Scientific Papers. Series D. Animal Science. Vol. LXVI, No. 2, 2023
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

NUTRITIONAL BENEFIT OF COMPOSITE FLOUR BASED ON GERMINATED SORGHUM AND CATERPILLAR FOR CHILD MALNUTRITION ERADICATION

Natia Joseph KOUADIO, Soro Mariam TIEKOUNGO, N`gbesso Amos EKISSI, Sea Bernard TEHI

Felix Houphouet-Boigny University, 22 BP 582 Abidjan 22, Abidjan, Ivory Coast (Cote D`Ivoire)

Corresponding author email: Jonatia2006@yahoo.fr

Abstract

The COVID-19 epidemic and the Russian-Ukrainian crisis have aggravated an already catastrophic food security and nutrition situation in the majority of low-income nations, with 12.9% of the population undernourished and over 45% of children under five dying. As a result, edible insects may be a good source of alternative protein as a dietary supplement. The goal of this study was to first assess the in vivo nutritional impact of composite flours made from sorghum and caterpillar and then choose the best flour for biochemical characterization, amino acid, fatty acid, and vitamin quantification. A statistical study demonstrated a significant difference in weight growth (7.57 ± 0.53 g/d and 10.82 ± 2.56 g/d), but no difference in the biological value (0.80-0.94) of the composite flours. F2 composite flour has a protein level of 22.31 ± 0.44% and the presence of important amino acids, a low fat content of 6.56 ± 0.07%, and the presence of vitamins A, B1, B2, B9, B12, C, and E. The nutritional potentialities F2 composite flour imply that this flour might be used in newborn feeding to prevent infant malnutrition in the current COVID epidemic and Russian-Ukrainian crisis.

Key words*: child malnutrition, complementary foods, germinated sorghum, protein, Shea caterpillars.*

INTRODUCTION

A balanced diet is essential to provide the body with the energy and nutrients it needs to function properly. In children, it helps optimize health, development, and school performance (CAPOP, 2012). However, this adequate nutrition is threatened by a number of factors, including climate change, rapid population expansion, natural resource degradation, and pressure on agricultural production (FAO 2019). Most recently, the COVID-19 pandemic and the Russian-Ukrainian crisis have exacerbated this already alarming situation (OECD, 2020). According to forecasts by the heads of the Food and Agriculture Organization of the United Nations, the International Monetary Fund, the World Bank Group, the World Food Programme, and the World Trade Organization, the global food and nutrition crisis will exceed 840 million people by 2030 if nothing is done (FAO, IFAD, UNICEF, WFP, and WHO in 2022). The consequences of this food crisis for children living in rural areas and in poor households, and whose mothers have not benefited from school education, are stunted growth and wasting (FAO, IFAD, WHO, WFP, and UNICEF, 2022). In addition, in Côte d'Ivoire, economic inflation leads women with limited financial resources to buy cheaper infant formula of very poor nutritional quality on local markets to feed their children (Kouadio et al., 2023). Faced with this crucial problem, the FAO, IFAD, WHO, WFP, and UNICEF, in their 2022 declarations, recommend the participation of public and private actors through the implementation of local and sectoral solutions that will make it possible to resolve the problem of undernourishment and its corollary of malnutrition. In Côte d'Ivoire, a local solution could come from the use of sorghum (*Sorghum bicolore*) and caterpillars (*Cirina butyrospermi*) to combat child malnutrition, the prevalence of which was estimated to be rising by 4.7% during the period 2018–2020 (FAOSTAT, 2021a). Sorghum is a food rich in starch, minerals, and vitamins, whose annual production in 2021 was 70,000 tons (FAOSTAT, 2021b). As for the caterpillar, it is a real source of protein (55.49%), essential amino acids, fat (23.10%), essential fatty acids, and nutrients (vitamins, polyphenols, etc.) (Foua Bi et al., 2015). Their use through food formulation technology would allow the production of complementary foods with high nutritional potential, whose consumption would solve the problems of child malnutrition in Côte d'Ivoire. In vivo nutritional assessment technology is a method that reports on the effectiveness of a food formula and allows for consideration of its impact on consumer well-being (FAO, 2013). The use of this method, coupled with food formulation technology, will allow the development of diets capable of combating malnutrition. Thus, this study aims to evaluate the in vivo nutritional impact of flours composed of sorghum and caterpillars and then select the best flour for its biochemical characterization and its quantification in amino acids, fatty acids, and vitamins.

MATERIALS AND METHODS

The material consisted of sorghum grain (*Sorghum bicolor*) purchased at the Gouro market in Adjamé, Abidjan, and shea caterpillars (*Cirina butyrospermi*) collected in the town of Ferkessédougou in Côte d'Ivoire.

1. Formulation of the composite flour of germinated sorghum and caterpillar

1.1. Preparation of the sprouted sorghum flour

The grains were threshed three times, sorted, and washed with water that included 1% bleach to produce the germinated sorghum flour. The cleaned grains were given 72 hours at laboratory room temperature (25 ± 2°C) to germinate. The germinated grains were then stripped of their seedlings, rinsed, and dried for 24 hours in an oven set at 45°C. The dried grains were blended in a blender (Binatome, China), and the resultant powder was sieved through a sieve with a 100 µm diameter. The finished flour was placed in glass jars and preserved in the freezer at -6°C.

1.2. Preparation of the shea caterpillar flour

The caterpillar meal was obtained following a series of unit operations that included sorting them, washing them with 1% bleach water, and drying them in an oven (Venticell, Fisher Bioblock Scientific) at 45°C for 72 hours. The dried caterpillars were crushed into flour using a blender (Binatome, China). The flour was then sieved through a 100 µm sieve and kept in a glass box in the refrigerator at - 6°C.

1.3. Formulation of the composite flour from germinated sorghum and caterpillar flour

The composite flour was produced by mixing previously manufactured sprouted sorghum and caterpillar flours. As a result, three formulations (F1, F2, and F3) were produced. The F1 recipe contains 95% germinated sorghum flour and 5% caterpillar flour. The F2 recipe contains 90% sprouted sorghum flour and 10% caterpillar flour. F3 is composed of 85% germinated sorghum flour and 15% caterpillar flour. All of the resulting composite flours are homogenized with a spatula until a homogenous mixture is achieved, then kept in glass jars at room temperature.

2. Nutritional characteristics of the composite flour of germinated sorghum and caterpillar

The animal experiments were carried out in accordance with Adrian et al. (1991) method. Twenty-five young weanling albino rats, aged 35 to 45 days and weighing 50 to 60 g on average, were purchased from the École Normale Supérieure (ENS) animal house in Abidjan, Côte d'Ivoire. The juvenile rats were separated into five groups of five rats each and kept in individual metabolic cages in at 25 ± 2°C room with urine and feces collecting facilities. After five days of acclimation, rats were fed five experimental diets for 15 days, comprising two control diets (with and without protein) and three composite meal diets. Throughout the trial, water was available at any time. Food consumption was assessed every day, and weight was checked every three days. Data on food intake were gathered by recording the amount of food ingested by each rat at baseline and the amount remained after feeding. The rats' weight increase or decrease was also tracked. Rat feces were collected daily, dried to a consistent weight at 85 ± 2.0°C, then pulverized for fecal nitrogen measurement. To avoid ammonia loss, urine samples were collected in vials containing 0.1 N HCl and maintained in a freezer until urinary nitrogen analysis. The Kjeldhal technique was used to determine rat fecal and urine nitrogen (AOAC, 2005). According to FAO/WHO (1989) and AOAC (2000) guidelines, protein efficiency ratio (PER), net protein utilization (NPU), biological value (BV), real digestibility (RD), and net protein retention (NPR) were assessed. Three rats from each batch were starved for 16 hours at the end of the animal experiment. After this period, the rats were sedated with ether and slaughtered for blood collection in red and purple tubes, respectively, to determine blood biochemical and haematological parameters.

3. Study of the biochemical and nutritional properties of the selected composite flour of germinated sorghum and caterpillar

3.1. Study of biochemical properties

The biochemical characteristics of the selected composite flour were investigated using the AOAC techniques (2005). Consequently, the AOAC (2005) technique was used to assess protein (Kjeldahl method, N x 6.25), fat (hexane Soxhlet extraction method), ash (muffle furnace method at 550°C), and fiber contents. Carbohydrate content was calculated by subtracting 100 from the sum of moisture, fat, protein, crude fiber, and ash content as defined by the AOAC (2005). Sample energy values were derived by multiplying the energy ingredients (protein, fat, and total carbohydrate) by their respective Atwater specific energy conversion coefficients (FAO, 2003).

3.2. Study of nutritional properties

The profiles of vitamins, amino acids, and fatty acids were measured by HPLC chromatography using an instrument of type SHIMADZU SPD 20 A, according to the technique of Abidi (2000). About the phenolic compounds, they were extracted in methanol using the technique of Singleton et al. (1999), and the phenolic profile was quantified using HPLC chromatography employing an equipment of type SHIMADZU SPD 20 A, according to the method of Abidi (2000).

3.3. Statistical investigation

The dietary assessment was carried out in quintuplicate, whilst the biochemical blood, hematological, and nutritional analyses were carried out in triplicate. On the figures, means, standard deviations, and error bars were computed using Microsoft Windows 10 Excel program. Duncan's test at the 5% threshold was used to compare the means of the different samples using XLSTAT software (version 2019, XLSTAT, USA). To locate samples with similar features, Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC) were used.

RESULTS AND DISCUSSIONS

Table 1 illustrates the weight gain, food consumption, efficiency coefficients, and protein retention of young rats fed composite flours. The juvenile rats fed with composite flours appeared to have more harmonious growth and development than the rats fed the control diets. The nutritional measures, namely the amount of composite flour consumed, weight growth, feed and protein efficiency coefficients, and the amount of protein retained, indicated a significant difference (P<0.05) in the three batches of rats.

Table 1. Weight gain, consumption, and efficiency coefficients of composite flours

Parameters / Diets	Weight gain (g/d)	Feed consumption (g/d)	Feed efficiency ratio	Protein efficiency ratio	Protein retention (g)
Control batch	8.21 ±0.37^{b}	8.66 ±1.58^{b}	0.98 ±0.20^{a}	6.77 ±1.37^{a}	5.57 ±1.08^{b}
F1	3.94 ±0.04^{d}	7.57 ±0.53^{b}	0.52 ±0.03^{b}	2.05 ±0.19^{c}	2.02 ±0.62^{c}
F2	6.34 ±0.20^{c}	9.51 ±0.50^{ab}	0.67 ±0.04^{b}	3.01 ±0.18^{b}	5.32 ±0.56^{c}
F3	9.07 ±1.17^{a}	10.82 ±2.56^{a}	0.88 ±0.24^{a}	3.50 ±0.90^{b}	7.34 ±1.68^{a}
PP	-1.78 ±0.09^{e}	4.82 ±0.54^{c}	-0.37 ±0.04^{c}	-4.56 ±0.55^{d}	

The values are the mean ± standard deviation of tests performed in quintuplicate. Values with different exponents are significantly different from each other at the 5% level (P<0.05) on the same line.

Duncan's test shows that the potentialities indicated at the parameter level are a function of the amount of caterpillar flour included in the sprouted sorghum meal. Similar findings in terms of feed intake and weight increase were reported by Kouadio et al. (2015) at the enriched Dockounou level. Rats fed the F3 diet showed maximum potential in all measures except the protein efficiency coefficient, where they did not differ significantly from those fed the F2 diet. Nonetheless, the values obtained for the feed efficiency coefficient are greater than 2.3 according to the PAG (Protein Advisory Group) guidelines and 2.7 according to FAO/WHO (1989) standards for rats given the F2 and F3 diets. Its conformity to the specified requirements shows that the F2 and F3 diets are of high nutritional quality, and their use may have a favorable influence on body development as well as maintenance.

Figure 1 depicts the protein digestibility of the young rats' composite diet. The lack of a significant difference in apparent digestibility between the control and F2 diet rats implies that the proteins in these feeds may have the same degrees of hydrolysis (Mazorra-Manzano, 2018). The digestibility rates of the F2 and F3 diets exceed 70%, which is the FAO/WHO minimal threshold (1989). In terms of actual digestibility, net protein use, and biological value, statistical analysis showed no significant difference (P<0.05) between rats fed F2 and F3 diets. This lack of difference shows that these two diets, while not including the same amounts of shea butter, have the same nutritional potential. Actual digestibility rates of 0.82 ±0.01 and 0.85±0.02 for the F2 and F3 diets, respectively, are higher than FAO/WHO recommendations (1989). These digestibility rates are equivalent to the 84.92%-84.50% achieved by Chrenkova et al. (2002) in rats given transgenic maize meal. Furthermore, at the level of 7F3A and 5F5A formulations, the extremely high biological value of these diets is equivalent to that of Vazquez-Rodrguez et al. (2013). These high numbers imply that eating the meal may have a favorable influence by promoting development and aiding in illness prevention.

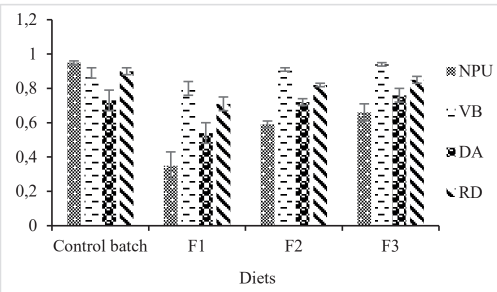

Figure 1. Protein digestibility of composite flour consumed by young rats

The content of biochemical components in the serum of rats fed the composite meal and the control batch is shown in Table 2. Statistical analysis showed that rats fed the control diet had a significant (P<0.05) influence on their blood glucose, blood uremia, and blood phosphorus levels compared to those fed the low-content composite flours.

Table 2. Metabolic parameters of rats fed with the composite meal

Parameters / Diets	Control batch	F1	F2	F3
Glucose (g/L)	0.79 ±0.04[a]	0.73 ±0.09[ab]	0.71 ±0.04[ab]	0.75 ±0.04[ab]
Total protein (g/L)	75.60 ±9.96[a]	77.80 ±10.87[a]	74.80 ±7.19[a]	76.00 ±10.02[a]
Creatinine (mg/L)	10.40 ±2.70[a]	8.20 ±1.64[ab]	7.20 ±0.84[b]	7.20 ±1.10[b]
Urea (g/L)	0.48 ±0.04[a]	0.43 ±0.09[ab]	0.41 ±0.04[ab]	0.45 ±0.04[ab]
Cholesterol (g/L)	0.52 ±0.09[b]	0.58 ±0.04[b]	0.69 ±0.05[a]	0.62 ±0.11[ab]
Triglycerides (g/L)	0.86 ±0.16[b]	0.80 ±0.07[b]	1.04 ±0.36[b]	1.64 ±0.21[a]
HDL (g/L)	0.33 ±0.08[b]	0.45 ±0.07[a]	0.48 ±0.11[a]	0.39 ±0.04[ab]
Ca (mg/dL)	160.66 ±46.02[a]	141.83 ±14.58[b]	135.00 ±10.7[b]	133.83 ±14.50[b]
Phosphorus (mmol/L)	24.97 ±9.21[a]	21.62 ±4.58[ab]	19.14 ±2.93[ab]	20.89 ±6.44[ab]
Ca/P ratio	2.11 ±3.64[a]	2.27 ±1.11[a]	2.06 ±3.29[a]	1.84 ±5.46[a]

Values are the mean ± standard deviation of trials conducted in quintuplicate. Values with different exponents are significantly different from each other at the 5% level (P < 0.05) on the same line.

The blood glucose levels of rats fed the composite flours are equivalent to those reported by Akapo et al. (2017) for fermented cassava and sun-dried cassava diets (0.65 and 0.79 g/L). Nevertheless, the results in this study are much lower than those reported by Laleg et al. (2019) for the FVHT and FLT diets (1.04 and 1.06 g/L). Consequently, the comparatively low serum levels of the rats given the composite flour show that blood glucose levels are well maintained by natural homeostasis (Kuo et al., 2015), because an abnormal glucose level is symptomatic of diabetes, according to Kim et al. (2013). Statistical analysis showed no significant change in total serum protein levels between the control rat batch and those given the composite flours. These values, however, are greater than the 0.40 to 0.65 g/L reference limit indicated by Kong et al. (2016). Its high total protein concentration in the blood shows caterpillars' good influence on rat growth, development, and well-being as a protein source. Statistical analysis showed a significant difference (P<0.05) in creatinine, cholesterol, triglycerides, HDL cholesterol, and calcium contents. Whereas the control rats had greater creatinine and calcium levels, the rats given the composite flours had higher cholesterol, triglyceride, and HDL-cholesterol levels. Calcium and phosphorus are vital elements for bones, neurons, and muscles. Also, they are the most plentiful in the body (Penido & Alon, 2012). The quantity of phosphate in the blood impacts the amount of calcium, and the two are inversely connected in humans (Levine et al., 2014). As a result, any deviations in the signs might indicate organ malfunction or inflammation within the body.

The immunological characteristics of young rats fed the composite meal are shown in Table 3.

Table 3. Immunological parameters of rats fed with the composite meal

Parameters / Diets	Control batch	F1	F2	F3
Hemoglobin g/100 mL	12.22 ±0.87^a	12.26 ±0.83^a	12.86 ±0.77^a	11.96 ±0.96^a
Hematocrit (%)	36.40 ±2.74^a	36.54 ±2.51^a	38.04 ±2.26^a	35.50 ±2.93^a
Neutrophils (%)	59.00 ±4.30^a	60.40 ±4.21^a	58.40 ±2.41^a	59.00 ±2.28^a
Basophils (%)	0^a	0^a	0^a	0^a
Eosinophils (%)	1.40 ±0.55^a	1.20 ±0.55^a	1.00 ±0.55^a	1.40 ±0.55^a
Monocytes (%)	8.40 ±1.34^a	8.00 ±1.64^a	8.00 ±1.58^a	7.60 ±1.58^a
Lymphocytes (%)	31.20 ±4.32^a	30.40 ±4.03^a	32.60 ±1.64^a	32.00 ±1.92^a

Values are the mean ± standard deviation of trials conducted in quintuplicate. Values with different exponents are significantly different from each other at the 5% level (P < 0.05) on the same line.

According to the statistical analysis, the rats' intake of the enhanced sorghum composite meal had no negative (P>0.05) effect on hemoglobin, hematocrit, neutrophil, basophil, eosinophil, monocyte, and lymphocyte contents compared to the rats given the control batch. The hemoglobin concentration of blood from rats fed the F2 composite meal was within the reference range advised by Melo et al. (2012), which is 12.8-15.9 g/100 mL. Its conformity to the specified requirements shows that hemoglobin content may support the body's smooth functioning via reversible oxygen fixation (Wajcman, 2005). Leukocytes are made up of neutrophils, basophils, eosinophils, monocytes, and lymphocytes that work together to protect the body against pathogenic germs and external chemicals (Wynn & Vannella, 2016). Hence, low blood levels of lymphocytes, eosinophils, and basophils might indicate the lack of any form of immunological response (inflammation, allergies, etc.). (Karasuyama et al., 2018; Arock, 2021). Yet, a higher than normal monocyte and neutrophil count implies an enhanced mobilization of these blood elements for primary defense of the body against primary viral and bacterial infections (Kumar et al., 2018).

1. Selection of the best composite flour from principal component analysis (PCA) and hierarchical ascending classification (HAC)

In order to determine the best composite flour, PCA was used to link the different composite flours to the nutritional factors investigated (Figures 2, 3, and 4).

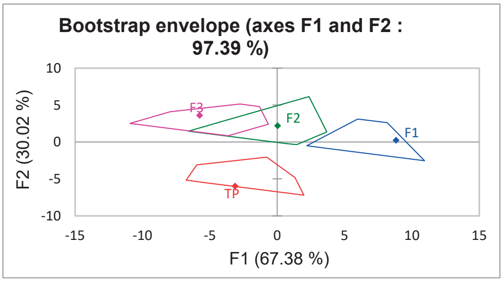

Figure 2. Bootstrap envelope showing points of similarity between composite flours

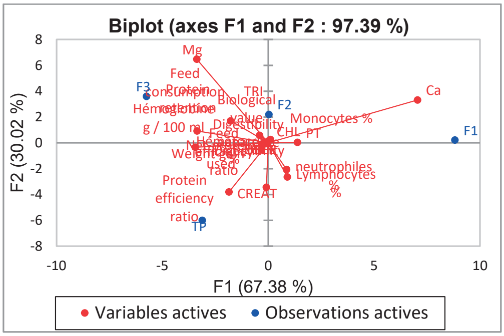

Figure 3. Principal component analysis showing the relationship between composite flours and nutritional parameters

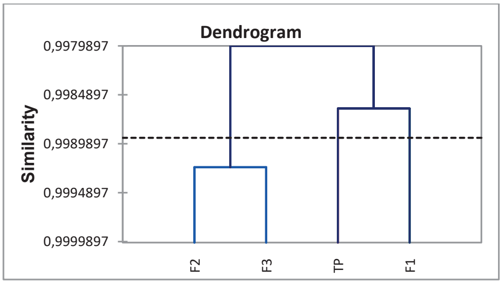

Figure 4. Hierarchical ascending classification of composite flours

The projection of the nutritional metrics and composite flours on the T1 and T2 axes in the biplot plane indicates a total of 97.39%. The F1 composite flour correlates favorably with the T1 and T2 axes, whereas the F2 and F3 composite flours correlate negatively with the T1 axis and positively with the T2 axis. The control batch has no correlation to the T1 or T2 axis. Figure 2 depicts the bootstrap analysis, which demonstrates a substantial difference between the composite flours and the control diet. Nonetheless, the nutritional properties of the composite flours F2 and F3 are similar. The plane distribution of the active variables (nutritional parameters) and active observations (composite flours) shows that the nutritional parameters weight gain, feed intake, feed efficiency ratio, protein efficiency ratio, apparent digestibility, digestibility, protein retention, amount of protein used, biological value, and creatinine are strongly shared by the composite flours F2 and F3. Based on the similarity of the active factors, the hierarchical analysis indicates that the F2 and F3 composite flours are similar but statistically distinct from the F1 composite flour and the control batch. On this basis, the composite flour F2 was chosen as the best flour since it contains a significant amount of caterpillar, which has intriguing nutritional properties.

2. Biochemical properties of the composite flour F2

Table 4 shows the biochemical content of the F2 composite flour. The ash, protein, carbohydrate, and calorie contents are in line with FAO/WHO (1991) recommendations for supplemental meals for children aged 3 to 36 months. Trumbo et al. (2002) estimate the daily protein requirement for a kid of this age group to be 0.87 g/kg /day. Consequently, for a 3-year-old child weighing 15 kg, consuming at least 100 g of F2 composite flour daily should give the body with 13.05 g of protein. This is significantly less than the protein content of 100 g of F2 composite flour. The energy content is greater than that determined by Kouadio et al. (2022) for a ready-to-eat plantain dockounou infant flour. The combination of carbohydrate, fat, protein, and fiber content results in a highly essential quantity known as energy value. It helps youngsters aged 3 to 36 months meet their body's development and maintenance demands (Butte, 2000). The ash levels are within suggested limits, implying that consuming F2 composite wheat might fulfil the body's mineral requirements.

Table 4. Biochemical composition of the composite flour F2

Parameters (mg/100 g DM)	Content	References*
Fiber (%)	7.00 ±0.50	<5
Ash (%)	0.93 ±0.23	<3
Titratable acidity (meq g/100 g)	6.15 ±0.26	ND
Fat (%)	6.56 ±0.07	10-25
Protein (%)	22.31 ±0.44	>15
Carbohydrates (%)	67.92 ±1.19	64
Starch (%)	58.88 ±1.07	ND
Energy (kcal/100 g)	420.01 ±3.45	400-425

Values are the mean ± standard deviation of trials performed in triplicate. Values with different exponents are significantly different from each other at the 5% level ($P<0.05$) on the same line; *FAO/WHO (1991).

3. Nutritional properties of F2 composite flour

The amino acid and fatty acid composition of F2 composite flour is shown in Table 5. This balanced profile is consistent with the F2 composite flour's relatively high protein level (22.31±0.44%). The essential amino acid concentration is lower than that found by Solomon et al. (2020) in beetle larvae, but greater than the IOM (Institute of Medicine's) guideline (2005). When ingested by youngsters, the F2 composite flour may thus be regarded as an excellent source of protein with high biological value due to its comprehensive profile of necessary and non-essential amino acids. High-performance liquid chromatography measurement of essential fatty acid concentrations indicates significant levels of palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, and arachidic acid. Notwithstanding the low fat content, the high quantities of essential fatty acids indicate that the F2 composite flour is of extremely high nutritional quality. Actually, essential fatty acids must be present in meals since the human body cannot generate them (Solomon et al., 2020). Moreover, these important fatty acids serve as precursors for the production of various vitamins and hormones required for optimal human body function.

Table 5. Amino acid and fatty acid content of the F2 composite flour

Amino acids (mg/100 g protein)		Fatty Acid (mg/100 g)	
Types	Content	Types	Content
Leucine	451.30 ± 0.01	Palmitic acid	705.50 ± 0.10
Methionine	163.60 ± 0.24	Stearic acid	692.70 ± 0.05
Phenylalanine	382.40 ± 0.01	Oleic acid	594.67 ± 0.57
Isoleucine	365.70 ± 0.01	Linoleic acid	468.20 ± 0.10
Valine	202.40 ± 0.21	Linolenic acid	459.80 ± 0.05
Histidine	423.67 ± 0.01	Arachidic acid	372.40 ± 0.30
Threonine	379.33 ± 0.51		
Tryptophan	368.40 ± 0.32		
Lysine	483.70 ± 0.22		
Arginine	332.33 ± 0.06		
Alanine	623.30 ± 0.11		
Glutamic acid	213.11 ± 0.01		
Glycine	523.70 ± 0.14		
Proline	373.60 ± 0.08		
Tyrosine	232.05 ± 0.33		

The values representing the contents are averages from trials carried out in triplicate.

4. Vitamins and phenolic content of F2 composite flour

The vitamin and phenolic content of F2 composite flour is shown in Table 6.

Table 6. Vitamins and phenolics content of composite flour

Vitamins (mg/100 g)		**Phenolic compounds (mg/100 g)**	
Types	Content	Types	Content
Vitamin A	534.93 ± 0.05	Caffeine	129.10 ± 0.08
Vitamin B1	589.97 ± 0.05	Catechin	804.81 ± 0.01
Vitamin B2	553.67 ± 0.57	Arbutin	511.21 ± 0.00
Vitamin B9	700.90 ± 0.01	Rutin	654.72 ± 0.02
Vitamin B12	275.53 ± 0.50	Naringenin	265.08 ± 0.07
Vitamin C	695.00 ± 0.00	Proto-catechin acid	391.03 ± 0.01
Vitamin E	235.40 ± 0.01	Gallic acid	574.50 ± 0.17
		Ellagic acid	166.93 ± 0.00
		Coumaric acid	114.52 ± 0.31
		Cinnamic acid	118.70 ± 0.07

Values are the mean ± standard deviation of trials performed in triplicate. Values with different exponents are significantly different from each other at the 5% level ($P < 0.05$) on the same line.

HPLC examination showed that various vitamins, particularly B vitamins, are present in appropriate levels. The concentrations in mg per 100 g of DM are substantially greater than those reported by Parker et al. (2020). Furthermore, the F2 composite meal satisfies the Trumbo et al. (2020) recommended daily requirement of vitamins for babies aged 6 to 12 months and children aged 1 to 3 years. In terms of phenolic compounds, HPLC quantification confirms the presence of various phenolic chemicals in the F2 composite flour, including caffeine, catechin, arbutin, rutin, naringenin, proto-catechin acid, gallic acid, ellagic acid, coumaric acid, and cinnamic acid. The presence of these phenolic compounds protects the body against the damaging effects of free radical reactions.

CONCLUSIONS

The purpose of this study was to assess the nutritional value of composite flours made from sorghum and Shea caterpillar. The statistical treatments linked with the zootechnical data demonstrate that the F2 composite flour has nutritional potentials that warrant its inclusion in newborn feeding. The conformity of the constants to the current norms at the level of biochemical, blood, and immunological parameters demonstrates that the intake of F2 composite flour has no abnormalities on the well-being of children aged 3 to 36 months. Because of its balanced profile in essential amino acids, fatty acids, vitamins, and phenolic components, the biochemical and nutritional characteristics of F2 composite flour reveal properties that validate its use as a post-weaning supplemental meal. The F2 composite flour might be a true answer to the problem of child malnutrition that exists in Côte d'Ivoire because of the Russo-Ukrainian crisis and COVID 19.

ACKNOWLEDGEMENTS

We are grateful to Dr. Gnahoué Goueh for granting us access to the *vivarium* of the École Normale Supérieure of Abidjan, Côte d’Ivoire.

REFERENCES

Abidi, S. L. (2000). Chromatographic analysis of tocol-derived lipid antioxidants. *Journal of Chromatography A*, 881, 197-216.

Adrian, R., & Frangne, R. (1991). Techniques d'analyse nutritionnelle. In *Principes de Techniques d'analyse*. Paris, F: Lavoisier TEC et DOC Publishing House, 451-478.

Akapo, O. A., Olayemi, W. A., Oso, A. O., Olorunsola, R. A., & Bamgbose, A. M. (2017). Nutritional evaluation of processed cassava root meal using albino rats. *Adv. Plants Agric Res., 7*(5), 392–395.

AOAC (2000). *Official Methods of Analysis.* 17th Edition, The Association of Official Analytical Chemists, Gaithersburg, MD, USA. Methods 925.10, 65.17, 974.24, 992.16.

AOAC (2005). *Official method of Analysis*. 18th Edition, Association of Officiating Analytical Chemists, Washington DC, Method 935.14 and 992.24.

Arock, M. (2021). Le polynucléaire basophile: du contrôle de l'immunité à celui des leucémies. *Annales Pharmaceutiques Françaises*, https://doi.org/doi:10.1016/j.pharma.2021.05.005

Butte, N. F. (2000). Fat intake of children in relation to energy requirements. *Am. J. Clin. Nutr.,* 72, 1246S–1252S.

Chrenková, M., Sommer, A., Ceresnáková, Z., Nitrayová, S., & Prostredná, M. (2002). Nutritional evaluation of genetically modified maize corn performed on rats. *Arch Tierernahr., 56*(3), 229-35.

FAO (2003). *Food and Agriculture Organization*, World Agriculture: Towards 2015/2030. An FAO Perspective.

FAO (2013). *Dietary protein quality evaluation in human nutrition*, FAO FOOD AND NUTRITION PAPER 92, Report of an FAO Expert Consultation, ISSN 0254-4725; 79p

FAO (2019). *The international Code of Conduct for the sustainable use and management of fertilizers*. Rome. https://doi.org/10.4060/CA5253EN

FAO, FIDA, OMS, PAM et UNICEF (2022). *Résumé de L'État de la sécurité alimentaire et de la nutrition dans le monde 2022.* Réorienter les politiques alimentaires et agricoles pour rendre l'alimentation saine plus abordable. Rome, FAO. https://doi.org/10.4060/cc0640fr

FAO, FIDA, UNICEF, PAM et OMS, *L'Etat de la sécurité alimentaire et de la nutrition dans le monde – Transformer les systèmes alimentair es pour une alimentation saine et abordable*

FAO/WHO (1989). *Protein quality evaluation*, Report of the joint FAO/WHO Expert consultation Bethesda, MD., USA, 58-66.

FAO/WHO (1991). CODEX CAC/GL 08, 1991. *Codex Alimentarius: Guidelines on Formulated Supplementary Foods for Older Infants and Young Children*, 4, 144.

FAOSTAT (2021a). *Food and Agricultural Organization, Food safety data;* domain, Rome, Italy. https://www.fao.org/faostat/en/#data/QCL

FAOSTAT (2021b). *Food and Agricultural Organization, Agricultural Data.* Crops and products domain, Rome, Italy. https://www.fao.org/faostat/en/#data/QCL

Foua-Bi, F. G, Meite, A., Dally, T., Ouattara, H., Kouame, K. G., & Kati-Coulibaly, S. (2015). Étude de la qualité biochimique et nutritionnelle de la poudre séchée d'Imbrasia oyemensis, chenilles consommées au Centre-Ouest de la Côte d'Ivoire. *Journal of Applied Biosciences,* 96, 9039–9048.

IOM (2012). *Institute of Medicine, Committee on Accelerating Progress in Obesity Prevention, Food and Nutrition Board*; Institute of Medicine et coll. Accelerating Progress in Obesity Prevention: Solving the Weight of the Nation. Washington, DC: The National Academies Press.

IOM (2005). *Institute of Medicine, Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Institute of Medicine, The National Academies Press. Washington, D.C.

Karasuyama, H., Miyake, K., Yoshikawa, S., Kawano, Y., & Yamanishi, Y. (2018). How do basophils contribute to Th2 cell differentiation and allergic responses? *Int Immunol., 30* (9), 391-396.

Kim, I. S., Kim, H. T., Kim, E. J., & Lee, E.J. (2013). A comparative study of the concentration of salivary and blood glucose in normal and diabetic subjects. *J. Exp. Biomed. Sci.,* 19, 105-111.

Kong, D. Y., Park, J. H., Lee, K. W., Park, H., & Cho, J.A. (2016). Comparative Analysis of 3 Experimental Mouse Model for Blood Hematology and Chemistry. *Biomedical Science Letters*, 22, 75-82.

Kouadio, A. J. L., Kra, K. A. S., Kouadio, N. J., Assoumou, E. C., Gonety, T., & Niamke, S. (2022). Production of Highly Nutritious Enriched Infant Flours from a Traditional Ready-to-Eat Dish: the Plantain Dockounou. *Journal of Food Research, 11*(3), 1-10.

Kouadio, N. J., Kra, K. A. S., Kouadio, A. L. J., Akoa, E. E. F., Wiafe, A. M., & Niamke, S. (2023). Biochemical, nutrients, functional and sensory properties of Dockounou flours enhanced with soybean and Voandzou. *GSC Advanced Research and Reviews, 14*(01), 024–035.

Kouadio, N. J., Mégnanou R-M., Akpa E., Akoa, E. E., Kra K. S., & Niamké, S. L. (2015). Impact of the nutritional supply of Dockounou with millet, soybean, cassava, sorghum flours in Wistar rat growth. *International Journal of Innovation and Applied Studies, 10*(2), 576-583.

Kumar, P. K., Nicholls, A. J., & Wong, C. H. Y. (2018). Partners in crime: neutrophils and monocytes/macrophages in inflammation and disease. *Cell Tissue Res., 371*(3), 551-565.

Kuo, T., McQueen, A., Chen, T.C., & Wang, J. C. (2015). Regulation of glucose homeostasis by glucocorticoids. *Adv Exp Med Biol*., 872, 99-126.

Laleg, K., Salles, J., Berry, A., Giraudet, C., Patrac, V., Guillet, C., Denis, P., Tessier, F. J., Guilbaud, A., Howsam, M., Boirie, Y., Micard V., & Walrand, S. (2019). Nutritional evaluation of mixed wheat-faba bean pasta in growing rats: impact of protein source and drying temperature on protein digestibility and retention. *Br J Nutr., 121*(5), 496-507.

Levine, B. S., Rodriguez, M., & Felsenfeld, A. J. (2014). Serum calcium and bone: effect of PTH, phosphate, vitamin D and uremia. *Nefrologia*, 34, 658-669.

Mazorra-Manzano, M. A. (2018). Proteins in Food Processing. Seafood proteins. *Woodhead Publishing Series in Food Science, Technology and Nutrition*, 445–475.

Melo, M. G. D., Dória, G. A. A., Serafini, M. R., & Araújo A. A. S. (2012). Valores de referência hematológicos e bioquímicos de ratos (*Rattus novergicus* linhagem Wistar) provenientes do biotério central da Universidade Federal de Sergipe. *Scientia Plena*, 8, 099910.

OCDE (2020). *Perspectives économiques de l'OCDE*, Rapport intermédiaire mars, Éditions OCDE, Paris. https://doi.org/10.1787/0262bc62-fr

Parker, M. E., Zobrist, S., Lutterodt, H. E., Asiedu, C. R., Donahue, C., Edick, C., Mansen, K., Pelto, G., Milani, P., Soor, S., Laar, A., & Engmann, C. M. (2020). Evaluating the nutritional content of an insect-fortified food for the child complementary diet in Ghana BMC *Nutrition*, 6, 7. https://doi.org/10.1186/s40795-020-0331-6

Penido, M. G., & Alon, U. S. (2012). Phosphate homeostasis and its role in bone health. *Pediatr. Nephrol.*, 27, 2039-2048.

Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999) Analysis of Total Phenols and Other Oxidation Substrates and Antioxidants by Means of Folin-Ciocalteu Reagent. *Methods in Enzymology*, 299, 152-178.

Solomon, D. M., Solomon, D. L., Jaryum, H. K., Dabak D. J., & Sambo H. S. (2020). Nutrient Potential and Economic Benefit of Varies Coleoptera (Grub Worm): Implication for Food Security. *EAS Journal of Nutrition and Food Sciences, 2*(5), 217-221.

Trumbo, P., Schlicker, S., Yates, A. A., & Poos, M. (2002). Food and Nutrition Board of the Institute of Medicine, The National Academies. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. *J. Am. Diet. Assoc., 102*(11), 1621-30.

Vazquez-Rodrıgueza, J. A., Amaya-Guerraa, C. A., Baez-Gonzaleza, J. G., Nunez-Gonzaleza, M. A., & Figueroa-Cardenasb, J. D. (2013). Study of the fortification with bean and amaranth flours in nixtamalized maize tortilla. *Journal of Food*, 11, 62-66.

Wajcman, H. (2005). Hémoglobines: structure et fonction. *EMC - Hématologie, 2*(3), 145–157.

Wynn, T. A., & Vannella, K. M. (2016). Macrophages dans la réparation, la régénération et la fibrose des tissus. *Immunité*, 44, 450–462.