56 ± 0.22 kcal/100g for F2) above 400 kcal/100g, along with low moisture (below 12%) and water activity below 0.6, ensuring good storage stability. Formulation F1 stands out for its higher protein content, suited to fistula patients, whereas F2, richer in lipids and energy, is better suited to the progressive refeeding of severely malnourished patients. The prepared gruels show a Bostwick consistometer flow of 5.0 to 5.5 cm/30s, corresponding to a semi-thick consistency whose suitability for patients with swallowing disorders should be assessed against the IDDSI framework. These gruels represent a locally available, economically accessible, and technologically suitable nutritional alternative for therapeutic use in hospital or community settings.

Keywords

Malnutrition, Digestive Fistula, High-Protein Gruel, Composite Flour, Congo-Brazzaville

1. Introduction

Hospital malnutrition constitutes a major clinical and nutritional challenge in resource-limited countries. Worldwide, 20% to 50% of patients are malnourished or at risk upon admission. In sub-Saharan Africa, reported hospital prevalence ranges from 46% to over 70%, depending on the country, the ward, and the screening tools used (MNA, SGA, GLIM criteria), with documented effects on morbidity, mortality, and length of stay [1]. Among the most severe complications, digestive fistula is a particularly debilitating condition, associated with major protein, fluid, mineral, and micronutrient losses that worsen patients' malnutrition status [2].

Nutritional management of malnourished patients, with or without fistula, requires increased energy and protein intake to meet the needs related to tissue repair, immune system synthesis, and wound healing. Current recommendations call for a protein intake of 1.5 to 2.5 g/kg/day and an energy intake of 30 to 40 kcal/kg/day for these populations [3]. However, industrial nutritional support products remain costly and poorly accessible in African settings, which justifies the development of suitable local solutions. The Republic of the Congo, being rich in food resources, has the assets needed to address the problems posed by food imports. The country has nearly 100 million hectares of arable land (covering nearly 30% of its territory), of which less than 4% is cultivated [4]. The country spends nearly 600 billion FCFA (about 1 billion dollars) importing food products. This heavy dependence, which represents a very large share of the goods imported by the country, is explained by the need to cover household consumption needs [5].

The valorization of local food resources for the formulation of enriched flours and therapeutic gruels is a strategy widely explored in Africa. In a recent study conducted in the Republic of the Congo, Gampoula *et al.* demonstrated the nutritional potential of composite flours based on legumes, cereals, and edible insects in combating severe malnutrition in post-abdominal-surgery patients. That study revealed protein contents ranging from 24.34% ± 0.93% to 27.37% ± 0.62%, lipid contents ranging from 8.51% ± 0.15% to 15.44% ± 0.61%, and an energy density ranging from 411.75 ± 6.15 to 429.32 ± 5.01 kcal/100g [6].

In the Republic of the Congo, the consumption of caterpillars (*Imbrasia truncata*), rich in protein (on the order of 60% of dry matter), represents a well-established food tradition that offers considerable nutritional potential still underexploited in a therapeutic context [7]. Combining these edible insects with legumes such as soybean and cereals such as maize or rice can lead to complementary formulations with favorable essential amino acid profiles.

The main objective of this study is to formulate two high-protein gruels (F1 and F2) based on local resources available in the Republic of the Congo and to characterize their physicochemical and functional properties, with a view to their use in the nutritional management of hospitalized malnourished patients, with or without digestive fistula.

2. Materials and Methods

2.1. Materials

The plant material used consisted of maize, soybean, pumpkin seeds, and rice. The maize, soybean, and pumpkin kernels were purchased at the Tsiémé market, located in the 5th district (Ouenzé) of Brazzaville. The rice was purchased at the Bourreau market, located in the 1st district (Makélékélé) of Brazzaville.

Images of the plant material purchased are shown in **Figure 1** below:

Figure 1. Image of the plant material used.

The animal-derived product used in our study consisted of smoked caterpillars, which were purchased at the Tsiémé market in the 5th district (Ouenzé) of Brazzaville (**Figure 2**).

Figure 2. Image of the animal material, caterpillar (*Imbrasia truncata*).

2.2. Flour Production Flow Diagrams

For the preparation of the base flours, 1 kg of each plant and animal material was required. The base flours were produced according to the diagram (**Figure 3**) below: production of maize, soybean, pumpkin, and caterpillar flour (line 1) and rice flour (line 2).

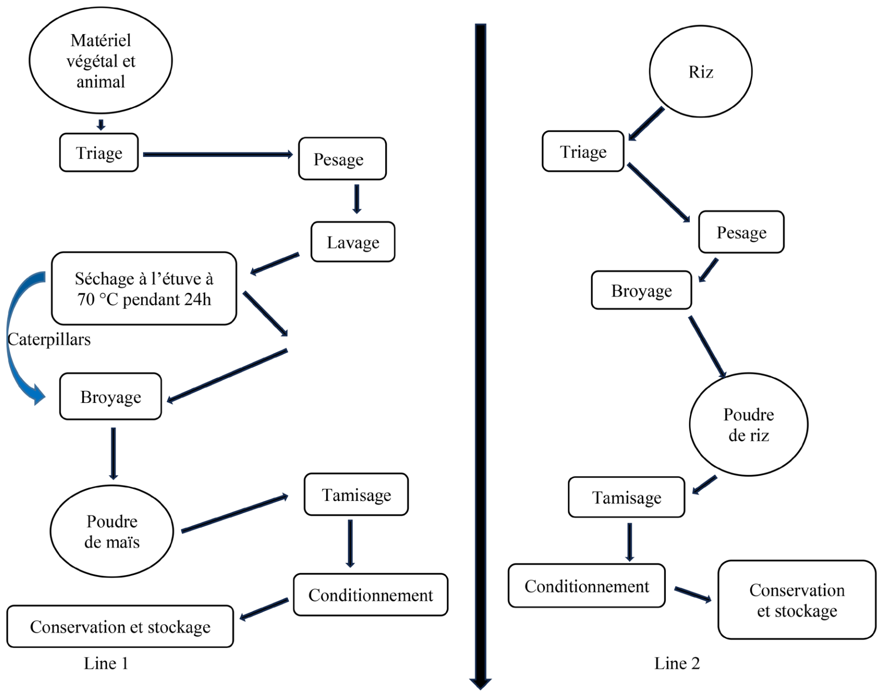

Figure 3. Flour production flow diagram.

Explanation of the unit operations used in the production of the various powders

Sorting: this essential unit operation consists of removing all impurities (broken grains, dead insects, straw, and others).

Weighing: this consists of taking the initial mass of the raw material.

Washing: After weighing, the raw material was washed with clean water to remove dust and any other type of impurity.

Drying: The products were dried in an oven at 70˚C for 24 h to reduce the moisture accumulated during washing and to preserve certain nutritional properties of the ingredients, such as heat-sensitive vitamins.

Roasting: This consists of roasting the grains at 137˚C for 25 min to eliminate antinutritional factors and improve organoleptic quality (color, odor, taste) through the "Maillard reaction", characterized by the appearance of a brown color and a pleasant odor. Rice and caterpillars were not roasted.

Milling: This step reduces the grains to powder using a mill. Milling was carried out using a laboratory screw mill.

Sieving: This operation separates coarse particles from fine particles to obtain a fine powder. In our case, we used a sieve with a mesh size of 160 μm.

Packaging, Preservation, and Storage: After sieving, the flours were stored in plastic containers and kept refrigerated at 4˚C to prevent any alteration of the product by microorganisms prior to characterization.

The composite flours were then obtained by homogeneously blending the fractions according to the defined proportions.

2.3. Formulation of Composite Flours

Two formulations (F1 and F2) were developed from five base flours. The blend proportions are shown in Table 1 below.

Table 1. Percentage of ingredients in formulated flours F1 and F2.

Flours and quantity / Base flour Farine de base	F1		F2	
	kg	%	kg	%
Soybean	1	33.34	3	42.86
Maize	-	-	2	28.57
Rice	1	33.33	-	-
Caterpillars	1	33.33	1	14.29
Pumpkin	-	-	1	14.29

The choice of proportions was guided by a twofold nutritional objective:

a) Achieving a protein content above 35% of dry matter, in line with the requirements of a high-protein diet suited to malnourished patients or those in the healing phase [3];

b) Ensuring amino acid complementarity between plant and animal sources, since soybean and caterpillars have complementary essential amino acid profiles [7] [8]. In formulation F1, the three ingredients were incorporated in equal parts (one third each) to maximize protein intake while maintaining good digestibility thanks to the rice starch, which also contributes to the smoothness of the gruel [9]. This formulation primarily targets fistula patients, for whom a high nitrogen intake is essential for tissue repair and fistula closure. In formulation F2, the soybean proportion is 42.86% to strengthen plant protein intake, while maize (28.57%) improves carbohydrate energy density and palatability. Pumpkin seeds (14.29%) and caterpillars (14.29%), incorporated in smaller proportions, respectively provide quality lipids (essential fatty acids) and complementary animal protein [10]. This formulation is more geared toward the progressive refeeding of severely malnourished patients, for whom the balance between energy and protein intake is essential to avoid refeeding syndrome [3].

2.4. Characterization of the Formulated Flours

Characterization of the formulated flours focused on physicochemical parameters and sensory properties.

2.4.1. Physicochemical Analyses

Moisture content was determined by oven-drying at 105˚C according to AOAC method 925.10 (2023). Protein was determined by the Kjeldahl method (AOAC 920.87, 1995), applying a conversion factor of 6.25. Lipid content was measured by Soxhlet extraction with hexane (AOAC 945.16, 2023). Ash was obtained by incineration at 550˚C in a muffle furnace (AOAC 942.05, 2023). Total carbohydrates were calculated by difference. Total fiber was determined according to AOAC 2011.25 (2023) by acid then alkaline hydrolysis. Energy value was estimated using Atwater coefficients. pH was measured by potentiometry on a 10% aqueous suspension, titratable acidity by titration with 0.1 N sodium hydroxide (ISO 750:1981), and fat acidity by ethanolic titration (NF ISO 7305:2019). Water activity (aw) was measured at 25˚C using a Rotronic-type hygrometer.

2.4.2. Functional Properties

The functional properties evaluated included oil absorption capacity (OAC) according to the method of Sosulski [11], water absorption capacity (WAC) and solubility index (SI) according to Phillips *et al.* [12] and Anderson *et al.* [13], the hydrophilic/lipophilic (H/L) ratio, swelling capacity (SC) by the method of Okezie and Bello [14], bulk density by volumetric ratio, and viscosity by Bostwick consistometer (reading at 30 s at 20˚C). To analyze viscosity, a preparation of 50 g of formulated flour was cooked in 250 mL of water for 15 min.

2.5. Statistical Analysis

Each parameter of a given sample was analyzed in triplicate. The results obtained made it possible to present the data as means ± standard deviations. Calculations were performed using Excel software.

3. Results and Discussion

3.1. Images of the Base Flours Produced

Images of the flours obtained are shown in Figure 4 below:

Figure 4. Image of the base flours.

Visual analysis of the images of the base flours shown in Figure 4 reveals a distinction in color and texture. Rice flour is white, unlike caterpillar flour, which is the darkest, with a very dark brown color. Maize flour is light yellow, soybean flour is light brown, while pumpkin flour is orange-yellowish with a lumpy texture.

3.2. Images of the Formulated Flours

The formulated composite flours are shown in Figure 5 below:

Figure 5. Image of the formulated flours produced.

The images shown in Figure 5 show the formulated flours F1 and F2, both of which are light beige-brown in color, with formulation 2 (F2) exhibiting a lumpy powder texture due to the presence of pumpkin flour. Formulation 1 (F1) is a darker powder due to its high caterpillar flour content. Formulation F2 has a slightly lighter color.

3.3. Physicochemical Composition of the Formulated Flours

The results of the physicochemical characterization of the two formulations are shown in Table 2.

Table 2. Physicochemical composition of formulated flours F1 and F2.

Parameters	F1	F2
Moisture (%)	5.66 ± 0.17	7.20 ± 0.38
aw	0.51 ± 0.00	0.49 ± 0.00
Protein (%)	39.66 ± 0.93	37.85 ± 0.06
Ash (%)	3.31 ± 0.05	4.16 ± 0.03
Lipids (%)	11.52 ± 0.60	17.80 ± 0.33
Carbohydrates (%)	39.85 ± 0.07	32.99 ± 0.04
Dietary fiber (%)	3.26 ± 0.03	3.53 ± 0.06
Energy value (kcal/100g)	421.67 ± 0.46	443.56 ± 0.22
pH	6.13 ± 0.60	6.45 ± 0.09
Titratable acidity (mmol H^+/100g)	0.88 ± 0.19	2.10 ± 0.01
Fat acidity (mg H_2SO_4/100g)	0.01 ± 0.00	0.01 ± 0.00

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Analysis of Table 2 shows:

3.3.1. Moisture and Water Activity

The moisture contents of the formulated flours range from 5.66% for F1 to 7.20% for F2. These values are slightly higher than the 5.38% ± 0.95% and 8.13% ± 0.66% reported by Gampoula *et al.* [6] for high-protein flours intended for malnourished patients after visceral surgery.

The water activities of F1 and F2 are 0.51 ± 0.00 and 0.49 ± 0.00, respectively. The water activity of F1 is slightly higher than that of F2. These water activities are similar to those reported by Gampoula *et al.* [6] for high-protein flours intended for malnourished patients after visceral surgery.

The low moisture contents (below 12%) and water activities below 0.6 ensure the microbiological stability of the flours during storage, this threshold being the one above which yeast and mold growth becomes possible [15].

3.3.2. Protein

Protein contents are high, reaching 39.66% for F1 and 37.85% for F2, respectively. The higher content of F1 is explained by the balanced proportion of caterpillar flour, which is particularly protein-rich, and soybean flour [7].

The protein contents of the two formulations (37.85% ± 0.06% - 39.66% ± 0.93%) are higher than the values reported for most African composite flours intended for infant or therapeutic nutrition. Gampoula *et al.* [6] report protein contents ranging from 27.37% ± 0.62% to 24.34% ± 0.93% in a study on high-protein flours based on caterpillars, maize, sorghum, and soybean intended for the management of post-visceral-surgery patients. Sanogo Bougma *et al.* [10], in their study on infant gruels based on sorghum, soybean, and moringa in Burkina Faso, report protein contents ranging from 16% to 22%, highlighting the benefit of incorporating edible insects such as caterpillars to significantly increase protein content. The addition of caterpillars (*Imbrasia truncata*) to boost the protein content of these formulations is consistent with the literature on entomophagy in Central Africa. Fogang Mba *et al.* [7] characterized *Imbrasia truncata* and *I. epimethea* in Cameroon, identified by DNA barcoding, and report approximately 20 g/100g fresh weight of protein, or on the order of 60% of dry matter. These contents were established using nitrogen-to-protein conversion factors determined specifically for these species (6.01 and 6.27), as the chitin in the exoskeleton makes the conventional factor of 6.25 unsuitable. The value of these matrices lies as much in protein quality as in raw content, with all essential amino acids exceeding the WHO/FAO/UNU reference profiles. Agbemafle *et al.* [16], working in Ghana on complementary foods based on orange-fleshed sweet potato enriched with edible insects at a 7:3 ratio, obtained 20.33 ± 0.58 g/100g of protein for the mixture containing crickets (*Acheta domesticus*) and 9.22 ± 0.20 g/100g for the one containing palm weevil larvae (*Rhynchophorus phoenicis*), compared to 16.08 ± 0.13 g/100g for the reference product, Weanimix. Our formulations F1 and F2 (37.85% -

39.66%) show significantly higher values; this is attributable to a much higher proportion of insects (33.33% caterpillars) and, above all, to the inclusion of soy, which was absent from the formulations used by *Agbemafle et al*.

3.3.3. Lipids

Lipid content is 11.52% ± 0.60% for F1 and 17.80% ± 0.33% for F2, the latter being enriched with particularly lipid-rich pumpkin seeds. Regarding lipid contents, formulation F2 shows lipid contents higher than the 8.51% ± 0.15% obtained by Gampoula *et al*. [6] in the Republic of the Congo for flours based on maize, soybean, sorghum, and caterpillars intended for post-visceral-surgery patients, while that of F1 remains below the 15.44% ± 0.61% obtained in the same study. The higher lipid intake of F2, related to the presence of pumpkin seeds, is nutritionally favorable for patients requiring a high energy density, particularly those in the refeeding phase after abdominal surgery or digestive fistula. These values are valuable, as these flours may provide an advantage for malnourished patients requiring a concentrated energy intake and essential fatty acids (omega-3 and omega-6) to support the immune response and wound healing [10].

3.3.4. Carbohydrates and Energy Value

Carbohydrate contents range from 32.99% ± 0.04% to 39.85% ± 0.07% for F2 and F1, respectively. The carbohydrate contents obtained are lower than those reported by certain authors, such as Gampoula *et al*. [17], who found contents between 54% and 61% with fish and yam flours, lower than the soybean + fish + sugar flours of Ponka *et al*. [18] (values between 85% and 88%), and lower than the high-protein flours intended for post-surgical malnourished patients reported by Gampoula *et al*. [6], who showed contents between 45.21% ± 0.01% and 59.24% ± 0.29%. A sufficient carbohydrate intake allows the body to avoid using protein as an energy source, which is important for tissue repair [19].

Energy values are 421.67 ± 0.46 kcal/100g for F1 and 443.56 ± 0.22 kcal/100g for F2. The energy value of F2 is higher than that of F1. The energy value of F1 and F2 is higher than the 411.75 ± 6.15 kcal/100g obtained by Gampoula *et al*. [6] with high-protein gruels based on cereals and caterpillars intended for malnourished patients after visceral surgery, but F1 remains below the 429.32 ± 5.01 kcal/100g obtained in the same study. The higher energy density of F2 compared with F1 may be due to its higher lipid content, lipids providing 9 kcal/g versus 4 kcal/g for protein and carbohydrates. This characteristic makes F2 suitable for the initial refeeding phases in patients with severe malnutrition, where a positive energy balance is a priority, while respecting the precautionary principle to avoid refeeding syndrome (RFS) [3]. These values remain below the energy density of 520 to 550 kcal/100g required for ready-to-use therapeutic foods under Codex guideline CXG 95-2022, which is expected given that these are reconstituted starch-based matrices rather than ready-to-use lipid pastes [20], but are consistent with the values reported for good-quality complementary gruels, around 120 kcal/100g of dry matter for the reconstituted gruel [21].

3.3.5. Ash and Dietary Fiber

Ash contents range from 3.31% ± 0.05% to 4.16% ± 0.03% for F1 and F2, respectively. The values obtained are higher than those reported by Soro *et al*. [15] for legume-based infant flours (1.5% - 2.5%) and than the 2% threshold usually adopted for infant flours [17]. This difference is explained by the incorporation of caterpillars and pumpkin seeds, matrices that are intrinsically richer in mineral matter than cereals and legumes alone. Minerals play an important role in the management of malnutrition: they help correct deficiencies, support the immune system, and prevent metabolic complications. This is why WHO protocols rely on therapeutic milks and ready-to-use foods fortified with a mineral and vitamin complex of specified composition. Analytically, ash content corresponds to the total mineral residue obtained after incineration of the organic matrix. As such, it is an initial indicator of a food's mineral richness, which elemental assay subsequently refines [6].

Fiber contents found were 3.26% ± 0.03% and 3.53% ± 0.06% for F1 and F2, respectively. These contents are higher than those found by Diallo *et al*. [22] for wheat and Bambara groundnut flours (0.40 and 1.00) and higher than the 1.19 ± 0.16 and 2.27 ± 0.09 reported by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients after visceral surgery. Dietary fiber helps maintain intestinal transit without inducing diarrhea, which is of particular importance in the post-abdominal-surgery context [23].

3.3.6. pH and Acidity

The pH values obtained are slightly acidic, ranging from 6.13 ± 0.60 for F1 to 6.45 ± 0.09 for F2. The pH values obtained are similar to those found by Diallo *et al*. [22] for legume and cereal flours (6.30 - 6.45) and to that of Njintang [24] (6.0 - 6.5) found for unfermented maize and sorghum flours. Similar values are reported in studies on lightly fortified fermented gruels [25], which show the protective effect of acidic pH on shelf life. The slightly acidic pH values (6.13 ± 0.60 - 6.45 ± 0.09) observed in our formulations are favorable for preservation and digestive tolerance. These near-neutral pH values also promote digestive enzymatic activity and gastric tolerance in convalescent patients [15].

Titratable acidity ranges from 0.88 ± 0.19 to 2.10 ± 0.01 mmol H^+/100g for F1 and F2, respectively, with F2 higher than F1. These values are lower than the 16.78 ± 0.13 and 25.94 ± 0.06 mmol H^+/100g obtained by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients after visceral surgery.

Fat acidity values range from 0.01 ± 0.00 to 0.01 ± 0.00 mg H_2SO_4/100g for F1 and F2, respectively; the two values are similar. These values are similar to the 0.005 ± 0.00 and 0.01 ± 0.00 mg H_2SO_4/100g reported by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients after visceral surgery. The low fat acidity levels indicate good chemical and microbiological stability of the products. Moreover, the very low fat acidity values (0.01 mg H_2SO_4/100g), well below the limit of 70 mg H_2SO_4/100g set by Codex STAN 152 [26], confirm the freshness and lipid stability of the formulated products.

3.4. Functional Properties of the Formulated Flours

The results of the functional properties are shown in Table 3.

Table 3. Functional properties of formulated flours F1 and F2.

Parameters	F1	F2
OAC (%)	99.06 ± 2.11	97.37 ± 3.96
WAC (%)	127.18 ± 2.98	122.13 ± 1.21
Solubility index (%)	84.75 ± 0.09	85.05 ± 0.17
H/L ratio	1.28 ± 0.17	1.25 ± 0.01
SC (%)	104.01 ± 0.04	105.00 ± 0.03
Density (g/mL)	0.49 ± 0.01	0.49 ± 0.00
Viscosity (cm/30s)	5.00 ± 0.01	5.50 ± 0.23

Analysis of Table 3 shows that:

3.4.1. Water and Oil Absorption Capacities

OAC values range from 97.37% ± 3.96% for F2 to 99.06% ± 2.11% for F1. The OAC of F1 is slightly higher than that of F2. WAC values are 127.18% ± 2.98% for F1 and 122.13% ± 1.21% for F2, respectively, that of F2 being slightly lower than that of F1.

The WAC of F1 and F2 are higher than the values of 57.27% ± 2.37% and 70.42% ± 8.26% reported by Gampoula *et al.* [6] for high-protein flours intended for malnourished patients after visceral surgery. In contrast, OAC values (99.06% ± 2.11% and 97.37% ± 3.96%) are markedly lower than the 199.91% ± 13.20% and 302.96% ± 7.42% of that same study, which may be related to the lower proportion of lipophilic matrices in our formulations. The high WAC values are explained by the protein richness of the formulations, proteins being known for their emulsifying and water-retention properties [8].

Both formulations show a good capacity to retain fat and water, respectively. These properties facilitate the preparation of homogeneous gruels and prevent phase separation in lipid-enriched preparations, an important technological advantage for formulations intended for administration in a clinical setting [27].

3.4.2. Solubility and Swelling

Solubility indices obtained range from 84.75 ± 0.09 to 85.05 ± 0.17 for F1 and F2, respectively; the two values are fairly close. The solubility indices obtained are higher than those reported by Diallo *et al.* [22] for Bambara groundnut and wheat flours (28.10 and 64.63) and by Pambou-Tobi *et al*. [28], who found values of 20 - 30, but lower than the 100 reported by Gampoula *et al*. [17] for a blend of gamboma yam and fish flours. These values are, however, similar to the 83.63 ± 0.50 and 84.63 ± 1.05 obtained by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients after visceral surgery.

Swelling capacity ranges from 104.01% ± 0.04% for F1 to 105.00% ± 0.03% for F2. The swelling capacities of the formulations are lower than those reported by Pambou-Tobi *et al*. [28] (250% - 320%) for flours composed of *Treculia obovoidea* and *Terminalia catappa* kernels and *Ipomoea batatas* leaves, and by Amoin *et al*. [21] (250% - 320%) for maize and sorghum infant gruels, but similar to the 102.5% ± 0.06% and 104.00% ± 0.19% obtained by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients after visceral surgery.

The swelling capacity of starch granules governs the energy density of gruels: the higher it is, the greater the volume of water bound during gelatinization, and the lower the dry-matter content achievable at an acceptable consistency. This constitutes a technological challenge in the formulation of high-nutritional-value gruels. Hydrolytic treatments such as the addition of exogenous amylases, malting, and lactic fermentation partially degrade the amylose and amylopectin chains. This lowers paste viscosity, allowing an increase in dry-matter content and, therefore, in energy density, without altering sensory acceptability [29]-[31].

3.4.3. H/L Ratio

H/L ratios are 1.28 ± 0.17 for F1 and 1.25 ± 0.01 for F2. The H/L ratio of F1 is slightly higher than that of F2. The H/L ratios found for formulations F1 and F2 are lower than those reported by Gampoula *et al*. [17] for gamboma yam and fish flours (1.33 and 2.12, respectively) and also lower than the 3.45 ± 1.83 and 4.71 ± 3.17 obtained with high-protein flours for malnourished patients [6], but higher than those of Diallo *et al*. [22] for wheat and Bambara groundnut flours (0.84 - 1.05) and of Njintang [24] for traditional unfermented maize, sorghum, and millet gruels (0.50 - 0.55). H/L ratios above 1 confirm the predominantly hydrophilic character of both flours, favorable to better integration in an aqueous medium during gruel preparation.

3.4.4. Density and Viscosity

The densities of the formulations are identical (0.49 ± 0.01 for F1 and 0.49 ± 0.00 for F2). They show a comparably light texture. The densities of F1 and F2 are lower than those found by Njintang [24] for local maize and sorghum flours (0.70 g/cm^3) and by Traoré *et al*. [30] for pearl millet flours from Burkina Faso (0.70 - 0.80 g/cm^3), but are close to those found by Gampoula *et al*. [6] for high-protein flours intended for malnourished patients (0.44 ± 0.10 and 0.48 ± 0.03). Density affects the amount of water needed to dilute the flour. A high-density flour requires a large amount of water to achieve a fluid consistency, which can affect dry-matter content and nutrient bioavailability [10].

The flow of the gruels on the Bostwick consistometer is 5.00 ± 0.01 cm/30s for

F1 and 5.50 ± 0.23 cm/30s for F2, with F2 flowing slightly better than F1. Since the Bostwick consistometer measures a flow distance, a higher value indicates a more fluid gruel: both formulations therefore show a semi-thick consistency. These values are lower than the 10 to 12 cm/30s flow rates reported by Amoin *et al.* [21] for malted or fermented infant gruels, indicating a higher viscosity for our formulations. This consistency is consistent with their high dry-matter content and high energy density, and illustrates the classic trade-off between nutritional density and fluidity [32]. Reducing it through malting, enzymatic hydrolysis, or extrusion cooking is a direct avenue for optimization, particularly if administration to patients with swallowing disorders were considered.

3.5. Images of the Prepared Gruels

Images of the gruels are shown in **Figure 6** below:

Formulation 1 (F1) Formulation 2 (F2)

Figure 6. Image of the gruels prepared from the formulations.

The images shown in **Figure 6** show that formulation F1 has a darker, browner shade than formulation F2. F2 is lighter in color. F2 shows light patches scattered throughout the mass, giving it a less homogeneous appearance than F1. These patches are due to the presence of pumpkin flour.

4. Prospects for Clinical Use

Based on their nutritional composition and functional properties, the two formulations show complementary profiles. Formulation F1, richer in protein (39.66% ± 0.93%) and with a slightly thicker consistency, appears particularly suited to patients with an active digestive fistula, for whom protein intake is necessary for fistula healing and tissue repair, in line with ESPEN recommendations [3], which call for 2.0 - 2.5 g/kg/day of protein in this case. Formulation F2, richer in lipids and more energy-dense (443.56 ± 0.22 kcal/100g), would be suitable for the refeeding phase of severely malnourished patients, where restoring energy reserves is a priority.

These results open up prospects for the use of these gruels in enteral or oral nutrition protocols in hospitals. Their low production cost, based on local raw materials, represents a considerable economic advantage over imported nutritional supplements. Further studies addressing microbiological quality, sensory evaluation, nutrient bioavailability, allergenic risks, and clinical trials in patients are needed to validate their therapeutic use.

5. Conclusions

This study made it possible to formulate and characterize two high-protein gruels (F1 and F2) based on local Congolese resources: soybean, maize, rice, pumpkin seeds, and caterpillars (*Imbrasia truncata*), with a view to their application in the nutritional management of malnourished patients with or without digestive fistula.

The physicochemical analyses demonstrate that both formulations have high protein contents (37.85% ± 0.06% - 39.66% ± 0.93%), energy values above 400 kcal/100 g, low moisture levels (below 12%), and water activities below 0.6, ensuring good stability and microbiological safety. Functionally, their high water and oil absorption capacities (WAC), good solubility index (SI), and measured consistency confirm their technological suitability for reconstitution into stable gruels that are usable in clinical settings.

Formulation F1, higher in protein, is particularly indicated for fistula patients requiring intense nitrogen intake for healing. Formulation F2, more energy-dense and lipid-rich, is better suited to the refeeding of severely malnourished patients. These gruels represent a locally accessible, economically viable, and technologically suitable nutritional alternative, whose clinical validation remains to be confirmed through trials.

Owing to their distinct nutritional profiles, both formulations appear to be promising candidates for therapeutic nutrition. Formulation F1, richer in protein, presents features of interest for fistula patients with high nitrogen requirements [3], while formulation F2, more energy-dense and lipid-rich, could be considered for the progressive refeeding of severely malnourished patients [3]. It should nonetheless be emphasized that these conclusions remain at the level of composition and technology: these are promising preliminary formulations, whose clinical application can only be considered after evaluation of digestive tolerance, actual nutrient digestibility, microbiological safety, and acceptability by the target patients [1]. These gruels therefore currently constitute locally accessible and economically viable nutritional prototypes, whose therapeutic relevance will need to be confirmed through rigorous preclinical and clinical studies.

Limitations of the Study

Several parameters essential to a complete nutritional validation were not measured in this study. The amino acid profile of the formulations was not determined, which precludes an objective assessment of protein quality or the digestibility-corrected chemical score (PDCAAS or DIAAS) [33]. Mineral and trace-element content (iron, zinc, calcium, phosphorus) was not assayed, limiting conclusions regarding the coverage of micronutrient needs in malnourished patients [1]. Antinutritional factors present in soybean and pumpkin seeds, such as phytates, trypsin inhibitors, and α-galactosides for the former, were not determined in the present study. These compounds are known to potentially lower protein digestibility, amino acid bioavailability, and mineral absorption. Accordingly, the Codex Alimentarius requires their reduction in formulations based on legumes and seeds [20]. The heat treatment applied during gruel production is expected to inactivate soybean antitrypsic activity, but phytates, being heat-stable, persist. Their assay, along with determination of the phytate/iron and phytate/zinc molar ratios, constitutes a direct perspective for this work. Finally, the microbiological quality of the finished products was not subjected to bacteriological analysis, which precludes certifying their safety for immunocompromised or vulnerable populations [15]. These missing data will need to be generated in future studies before any clinical use can be recommended.

Author Contributions

Conceptualization: **Gampoula, R.H.**, **Nguebili Ngandzounou, E.J.**; Methodology: **Gampoula, R.H.**; Formal Analysis: **Gampoula, R.H.**, **Nabsiona Mfouka, P.C.**; Investigation: **Gampoula, R.H.**, **Mahoumi Souleymane, H.L.** and **Nabsiona Mfouka, P.C.**; Resources: **Elenga, M.**, **Tamba Sompila, A.W.G.**, **Ntsossani, S.P.**; Supervision: **Gampoula, R.H.**; Writing original draft preparation: **Gampoula, R.H.**; Writing review and editing: **Gampoula, R.H.**, **Elenga, M.**, **Tamba Sompila, A.W.G.**; All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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