Journal of Biosciences and Medicines, 2026, 14(7), 388-404
https://www.scirp.org/journal/jbm
ISSN Online: 2327-509X
ISSN Print: 2327-5081

Physicochemical Characterization of High-Protein Gruels Intended for Malnourished Patients after Visceral Surgery

Reyes Herdenn Gampoula[1*], Michel Elenga[2], Arnaud Wenceslas Geoffroy Tamba Sompila[2], Roniche Nguie[3], Sylvia Pétronille Ntsossani[2], Haïchate Lucadéïde Mahoumi Souleyman[2], Eminance Jauffrey Nguebili Ngandzounou[4], Monika Vartey Mboussa Oleba[5]

[1]National Institute for Research in Engineering Sciences, Innovation and Technology, Food Processing Laboratory, Brazzaville, Republic of the Congo
[2]National Institute for Research in Engineering Sciences, Food Processing Laboratory, Brazzaville, Republic of the Congo
[3]National Institute for Research in Engineering Sciences, Food Microbiology Laboratory, Brazzaville, Republic of the Congo
[4]Digestive Surgery Department, University Hospital Center of Brazzaville, Brazzaville, Republic of the Congo
[5]Department of Food Sciences and Technologies, National Higher Polytechnic School, Marien Ngouabi University, Brazzaville, Republic of the Congo
Email: *herdenngampoula@gmail.com

How to cite this paper: Gampoula, R.H., Elenga, M., Tamba Sompila, A.W.G., Nguie, R., Ntsossani, S.P., Mahoumi Souleyman, H.L., Nguebili Ngandzounou, E.J. and Mboussa Oleba, M.V. (2026) Physicochemical Characterization of High-Protein Gruels Intended for Malnourished Patients after Visceral Surgery. *Journal of Biosciences and Medicines*, **14**, 388-404.
https://doi.org/10.4236/jbm.2026.147030

Received: June 23, 2026
Accepted: July 26, 2026
Published: July 29, 2026

Abstract

Post-surgical malnutrition is a frequent complication following visceral surgery, worsening the risks of complications and mortality. In the Republic of Congo, the lack of food formulations suited to these patients constitutes a major obstacle to their nutritional recovery. This study aimed to formulate and to characterize, from a physicochemical and functional standpoint, two high-protein gruels based on local raw materials, intended for malnourished patients after visceral surgery. The ingredients used include soybean, maize, sorghum, rice, smoked caterpillars (Imbrasia truncata), biscuits and spaghetti, which were purchased at the Total and Tsiémé markets. Selected physicochemical parameters (proteins, carbohydrates, lipids, ash) and functional properties (WAC, SI, WHC) were determined. The results show that the two formulations (F1 and F2) exhibit an acceptable moisture content (5.38 ± 0.95% for F2 and 8.13 ± 0.66% for F1) and a water activity below 0.6, ensuring microbiological stability. Protein contents are high (24.34 ± 0.93% for F2 and 27.37 ± 0.62% for F1), exceeding the 13% recommended by the WHO for infant flours and meeting the requirements of high-protein diets. The energy value is high (411.75 ± 6.15 kcal/100g for F2 and 429.32 ± 5.01 kcal/100g for F1). From a functional standpoint, the flours show a good water absorption capacity

(199.91 ± 13.20 to 302.96 ± 7.42%) and oil absorption capacity (57.27 ± 2.37 to 70.42 ± 8.26%), as well as a slightly acidic pH favouring their preservation. These results confirm that flours F1 and F2 display satisfactory nutritional and technological characteristics for use in postoperative clinical nutrition, particularly in the management of patients malnourished following visceral surgery.

Keywords

Composite Flours, Edible Insects, Proteins, Malnourished Patients, Congo-Brazzaville

1. Introduction

Visceral surgery, which encompasses operations on abdominal organs such as the intestine, stomach, liver or pancreas, induces substantial metabolic stress and an increase in nutritional requirements, particularly in energy and proteins. In operated patients, especially those with severe digestive pathologies, malnutrition is frequent and may compromise wound healing, prolong hospital stay and increase the risk of postoperative infections, or even affect the vital prognosis. According to the ESPEN 2017 recommendations [1] and the work of Arvanitakis *et al.* [2], appropriate nutritional management is essential in the postoperative period to limit these complications and improve clinical outcomes.

In the Republic of Congo, hospital nutritional management still relies largely on generic foods poorly suited to the clinical specificities of surgical patients. Local high-protein-density formulations, designed from available and affordable raw materials, represent a promising alternative to costly imported products. Soybean, cereals (maize, sorghum, rice) and edible insects such as smoked caterpillars (Imbrasia truncata) constitute sources of proteins and essential fatty acids widely consumed in the Congo basin [3]. Their incorporation into composite gruel formulations could meet both the nutritional requirements of postoperative recovery and the economic constraints of Congolese hospitals.

However, the valorization of these local resources within the framework of clinical nutrition requires a rigorous evaluation of their physicochemical and technological properties. Knowledge of the biochemical composition, functional properties and stability of the flours is essential to ensure the food safety and nutritional efficacy of gruels intended for malnourished patients. Viscosity, water absorption capacity and energy density are, in particular, determining criteria for the acceptability and tolerance of feeding in abdominal surgery patients [4].

Gruels are food forms that are widely consumed and well tolerated, particularly suited to patients with reduced appetite or presenting chewing or digestion difficulties. Enriched with protein sources (maize, sorghum, caterpillars, spaghetti, biscuits, soybean, rice), they can become an effective nutritional support, provided they have a balanced composition, good digestibility and an appropriate texture [5].

The present study therefore aims to formulate two high-protein composite flours based on local raw materials (soybean, maize, sorghum, rice, smoked caterpillars, biscuits, spaghetti) and to evaluate their physicochemical and functional characteristics with a view to their use in the nutrition of malnourished patients after visceral surgery in Congo-Brazzaville.

2. Materials and Methods

2.1. Materials

Biological Material

The biological material used consists of plant material and animal material.

The plant material used comprises: biscuits, spaghetti, maize, soybean, sorghum and rice. These products, together with the biscuits, were purchased at the Tsiémé market located in Ouenzé, 5th district of Brazzaville.

The images of the plant material used are presented in **Figure 1** below:

Figure 1. Images of the plant material used.

The animal material used in this study consists of smoked caterpillars, purchased at the Tsiémé market in the 5th district of Brazzaville (**Figure 2**).

Figure 2. Caterpillars (Imbrasia truncata).

2.2. Methods

Production of the Flours

Six (06) different base flours were obtained from the following materials: soybean, sorghum, maize, caterpillar, spaghetti, biscuits and rice.

1. Processing diagram of the different base flours

The diagram of the transformation of the base materials into flour is presented in Figure 3 below.

The production of soybean, sorghum, maize and caterpillar flours follows line 1, whereas that of rice flour follows line 2.

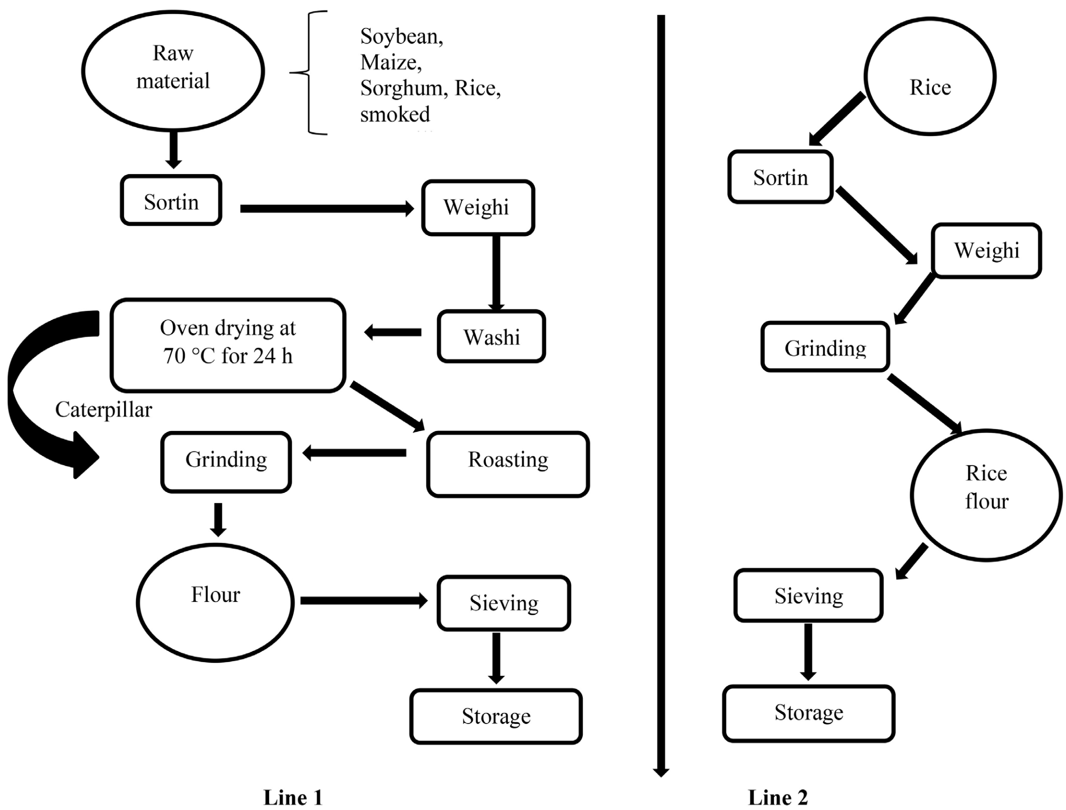

Figure 3. Processing diagram of the different base flours.

2. Description of the operations presented in the diagram

1) Sorting: This essential unit operation consists in removing all impurities (broken grains, waste and others).

2) Weighing: Recording the weight of each raw material on a precision balance.

3) Washing: This step allows the samples to be washed with clean water in order to remove dust and any other type of impurity.

4) Drying: This step removes the moisture accumulated during grain washing.

5) Roasting: Maize, soybean and sorghum grains were roasted at 137˚C for 20 min in order to eliminate anti-nutritional factors and to improve the organoleptic properties of the grains through the Maillard reaction, producing a brown colour. Caterpillars and rice were not roasted.

6) Grinding: This step consists in reducing the grains to powder in order to obtain a flour. After grinding, six different flours were obtained: maize, sorghum, soybean, rice, spaghetti, biscuit and caterpillars.

7) Sieving: This operation consists in separating fine particles from coarse particles using a sieve with appropriate mesh.

3. Formulation of the blends

The proportions of the ingredients were defined on the basis of two nutritional objectives: to reach a protein content above 20%, in accordance with the recommendations for high-protein diets intended for malnourished patients after surgery [1], and to ensure an adequate energy density (greater than or equal to 400 kcal/100g). Formulation F1, composed mainly of soybean (61.15%) and rice (30%), was designed as a plant-based high-protein source. Formulation F2 was made up of several cereals (maize, sorghum, rice) with the incorporation of smoked caterpillars (Imbrasia truncata) at 7.33%, in order to enrich the essential amino acid profile and to explore the addition of animal proteins in high-protein formulations.

For the formulation of the composite flours, the following formulations were used (**Table 1**):

Table 1. Quantities used for the formulation of the composite flours.

Products	Formulation 1 (F1)		Formulation 2 (F2)	
	Kg	%	kg	%
Soybean	2	48.80	4	28.60
Sorghum	-	-	1	7.10
Maize	-	-	4	28.60
Rice	1	24.40	4	28.60
Biscuits	0.878	21.42	-	-
Caterpillars	-	-	1	7.10
Spaghetti	0.22	5.40	-	-

2.3. Physicochemical Characterization and Properties

Moisture content was determined by oven drying at 105˚C according to AOAC method 925.10 (2023) [6]. Proteins were assayed by the Kjeldahl method (AOAC 920.87, 1995) [7]. Lipid content was measured by Soxhlet extraction with hexane (AOAC 945.16, 2023) [6]. Ash was obtained by incineration at 550˚C in a muffle furnace (AOAC 942.05, 2023) [6]. Total carbohydrates were calculated by difference. Total fibre was determined according to AOAC 2011.25 (2023) [6]. The energy value was estimated using the Atwater coefficients. The pH was measured by potentiometry on a 10% aqueous suspension, the titratable acidity by titration with 0.1 N sodium hydroxide (ISO 750: 1981) [8], and the fat acidity by ethanolic titration (NF ISO 7305: 2019) [9]. Water activity (aw) was measured at 25˚C using a Rotronic-type hygrometer.

The functional properties evaluated include the oil absorption capacity (OAC) according to the method of Sosulski [10], the water absorption capacity (WAC) and the solubility index (SI) according to Phillips *et al.* [11] and Anderson *et al.* [12], the hydrophilic/lipophilic ratio (H/L), the swelling capacity (SC) by the method of Okezie and Bello [13], the apparent (bulk) density by volumetric ratio, and the viscosity by Bostwick consistometer (reading at 30 s at 20˚C). To evaluate viscosity, 50 g of flour was prepared with 200 mL of water for 3 min.

2.4. Statistical Analysis of the Results

A single sample of each formulation was obtained and analysed. Each parameter was analysed 3 times. For the analysis of the results of the biochemical composition and functional properties, the following statistical values were considered: mean and standard deviation.

3. Results and Interpretation

3.1. Images of the Base Flours and Composite Flours

The base flours are presented in Figure 4 below:

Figure 4. Flours of the base samples.

The formulated composite flours are presented in Figure 5 below:

Figure 5. Composite flours.

3.2. Physicochemical Composition and Functional Properties of the Composite Flours

The parameters relating to the biochemical composition and the techno-functional properties of the samples are presented in Table 2 and Table 3.

3.2.1. Physicochemical Composition of the Composite Flours

The data on the physicochemical characterization of the formulated flours are presented in Table 2 below:

Table 2. Physicochemical composition of the composite flours.

Parameters	Flour 1 (F1)	Flour 2 (F2)
Water (%)	8.13 ± 0.66	5.38 ± 0.95
aw	0.47 ± 0.00	0.52 ± 0.01
Proteins (%)	27.37 ± 0.62	24.34 ± 0.93
Lipids (%)	15.44 ± 0.61	8.51 ± 0.15
Carbohydrates (%)	45.21 ± 0.01	59.24 ± 0.29
Ash (%)	3.84 ± 0.10	2.52 ± 0.09
Energy value (kcal/100g)	429.32 ± 5.01	411.75 ± 6.15
Dietary fibre	2.27 ± 0.09	1.19 ± 0.16
pH	6.66 ± 0.01	6.60 ± 0.013
Titratable acidity (mmol H+/100g)	25.94 ± 0.06	16.78 ± 0.13
Fat acidity (mg H_2SO_4/100g)	0.01 ± 0.00	0.005 ± 0.00

Analysis of Table 2 shows that:

1) Moisture

The composite flours present a water content ranging between 5.38 ± 0.95 and 8.13 ± 0.66%, and an aw between 0.47 ± 0.00 and 0.52 ± 0.01. The water content obtained is similar to the 7.19 - 8.21% of maize + soybean + smoked fish + sugar flours [14] and also to that of the Attiéké + soybean (5%) blends obtained by Zannou-Tchoko *et al.* [15]. The water content of these flours complies with the 12% standard set by the WHO for good flour preservation [16]. These flours present a good water activity below 0.6, the value above which certain moulds and yeasts can develop.

2) Proteins

The high protein content ranges between 24.34 ± 0.93 and 27.37 ± 0.62%. The protein level of flour F1 is higher than that of flour F2. This is explained by a higher level of soybean flour (rich in protein) in formulation F1 compared with formulation F2. These protein contents are higher than the 8.46 ± 0.03 and 11.01 ± 0.77% found respectively with flours made of maize + soybean + peanut + sugar and maize + soybean + smoked fish + sugar [14]. Owing to this richness in proteins, these flours can be used in high-protein diets to facilitate wound healing and combat muscle wasting.

Caterpillar flour in the diet of malnourished patients after surgery is important, because caterpillars are rich in essential amino acids such as histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine [3]. Soybean, for its part, is recognized as a high-quality plant-based alternative to animal proteins and a complete plant source of protein, containing all nine essential amino acids [17].

Proteins play a fundamental role in the nutritional recovery of severely malnourished individuals and of patients having undergone abdominal surgery. Indeed, they are essential for wound healing and tissue regeneration after surgery, and they take part in the synthesis of antibodies and digestive enzymes. In severely malnourished patients, a sufficient protein intake helps to maintain muscle mass [18]. These flours are therefore particularly suited to the high-protein postoperative diets recommended by the ESPEN guidelines [1].

3) Lipids

The lipid content ranges between 8.51 ± 0.15 and 15.44 ± 0.61%. The lipid level of Flour 1 is higher than that of flour F2. The high lipid level of F1 compared with F2 can be explained by the substantial contribution of soybean flour (20% lipids) to the blend. The lipid content of F1 is higher than the 10% and 8% found by Zannou-Tchoko *et al.* [15] respectively in infant flours made of attiéké + soybean and cassava + soybean. These contents of F1 and F2 are also far higher than the values found by Ponka *et al.* [14] in flours made of soybean + fish + sugar (2% maximum lipid content).

The lipids of caterpillars are rich in certain essential fatty acids such as oleic acid C18:1 (7.4%), linoleic acid C18:2 (7.6%) and linolenic acid C18:3 (36.8%) [3]. Soybean is a major source of antioxidants and phylloquinone, since its oil contains vitamin E (27.3 mg/100g, *i.e.* 182% of the daily requirement) and vitamin K1 (412 µg/100g, *i.e.* 343% of the daily requirement) [19]. Sorghum oil is composed mainly of unsaturated fatty acids (84%), including linoleic acid (C18:2, 45 - 55%) and oleic acid (C18:1, 25 - 35%), with a lower proportion of saturated fatty acids such as palmitic acid (C16:0, 10 - 15%). This composition gives it a nutritional profile close to that of other oils such as maize and sunflower oils. Lipids are important in a diet because they provide energy (9 kcal/g), which is important for organisms with high energy requirements but a reduced food intake capacity. By providing energy, lipids protect proteins from degradation in order to balance the body's energy requirements. Lipids are made up of fatty acids, among which omega-3 and omega-6 have beneficial effects on the postoperative inflammatory response. Lipids facilitate the absorption of vitamins A, D, E and K, essential for wound healing and immunity [20].

4) Carbohydrates

The carbohydrate content ranges between 45.21 ± 0.01 and 59.24 ± 0.29%. The carbohydrate content of F2 is higher than that of F1. The carbohydrate contents obtained are slightly similar to those of the fish and yam flours of Gampoula *et al.* [21] (content between 54 and 61%) but lower than the soybean + fish + sugar flours of Ponka *et al.* [14] (values between 85 and 88%).

Carbohydrates are essential in a diet because, according to the RDIs (Recommended Daily Intakes), the carbohydrate energy contribution in a ration is between 45 and 55%. After surgery, metabolic requirements increase. A sufficient carbohydrate intake allows the body to avoid using proteins as an energy source, which is important for tissue repair [22].

5) Ash

The ash content oscillates between 2.52 ± 0.09 and 3.84 ± 0.10%. The ash content of F2 is lower than that of F1. The ash content is higher than that of the soybean + fish + sugar gruels of Ponka *et al.* [14], whose maximum value was 1%; however, it is lower than the 5% found upon substitution of 20% of wheat flour with bambara groundnut [23]. Caterpillars, soybean, sorghum and the other cereals are rich in micronutrients, among which are K, P, Ca, Na, Zn, Fe, Cu and Mg [3] [24] [25].

Minerals play a vital role in the management of malnourished patients; they help to combat deep deficiencies, support the immune system and prevent metabolic complications [26]. The WHO emphasizes the importance of vitamin-mineral mixtures in therapeutic milks and ready-to-use foods. The ash content determines the quantity of minerals contained in a product [27]. Ash content reflects the total mineral content of the food and serves as an initial indicator of its mineral richness [28].

6) Energy value

The high energy value ranges from 411.75 ± 6.15 to 429.32 ± 5.01 kcal/100g. The energy value of F2 is lower than that of F1. The energy value of the flours is similar to the 400 - 440 kcal/100g found with the flours of Treculia obovoidea + Terminalia catappa almonds + Ipomoea batatas leaves [29]. A balanced energy value is essential in the fight against severe malnutrition, because it covers the metabolic requirements of patients, restores body reserves and contributes to tissue growth and repair. Ready-to-use therapeutic foods (RUTF) and enriched milks (F-75, F-100) are formulated to provide a high energy density (520 - 550 kcal/100g) [30]. After abdominal surgery, metabolic requirements increase, and a sufficient caloric intake allows the body to spare its proteins by preventing them from being used as an energy substrate at the expense of tissue repair [20].

7) Dietary fibre

The dietary fibre ranges between 1.19 ± 0.16 and 2.27 ± 0.09%. The fibre content of F1 is higher than that of F2. The fibre content is higher than that of the wheat + bambara groundnut flours (0.40 + 1.00) found by Diallo *et al.* [23]. Dietary fibre acts as a broom allowing better intestinal transit and thus better elimination of waste. It helps combat the constipation frequent after abdominal surgery. It promotes the growth of bacteria, strengthening intestinal immunity. Fibre slows carbohydrate absorption, stabilizing blood glucose in weakened patients [4].

8) pH and titratable acidity

The pH of the flours ranges between 6.60 ± 0.013 and 6.66 ± 0.01. The pH values of the two formulations are similar.

The titratable acidity values oscillate between 16.78 ± 0.13 and 25.94 ± 0.06 mmol H+/100g. The titratable acidity of F1 is higher than that of F2.

The pH obtained is similar to that of the wheat + bambara groundnut flours (6.30 to 6.45) found by Diallo *et al.* [23] and to that of Njitang [31] (6.0 - 6.5) found with unfermented maize and sorghum flours. The composite flours obtained present an acidic pH. Acidic pH values allow good preservation because they inhibit the proliferation of certain microorganisms, which is essential for products intended for vulnerable individuals. An acidic pH prolongs the shelf life of flours and gruels by reducing the risk of spoilage [32].

Titratable acidity makes it possible to determine the level of organic acids present in a food. A high titratable acidity may indicate fermentation or degradation, whereas a low, controlled value ensures a stable and wholesome flour [32].

9) Fat acidity

The fat acidity ranges between 0.005 ± 0.00 and 0.01 ± 0.00 mg H_2SO_4/100g. The value of F1 is higher than that of F2. Fat acidity makes it possible to measure the level of free fatty acids in the flours. This value serves to verify the quality of the lipids contained in the flours. As these values are below 70 mg H_2SO_4/100g, the flours produced are of good quality (Codex STAN 152 [33]).

3.2.2. Functional Properties of the Composite Flours

The values of the functional properties of the formulated flours are presented in **Table 3** below:

Table 3. Functional properties of the composite flours.

Parameters	Flour 1 (F1)	Flour 2 (F2)
WAC (%)	302.96 ± 7.42	199.91 ± 13.20
SI	83.63 ± 0.50	84.63 ± 1.05
OAC (%)	70.42 ± 8.26	57.27 ± 2.37
H/L	4.71 ± 3.17	3.45 ± 1.83
SC (%)	104.00 ± 0.19	102.5 ± 0.06
D (density)	0.44 ± 0.10	0.48 ± 0.03
Viscosity (cm/30 s)	7 ± 0.05	9 ± 0.07

Analysis of **Table 3** shows that:

1) Water absorption capacity (WAC) and solubility index (SI)

The water absorption capacity (WAC) of the composite flours ranges between 199.91 ± 13.20 and 302.96 ± 7.42%, with a solubility index ranging between 83.63 ± 0.50 and 84.63 ± 1.05. The WAC of F1 is higher than that of F2, whereas the SI of F2 is similar to that of F1.

The WAC values found are higher than those of the wheat + bambara groundnut flours obtained by Diallo *et al.* [23] (96.95 to 190.36%) but similar to the

199.02% found by Gampoula *et al.* [21]. A high water absorption capacity makes a flour particularly suited to bakery and pastry uses. Indeed, the more the flour retains water, the softer and easier to handle the resulting dough, while preserving good freshness after baking [23]. The water absorption capacity of gruels is a limiting factor of their energy value. A gruel with a high WAC requires substantial dilution, which leads to a low energy density of the prepared gruels. This effect limits their nutritional contribution for children, hence the importance of adding amylases or modifying the manufacturing processes in order to reduce viscosity and increase the dry-matter content [31].

The flours obtained present an SI far higher than that of the bambara groundnut + wheat flours, which showed SI values ranging between 28.10 and 64.63 [23], but lower than the 100 obtained with the gamboma yam + bambara groundnut + fish gruel [21]. A high index indicates a better breakdown of starch, which makes the gruel easier to assimilate. It allows more flour to be added without making the gruel too viscous, which increases the energy density. Gruels with a good solubility index are more fluid, easy to swallow and better accepted by malnourished children [31].

2) Oil absorption capacity (OAC)

The oil absorption capacity (OAC) of the formulations ranges between 57.27 ± 2.37 and 70.42 ± 8.26%. The OAC of F1 is higher than that of F2. The OAC of the flours produced is lower than the values obtained with a wheat + bambara groundnut flour blend (between 93.53 and 123.30%) by Diallo *et al.* [23], than the 80% obtained by Gampoula *et al.* [21] on gamboma yam + bambara groundnut + fish flours, but lower than the 100 and 250% found by Njintang [34] and than the 180 and 220% found by Mbome *et al.* [35]. These high OAC values show that flours F1 and F2 present a good retention of the aromas that could be added during cooking. The OAC of a plant-derived product is defined by the ability of a food component to trap oil, which influences the techno-functional properties of the formulated food products [36].

3) Hydrophilic/Lipophilic ratio

The hydrophilic-lipophilic (H/L) ratios of the formulations are close and range between 3.45 ± 1.83 and 4.71 ± 3.17. The H/L values obtained for the formulated flours are higher than those of the gamboma yam + bambara groundnut + fish flour prepared by Gampoula *et al.* [21], who found 1.99, and also than those of the wheat + bambara groundnut flour (0.84 - 1.05) found by Diallo *et al.* [23]. As the H/L ratio is above 1, the formulated flours F1 and F2 are more affine to water than to oil.

A good H/L balance allows better stabilization of flour blends containing lipids, which is useful for enriched preparations [37].

4) Swelling capacity (SC)

The swelling capacity of the flours ranges between 104.00 ± 0.19 and 102.5 ± 0.06% for F1 and F2 respectively. These two swelling capacities are similar. The SC of the composite flours is lower than those reported by certain authors, such as 250 - 320% by Pambou-Tobi *et al.* [29] with flours made of Treculia obovoidea + Terminalia catappa almonds + Ipomoea batatas leaves, 250 - 320% by Kouassi Kunimboa *et al.* [38] with infant gruels of maize and sorghum, 200 - 250 by Traoré *et al.* [39] with pearl millet flours in Burkina Faso, and 240 - 280 by Watad *et al.* [40] with a plantain + sesame + baobab blend flour.

A good swelling capacity makes it possible to obtain lighter, more digestible and more pleasant-to-consume gruels or pastes. It promotes food hydration, which is essential for patients with increased water requirements or sensitive digestion [37].

The higher the swelling capacity, the more viscous the gruel, especially for children. An increase in SC decreases the energy density. The addition of amylases, fermentation or germination reduces viscosity and makes it possible to increase the dry-matter content without altering acceptability [31] [35] [39].

5) Density (d)

The densities relative to water (D) are close and range between 0.44 ± 0.10 and 0.48 ± 0.03. The densities obtained are lower than the 0.70 - 0.80 found with pearl millet flours (Burkina Faso) by Traoré *et al.* [39], than the 0.65 - 0.75 with fermented maize and sorghum flours by Mbome *et al.* [35] in 2005, and than the 0.70 obtained by Njitang [31] with local flours (maize, sorghum). A flour with low density is lighter, which can facilitate digestion and the formulation of gruels suited to fragile patients. Knowing the density makes it possible to better dose the ingredients according to volume, which is essential for controlled diets [37].

6) Viscosity

The viscosity of the gruels made from the formulated flours oscillates between 7 ± 0.05 and 9 ± 0.07 cm/30 s. Gruel F1 is more fluid than F2. The viscosities of F1 and F2 are similar to the 1000-2000 cP obtained by Trèche [41] on infant gruels. 1000 - 2000 cP corresponds to a viscosity of about 7 - 10 cm/30s on the Bostwick consistometer. Viscosity depends on the quantity of water used to prepare the gruel and on the cooking time. The quantity of water used, the cooking time and the WAC index are important factors in determining the final energy density of a preparation. The moderate viscosity of the gruels (7 to 9 cm/30s) offers a significant clinical advantage. In patients having undergone visceral surgery, foods that are too viscous can exert mechanical pressure on intestinal sutures and impede transit at the anastomoses. An appropriate viscosity ensures digestive tolerance and acceptance of the diet during the convalescence phase [4].

3.3. Images of the Gruels Prepared from the Composite Flours

The images of the gruels prepared from the composite flours are presented in **Figure 6** below:

On the basis of the images presented, a difference in colour can be observed between the two gruels prepared from composite flours. Formulation 1 presents a lighter, more uniform brown-beige colour. Formulation 2 presents a darker brown-beige colour and appears slightly speckled or dotted with darker points. These colour variations are the result of a different composition of the composite flours (that is, of the types or proportions of ingredients used). Thus, the darker colour is due to the caterpillar flour.

Formulation 1 **Formulation 2**

Figure 6. Image of the prepared gruels.

4. Conclusions

The aim of this work was to characterize gruel recipes used for patients after abdominal surgery.

The flours obtained presented a good moisture content (5.38 ± 0.95 and 8.13 ± 0.66%) and a low water activity (0.47 ± 0.00 and 0.52 ± 0.01). These flours ensure good microbiological stability and good preservation. Formulations F1 and F2 used after surgery are rich in proteins (24.34 ± 0.93 and 27.37 ± 0.62%). These flours present a marked nutritional importance, particularly in high-protein diets. These flours presented a low carbohydrate content (45.21 ± 3.01 and 59.24 ± 0.29) but a good energy value (411.75 ± 6.15 and 429.32 ± 5.01 kcal/100g DM) likely to meet the energy requirements of patients while sparing proteins.

For the functional parameters, these flours presented low WAC values (199.91 ± 13.20 and 302.96 ± 7.42%) owing to their low carbohydrate content. The flours presented high OAC values (57.27 ± 2.37 and 70.42 ± 8.26), which showed that these flours had good water retention and revealed a technological aptitude favourable to their use in various food products, notably bread, pasta and thickened gruels.

Moreover, the weakly acidic pH values and the low levels of fat acidity confirm the chemical stability and the quality of the lipids present.

Thus, flours F1 and F2 stand out for their promising nutritional characteristics and functional properties. They constitute preliminary trials whose importance for postoperative clinical nutrition deserves to be explored, with further work on clinical tolerance, digestibility, microbiological quality and organoleptic properties by patients. The current data demonstrate their biochemical composition and technological functionality, but do not yet allow conclusions to be drawn regarding their clinical efficacy.

As perspectives, this study presents several limitations that should be highlighted. The amino acid profile of the composite flours was not determined, which does not allow the protein quality in the strict sense to be confirmed. The mineral content (K, Ca, Fe, Zn, Mg) was not determined. The anti-nutritional factors present in soybean, sorghum and caterpillars, such as trypsin inhibitors, phytates or tannins, were not determined, although they can reduce the bioavailability of nutrients in fragile patients. Finally, the microbiological quality of the flours and prepared gruels was not evaluated, which is an indispensable prerequisite before any use in a clinical setting. These aspects will have to be integrated into future work in order to validate the safety and nutritional efficacy of these formulations in the context of postoperative management.

Acknowledgements

The authors express their profound gratitude to the University Hospital Centre of Brazzaville for making the food formulations intended for analysis available to the laboratory, thereby bringing scientific research closer to clinical realities. Our thanks also go to the National Higher Polytechnic School (ENSP) for making its students available, whose commitment and rigour contributed significantly to the completion of this work. Finally, we extend particular recognition to INRSIIT, which mobilized its researchers and opened the doors of its laboratory, providing the technical means indispensable for conducting the physicochemical and functional analyses.

Conflicts of Interest

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

References

[1] Weimann, A., Braga, M., Carli, F., Higashiguchi, T., Hübner, M., Klek, S., *et al.* (2017) ESPEN Guideline: Clinical Nutrition in Surgery. *Clinical Nutrition*, **36**, 623-650. https://doi.org/10.1016/j.clnu.2017.02.013

[2] Arvanitakis, M., Ockenga, J., Bezmarevic, M., Gianotti, L., Krznaric, Z., Lobo, D.N., Nunes, G., Pichard, C., Preiser, J.C., Wernerman, J. and Deutz, N. (2008) Nutrition in Acute Pancreatitis: A Position Paper of the Working Group for Nutrition and Acute Pancreatitis of the European Society for Clinical Nutrition and Metabolism (ESPEN). *Clinical Nutrition*, **27**, 195-201.

[3] Mabossy-Mobouna, G., Kinkela, T. and Lenga, A. (2017) Apports nutritifs des chenilles d'Imbrasia truncata consommées au Congo-Brazzaville. *Journal of Animal and Plant Sciences*, **31**, 5050-5062. http://www.m.elewa.org/JAPS

[4] Benkahla, Y.K. and Makhlouf, H. (2021) Importance des régimes alimentaires conseillés dans des cas post-opératoires. Mémoire de Master, Université Abdelhamid Ibn Badis de Mostaganem. https://123dok.net/document/y8g0ek4z-importance-des-regimes-alimentaires-conseilles-dans-des-cas-post-operatoires.html

[5] Bamisagora (2024). Les bouillies—Généralités (Version du 23/11/2024). https://bamisagora.org/documents_pdf/02B-Les_bouillies-Generalites.pdf

[6] AOAC (2023) Official Methods of Analysis of AOAC International. 22nd Edition, AOAC International.

[7] AOAC International (1995) Official Method 920.87: Protein (Total) in Flour—

Kjeldahl Method. In: *Official Methods of Analysis of AOAC International*, 16th Edition, AOAC International.

[8] International Organization for Standardization (ISO) (1981) ISO 750:1981—Fruits, légumes et produits dérivés—Détermination de la teneur en acidité titrable. ISO.

[9] AFNOR (2019) NF ISO 7305:2019—Céréales et produits céréaliers—Détermination de l'acidité grasse (méthode de référence). Association Française de Normalisation (AFNOR).

[10] Sosulski, F.W. (1962) The Centrifuge Method for Determining Flour Absorption in Hard Red Spring Wheat. *Cereal Chemistry*, **39**, 344-350.

[11] Phillips, R.D., Chinnan, M.S., Branch, A.L., Miller, J. and McWatters, K.H. (1988) Effects of Pretreatment on Functional and Nutritional Properties of Cowpea Meal. *Journal of Food Science*, **53**, 805-809. https://doi.org/10.1111/j.1365-2621.1988.tb08959.x

[12] Anderson, R.A., Conway, H.F., Pfeifer, V.F. and Griffin, E.L. (1969) Gelatinization of Corn Grits by Roll and Extrusion Cooking. *Cereal Science Today*, **14**, 4-12.

[13] Okezie, B.O. and Bello, A.B. (1988) Physicochemical and Functional Properties of Winged Bean Flour and Isolate Compared with Soy Isolate. *Journal of Food Science*, **53**, 450-454. https://doi.org/10.1111/j.1365-2621.1988.tb07728.x

[14] Ponka, R., Tchatchoua Nankap, E.L., Tabot Tambe, S. and Fokou, E. (2016) Composition nutritionnelle de quelques farines infantiles artisanales du Cameroun. *International Journal of Innovation and Applied Studies*, **16**, 280-292.

[15] Zannou-Tchoko, V., Ahui Bitty, L., Kouamé, K., Bouaffou, K. and Dally, T. (2011) Utilisation de la farine de maïs germée source d'alpha-amylase pour augmenter la densité énergétique des bouillies de sevrage à base de manioc et de son dérivé, l'attiéké. *Journal of Applied Biosciences*, **37**, 2477-2484.

[16] Soro, S., Konan, G., Koffi, E., Elleingand, E. and N'guessan, D. (2013) Formulation d'aliments infantiles a base de farines d'igname enrichies au soja. *African Journal of Food, Agriculture, Nutrition and Development*, **13**, 8313-8339. https://doi.org/10.18697/ajfand.60.12655

[17] Friedman, M. and Brandon, D.L. (2001) Nutritional and Health Benefits of Soy Proteins. *Journal of Agricultural and Food Chemistry*, **49**, 1069-1086. https://doi.org/10.1021/jf0009246

[18] Isabel, T.D. and Correia, M. (2003) The Impact of Malnutrition on Morbidity, Mortality, Length of Hospital Stay and Costs Evaluated through a Multivariate Model Analysis. *Clinical Nutrition*, **22**, 235-239. https://doi.org/10.1016/s0261-5614(02)00215-7

[19] USDA (2025) FoodData Central: Soybean Oil, Nutrition Facts and Analysis. United States Department of Agriculture. https://fdc.nal.usda.gov

[20] Barazzoni, R., Deutz, N.E.P., Biolo, G., Bischoff, S., Boirie, Y., Cederholm, T., *et al.* (2017) Carbohydrates and Insulin Resistance in Clinical Nutrition: Recommendations from the ESPEN Expert Group. *Clinical Nutrition*, **36**, 355-363. https://doi.org/10.1016/j.clnu.2016.09.010

[21] Gampoula, R.H., Dzondo, G.M., Moussounga, J.E., Diakabana, P., Pambou-Tobi, T., Tamba Sompila, A.W.G. and Nguie, R. (2020) Development of a Process for Formulating Infant Flour Based on Yam (*Dioscorea cayenensis*) Enriched with Protein by Incorporating Food Additives of Agricultural and Fishery Origin. *Journal of Biotechnology and Biochemistry*, **6**, 24-32.

[22] Barazzoni, R., Bischoff, S.C., Breda, J., Wickramasinghe, K., Krznaric, Z., Nitzan, D.,

et al. (2020) ESPEN Expert Statements and Practical Guidance for Nutritional Management of Individuals with SARS-CoV-2 Infection. *Clinical Nutrition*, **39**, 1631-1638. https://doi.org/10.1016/j.clnu.2020.03.022

[23] Diallo, S.K., Soro, D., Koné, K.Y., Assidjo, N.E., Yao, K.B. and Gnakri, D. (2015) Fortification et substitution de la farine de blé par la farine de Voandzou (*Vigna subterranea* L. Verdc) dans la production des produits de boulangerie. *International Journal of Innovation and Scientific Research*, **18**, 434-443.

[24] Souci, F.K. (2008) La composition des aliments: Tableaux des valeurs nutritives. 7th Edition, MedPharm Scientific Publishers/Taylor & Francis.

[25] Pontieri, P., Troisi, J., Calcagnile, M., Bean, S.R., Tilley, M., Aramouni, F., *et al.* (2022) Chemical Composition, Fatty Acid and Mineral Content of Food-Grade White, Red and Black Sorghum Varieties Grown in the Mediterranean Environment. *Foods*, **11**, Article No. 436. https://doi.org/10.3390/foods11030436

[26] Yadav, P. and Jain, J. (2023) Importance of Macrominerals and Microminerals among Children Suffering with Severe Acute Malnutrition. *International Journal of Research Publication and Reviews*, **4**, 243-245.

[27] World Health Organization (WHO) (2023) Micronutrient Intake in Children with Severe Acute Malnutrition. eLENA Guidelines. World Health Organization.

[28] Pourquoi est-il important de déterminer la teneur en cendres des aliments? Assurer la qualité, la nutrition et l'authenticité. https://fr.kindle-tech.com/faqs/why-is-it-important-to-determine-the-ash-content-of-food

[29] Pambou-Tobi, N.P.G., Tamba Sompila, A.W.G., Bita, A.M., Moussounga, J.E., Ntsossani, S.P., Diaboua, J.F., *et al.* (2021) Development of a Process for Formulating Infant Flours from the Almonds of *Treculia obovoidea*, *Terminalia catappa* Linne as Well as *Ipomoea batatas* Lam Leaves. *Open Journal of Applied Sciences*, **11**, 1046-1059. https://doi.org/10.4236/ojapps.2021.119077

[30] World Health Organization (WHO) (2013) Updates on the Management of Severe Acute Malnutrition in Infants and Children. World Health Organization.

[31] Njitang, Y. (2007) Amélioration de la densité énergétique des bouillies de sevrage par l'utilisation d'amylases locales. Thèse de Doctorat, Université de Ngaoundéré.

[32] Metrohm, A.G. (2021) Valeur pH et TTA dans la farine, la pâte et le pain. Metrohm. https://www.metrohm.com/fr_fr/applications/application-notes/aa-t-001-100/an-t-219.html

[33] Codex Alimentarius (1985) Norme générale pour les contaminants et les toxines présents dans les produits de consommation humaine et animale (Codex STAN 152). FAO/WHO.

[34] Njintang, N.Y., Mbofung, C.M.F. and Waldron, K.W. (2001) *In Vitro* Protein Digestibility and Physicochemical Properties of Dry Red Bean (*Phaseolus vulgaris*) Flour: Effect of Processing and Incorporation of Soybean and Cowpea Flour. *Journal of Agricultural and Food Chemistry*, **49**, 2465-2471. https://doi.org/10.1021/jf0011992

[35] Mbome, L., Nout, M.J.R. and Hounhouigan, J.D. (2005) Nutritional Quality of Cereal-Based Weaning Foods after Fermentation and Enzyme Addition. *Food Chemistry*, **92**, 737-746.

[36] Zarroug, Y., Nasri, S., Sfayhi, D., Zoghlami Khelil, A., Ferjani, E. and Kharrat, M. (2022) Formulation de biscuits enrichis par la farine des graines de *Vicia narbonensis* L. *Annales de l'INRAT*, **95**, 150-159.

[37] Dan, C.G., Ban Koffi, L., Yao, K., Nemlin, J.G. and Kouamé, P. (2021) Effect of Rip-

ening on the Functional Properties of Flours from Gnagnan Berries (*Solanum anguivi* Lam.) Cultivated in Côte d'Ivoire. Afrique Science. https://www.afriquescience.net/admin/post-pdfs/64a15a1fe3cd85e0b0483e77d5ea18941729801438.pdf

[38] Amoin, A., Agbo, E., Dago, A., Gbogouri, A., Brou, D. and Dago, G. (2015) Comparaison des caractéristiques nutritionnelles et rhéologiques des bouillies infantiles préparées par les techniques de germination et de fermentation. *International Journal of Biological and Chemical Sciences*, **9**, 944-953. https://doi.org/10.4314/ijbcs.v9i2.31

[39] Traoré, T., Mouquet, C., Icard-Vernière, C. and Trèche, S. (2004) Nutritional Consequences of the Reduction of Viscosity of Gruels Prepared from Pearl Millet Flours. *International Journal of Food Science and Nutrition*, **55**, 29-38.

[40] Watad, G.F., Ngaha Damndja, W., Agume Ntso, A.S. and Aba, R.E. (2025) Formulation and Characterization of Infant Flours from Plantain, Sesame Seeds and Baobab Pulp. Springer.

[41] Trèche, S. (1996) Influence de la densité énergétique et de la viscosité des bouillies sur l'ingéré énergétique des nourrissons. *Santé: Cahiers d'Études et de Recherches Francophones*, **6**, 237-243.