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Nutritional Properties of Caterpillar Powder *(Imbrasia oyemensis)* and T45 Wheat Flour

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Abstract The present study was developed to investigate the nutritional properties of dried caterpillar *(Imbrasia oyemensis)* powder and wheat flour. The physicochemical composition was determined by standard methods (AOAC). The physicochemical analysis of 100g of *Imbrasia oyemensis* caterpillar powder, reveals a high content of protein (52.12%), lipid (20.58%), ash (3.62%), fiber (3.2%) and a low content of carbohydrate (17.24%) with an energy value of 462.66 Kcal/100g. Wheat flour is mainly rich in carbohydrates (78.04%) and has a low protein (10.7%), lipid (1.26%), ash (0.52%) and fiber (0.12%) content with an energy value of 365.78 Kcal/100g. The amino acid profile of *Imbrasia oyemensis* caterpillar powder indicates the presence of 16 amino acids. Histidine records the highest content with 118.4 mg/g protein while methionine and cysteine indicate the lowest content with 4.47 mg/g protein and are a limiting factor. Wheat flour contains 7 essential amino acids in very low proportions with the exception of methionine and cysteine which has the highest content with 18.31 mg/g of protein. The fatty acid profile in the fatty material from *Imbrasia oyemensis* caterpillar powder reveals the existence of seven (7) fatty acids. This fatty acid profile is composed of four (4) saturated fatty acids (53%) and three (3) unsaturated fatty acids (46.66%). Calcium (224.7 mg/100g), sodium (497.9 mg/100g), potassium (602.9 mg/100g), magnesium (254.1 mg/100g) contents of *Imbrasia oyemensis* caterpillar powder are significantly higher ($p<0.05$) than those of wheat flour. The molar ratios of Phytates/Iron, Phytates/Zinc and Oxalate/Calcium show that caterpillar powder *(Imbrasia oyemensis)* could not interfere with the assimilation of iron, zinc and calcium. Thus, the incorporation of caterpillar powder *(Imbrasia oyemensis)* into wheat flour for use in nutrition and food technology could be an alternative in the fight against protein-energy malnutrition.

Keywords: *nutritional properties, caterpillar powder (Imbrasia oyemensis), wheat flour, protein-energy malnutrition*

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1. Introduction

Population growth and rapid urbanization will create a high demand for food and especially animal protein, thus accentuating the problem of malnutrition [1]. According to the National Institute of Statistic [2], about 5% of the Ivorian population has difficulty accessing traditional animal proteins such as meat and fish. In addition to legumes and conventional food resources (meat, fish), other locally available and highly valued alternatives may be available, such as snails, winged termites and especially caterpillars [3]. Caterpillars, or butterfly larvae, are widely consumed by people looking for protein sources to replace meat and fish.

They also constitute a nutritional and food arsenal in the fight against malnutrition and or food security. In Ivory Cost, caterpillars of the species *Imbrasia oyemensis* are widely consumed, particularly in the western forest zone of the country where they are widely available [4]. In spite of the evolution of the consumption of caterpillars, few studies have been devoted to it for a better dynamization of the caterpillar sector. One of the alternatives is the transformation of the caterpillar *(Imbrasia oyemensis)* into powder. The physical aspect of the caterpillars makes their consumption more or less difficult. Thus, the incorporation of caterpillar powder *(Imbrasia oyemensis)* into wheat flour could improve its level of consumption and be an alternative in the fight against protein-energy malnutrition. In fact, in developing countries, particularly in sub-Saharan Africa, research efforts are being made to partially replace wheat flour with locally available flours [5]. Trials to substitute wheat flour with flours from local products rich in carbohydrates such as cereals (maize, rice, sorghum, millet), tubers (cassava, taro, sweet potato, yam), and rich in protein (cowpeas, soybeans) have been successful [6,7]. Because of their high nutritional value, caterpillars are mixed in some regions with cereal flour to prepare a porridge that helps combat child malnutrition [8].

The general objective of this study is to valorize the consumption of caterpillar *(Imbrasia oyemensis)* powder for the fight against protein-energy malnutrition.

This work will result in:

- Determination of the global and specific chemical composition of caterpillar *(Imbrasia oyemensis)* powder and wheat flour.

- Evaluation of the physico-chemical characteristics of the fat extracted from the caterpillar powder *(Imbrasia oyemensis)*.

2. Material and Methods

2.1. Biological Material

The biological material consists of dried caterpillars of *Imbrasia oyemensis* and wheat flour Type 45. The dried caterpillars *(Imbrasia oyemensis)* were purchased on the markets of the cities of Bouaflé and Zuénoula (central-west Ivory Cost).

2.2. Methods

2.2.1. Production of the Caterpillar Powder *(Imbrasia Oyemensis)*

Two (2) kg of dried *Imbrasia oyemensis* caterpillars were sorted and then cleared of any kind of waste. They were then put in the oven at 65°C for 72 hours, then crushed with a blender to obtain the caterpillar powder. The powder obtained was put in covered jars and stored in the refrigerator at 4°C.

2.2.2. Determination of the Overall Chemical Composition of Caterpillar Powder and Wheat Flour

The moisture content was carried out by desiccation at 105°C for 24 h according to the method [9]. The dry matter content is obtained by subtracting the moisture content by 100% [9]. Fat content was determined by the soxhlet method [9]. Protein content is determined by the method [9] using Kjeldahl. The carbohydrate content is calculated by the difference method [9]. The total sugar content is determined by the phenol-sulfuric method as described by [10]. Quantification of reducing sugars is performed according to the method of [11].

The ash content was determined by incineration in a muffle furnace at 550°C for 12 h [9].

The determination of the crude fiber content is performed according to the [9] method.

The total energy value is determined by calculation according to the [9] method.

The pH and titratable acidity are determined according to the [9] method.

2.2.3. Determination of the specific chemical composition

2.2.3.1. Determination of the Profile in Amino Acids

Amino acids are determined by high performance liquid chromatography (HPLC). One (1) g of flour delipidated by 10 ml of HCl (6N), was dried at 110°C in an oven for 24 h, then under a nitrogen flow. The dry residue was taken up in 10 ml of 0.2 N sodium citrate at pH 2.3. The homogenized mixture was centrifuged at 3000 rpm for 25 min at 0°C.

The collected supernatant was filtered through Whatman No. 4 paper and then through a 0.45 µm millipore filter (Sartorius AG, Goëttingen, Germany). The treated supernatants were stored at -20 °C before analysis. The amino acid composition of the samples was determined after hydrolysis with 6 M HCl with phenol (1%) at 150 °C for 60 minutes.

Analyses were performed in triplicate. The identification of the amino acids in the different samples was done by comparing the retention times of the eluted compounds to the retention times of the reference solutions. The concentrations of the amino acids in the studied flour samples were determined from the average of the peak areas of the reference (control) solutions.

The chemical index is the lowest percentage of an essential amino acid relative to the reference protein (1998) and the calculated biological value is the difference between 100% and the chemical index.

2.2.3.2. Determination of the Fatty Acid Profile

The analysis of free and total fatty acid methyl esters was performed on a gas chromatograph HP 6890 series GC system. The identification of representative methyl ester peaks was performed using reference substances (methyl esters) and this was done by comparing the retention times of each peak in the chromatogram with those obtained for the standards. The volume of the injected esterified sample was one microliter (1µL).

2.2.3.3. Physicochemical Characterization of the Fat

The iodine indice, representing the number of grams of iodine fixed per 100 g of oil fat, was determined according to the standard analytical method [12]. The peroxide indice, corresponding to the amount of peroxide-active oxygen contained in 1 kg of fat, was determined according to the standard analytical method [13]. The saponification indice was determined according to the standard analysis method [14].

The acid indice was determined according to the standard analytical method [15]. The refractive indice was measured with an RFM 81 multisecale refractometer (Automatic Refractometer) according to the standard analysis method [16].

Color was measured using a colorimeter (Lovibond RT Colour Measurement Kit V2.28) with a 10° viewing window and a D65 light source.

2.2.3.4. Determination of Mineral Elements

The mineral elements that are calcium, sodium, potassium, magnesium, iron, zinc and copper are determined by atomic absorption spectrophotometry using an atomic absorption spectrophotometer Perkin Elmer. AA S 800 [17].

2.2.3.5. Determination of Anti-nutritional Factors

Oxalates are quantified according to the method of [18], using potassium permanganate (KMnO4). Phytates are quantified by the method of [19], based on the decoloration of Wade's reagent by phytates. Tannins are determined by the method of [20]. The flavonoid content is determined by the method of [21].

2.2.3.6. Calculation of the Molar Ratios and the Assimilation Index

2.2.3.6.1. Molar ratio Phytate/Iron

The molar ratio of Phytate/Iron was calculated according to the formula of [22].

$$\mathbf{Molarratiophytate / iron} = (\mathbf{PC / MMP}) / (\mathbf{IC / AMI})$$

PC: Phytate content; MMP: Molar mass of phytic acid (660,04 g/mol)
IC: Iron content; AMI: Atomic mass of iron (55,84 g/mol).

2.2.3.6.2. Molar ratio Phytate/Zinc

The molar ratio Phytate/Zinc was determined using the equation of [22].

$$\mathbf{Molar\ ratioPhytate / Zinc} = (\mathbf{PC / MMP}) / (\mathbf{ZnC / AMZn})$$

PC: Phytate content; MMP: Molar mass of phytic acid (660,04 g/mol)
ZnC: Zinc content; AMZn: Atomic mass of Zinc (65,38 g/mol)

2.2.3.6.3. Calcium Assimilation Index

The calcium assimilation index (OC/CaC) was determined by calculation [23].

$$\mathbf{Calciumassimilationindex} = \mathbf{OC / CaC}$$

OC: Oxalate Content**; CaC:** Calcium Content

2.3. Statistical Analysis

The data were analyzed using the GRAPH PAD Prism 7.0 software. A significance level ($p< 0.05$) is chosen for the comparison of results.

3. Results

3.1. Global Chemical Composition of Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

The analysis of the chemical composition of 100 g of *Imbrasia oyemensis* caterpillar powder and wheat flour revealed a low moisture content of *Imbrasia oyemensis* caterpillar powder which was 6.43 ± 0.08 g compared to that of wheat flour (10.6 ± 0.1 g).

The dry matter content of caterpillar *(Imbrasia oyemensis)* powder and wheat flour was 93.57 ± 0.15 g and 89.4 ± 0.24 g respectively.

Caterpillar powder *(Imbrasia oyemensis)* contained a higher protein and fat content with 52.12 ± 0.44 g and 20.58 ± 0.76 g respectively. In contrast to caterpillar powder, wheat flour contained a very low protein and fat content with 10.7 ± 0.05 g and 1.26 ± 0.15 g respectively.

The ash (3.62 ± 0.03 g) and fiber (3.2 ± 0.05 g) contents of caterpillar *(Imbrasia oyemensis)* powder were higher than those of wheat flour which were 0.54 ± 0.02 g and 0.12 ± 0.12 g respectively.

Caterpillar powder *(Imbrasia oyemensis)* had lower levels of total sugars (0.32 ± 0.005 g) and reducing sugars (0.027 ± 0.04 g) compared to wheat flour, which contained 2.31 ± 0.015 g and 0.044 ± 0.003 g of total sugars and reducing sugars respectively.

Wheat flour had a higher carbohydrate content (78.04 ± 0.08 g) compared to *Imbrasia oyemensis* caterpillar powder (17.24 ± 0.32 g).

The energy value (Kcal/100g DM) of *Imbrasia oyemensis* caterpillar powder (462.66 ± 1.42 Kcal) was higher than that of wheat flour (365.78 ± 1.85 Kcal).

The acidity level of caterpillar *(Imbrasia oyemensis)* powder and wheat flour were 0.7 and 0.1, respectively.

The caterpillar *(Imbrasia oyemensis)* powder and wheat flour were slightly acidic with pH values of 5.5 and 5.6, respectively (Table 1).

Table 1. Global chemical composition of caterpillar powder *(Imbrasia oyemensis)* and wheat flour

Parameters	Caterpilar powder *(Imbrasia oyemensis)*	Wheat flour
Moisture (g/100g FM)	6,43 ± 0,08	10,6 ± 0,1
Dry matter (g/100g DM)	93,57 ± 0,15	89,4 ± 0,24
Fat (g/100g DM)	20,58 ± 0,76	1,26 ± 0,15
Protein (g/100g DM)	52,12 ± 0,44	10,7 ± 0,05
Carbohydrate (g/100g DM)	17,24 ± 0,32	78,04 ± 0,08
Total sugar (g/100g DM)	0,32 ± 0,005	2,31 ± 0,015
Reducing sugar (g/100g DM)	0,027 ± 0,04	0,044 ± 0,003
Ash (g/100g DM)	3,62 ± 0,03	0,54 ± 0,02
Fiber (g/100g DM)	3,2 ± 0,057	0,12 ± 0,12
Acidity	0,7 ± 0,00	0,1 ± 0,00
pH	5,5 ± 0,00	5,6 ± 0,00
Energy value (Kcal/100g de DM)	462,66 ± 1,42	365,78 ± 1,85

The values are the mean ± standard deviation of three determinations.
FM: Fresh Matter; **DM:** Dry Matter.

3.2. Specific Chemical Composition of Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

3.2.1. Amino acid Profile of Caterpillar Powder *(Imbrasia oyemensis)* and wheat flour

The amino acid profile of *Imbrasia oyemensis* caterpillar powder revealed the presence of 16 amino acids including nine (9) essential amino acids and seven (7) non essential amino acids. Total essential amino acids were 572.56 mg/g protein. The level of non-essential amino acids was 523.58 mg/g protein.

The sulfur amino acids methionine and cysteine had the lowest content with 4.47 mg/g of protein, while histidine had the highest content with 118.4 mg/g of protein.

The leucine/isoleucine and leucine/lysine ratios were 1.24 and 0.78 respectively. The wheat flour protein contained seven (7) essential and five (5) non-essential amino acids with respective levels of 47.22 mg/g and 26.49 mg/g of protein.

These amino acids were present in low proportions with the exception of methionine and cysteine which had the highest content with 18.31 mg/g protein. The leucine/lysine ratio of the wheat flour was 1.5.

The chemical index of the *Imbrasia oyemensis* caterpillar powder was 17.88% while the calculated biological value was 82.12 % (Table 2).

3.2.2. Fatty Acid Composition of Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

The fatty acid profile in the fat from *Imbrasia oyemensis* caterpillar powder revealed the existence of seven (7) fatty acids. This fatty acid profile was composed of four (4) saturated fatty acids which are stearic acid (8.34 g/100g), palmitic acid (42.71 g/100g), lauric acid (1.73 g/100g), and myristic acid (0.56 g/100g).

The unsaturated fatty acids were three (3), of which a mono unsaturated which is the oleic acid (37,55 g/100g) and two polyunsaturated which are the linoleic acid (7,45 g/100g) and the linolenic acid (1,66 g/100g). The degree of saturation indicated that this fat was composed of 53.34% of saturated fatty acids and 46.66% of unsaturated fatty acids of which, 37.55% of monounsaturated fatty acids and 9.11% of polyunsaturated fatty acids.

Table 2. Amino acid profile of caterpillar powder *(Imbrasia oyemensis)* and wheat flour

Amino acid	Caterpilar powder *Imbrasia oyemensis* (mg/g of protein)	Wheat flour (mg/g of protein)	FAO reference protein (1998)
Leucine	65,7 ± 0,75	5,33 ± 0,02	77
Isoleucine	52,9 ± 1,46	-	28
Lysine	83,38 ± 1,37	3,54 ± 0,01	58
Tryptophan	15,55 ± 0,85	5,62 ± 0,04	11
Histidine	118,4 ± 0,69	-	19
Threonine	74,75 ± 0,33	6,42 ± 0,01	34
Valine	62,73 ± 0,79	2,7 ± 0,02	35
Phenylalanine+ Tyrosine	95,68 ± 2,65	5,3 ± 0,02	63
Methionine+ Cysteine	4,47 ± 0,03	18,31 ± 0,12	25
Leucine/lysine Leucine/isoleucine	0,78 1,24	1,5 -	
Total essential amino acids	572,56	47,22	
Serine	61,16 ± 0,2	7,72 ± 0,01	
Glycine	80,2 ± 0,06	2,27 ± 0,2	
Proline	56,13 ± 0,97	-	
Alanine	72,19 ± 0,06	-	
Glutamic Acid	50,5 ± 5	7,79 ± 0,02	
Arginine	100,8 ± 0,3	6,46 ± 0,02	
Aspartic acid	102,6 ± 0,02	2,25 ± 0,3	
Total non-essential amino acids	523,58	26,49	
Total amino acids	1096,14	73,71	
Chemical index	17,88 %		
Biological value	82,12 %		

Values are the mean ± standard deviation of three determinations.

Table 3. Fatty acid profile (g/100g of total fatty acids) of the fat of caterpillar *(Imbrasia oyemensis)* and wheat flour

Fatty acid	Caterpillar powder (*Imbrasia oyemensis*)	Wheat flour
Lauric acid (C12 :0)	1,73 ± 0,005	-
Myristic acid (C14 :0)	0,56 ± 0,008	-
Palmitic acid (C16 ; 0)	42,71 ± 0,05	0,13 ± 0,01
Stearic acids (C18 :0)	8,34 ± 0,01	0,14 ± 0,02
Total saturated fatty acids	53,34 %	-
Oleic acid (C18 ; 1n9)	37,55 ± 0,017	0,88 ± 0,02
Linoleic acid (C18 ; 2n6)	7,45 ± 0,03	-
Linolenic acid (C18 ; 3n3)	1,66 ± 0,05	-
Total unsaturated fatty acids	46,66 %	-
Mono unsaturated fatty acids	37,55 %	-
Polyunsaturated fatty acids	9,11 %	-

The values of the different fatty acids are the mean ± standard deviation of three determinations.

The fatty acid composition of the wheat flour fat showed the presence of three fatty acids in very low proportions. This fatty acid composition revealed the existence of two saturated fatty acids including palmitic acid (0.13 g/100g) and stearic acid (0.14 g/100g) and one monounsaturated fatty acid which is oleic acid (0.88 g/100g) (Table 3).

3.2.3. Physicochemical Characteristics of the Fat of the Caterpillar Powder *(Imbrasia oyemensis)*

The physicochemical characteristics of the fat of the caterpillar *(Imbrasia oyemensis)* powder are presented in Table 4. The fat from the *Imbrasia oyemensis* caterpillar powder was dark brown in color with a semi-solid appearance. This fat showed an acid value of 10.10 ± 0.113 mg KOH/g fat and an oleic acidity of 5.01 ± 0.15 %.

The saponification value was 140.59 ± 1.23 mg KOH/g fat and the unsaponifiable content was 1.42 ± 0.02%. The iodine and peroxide indices of *Imbrasia oyemensis* caterpillar fat were 51.36 ± 0.115 g iodine/100 g fat and 0.79 ± 0.01 meq oxygen/kg fat, respectively.

Table 4. Physicochemical characteristics of the fat of the caterpillar powder *(Imbrasia oyemensis)*

Physico-chemical characteristics	Parameters values
Color	Dark brown
Aspect	Semi-solid
Refractive indice	1,38 ± 0,005
Acid indice (mg de KOH/ g of fatty matter)	10,10 ± 0,113
Oleic acidity (%)	5,01 ± 0,15
Saponification indice (mg de KOH/g of fatty matter)	140,59 ± 1,23
Unsaponifiable matter content (%)	1,42 ± 0,02
Iodine indice (g d'iode/100 g of fatty matter)	51,36 ± 0,115
Peroxyde indice (meq d'oxygène/of fatty matter)	0,79 ± 0,01

Each value is the mean ± standard deviation of three determinations.

3.2.4. Mineral Content of Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

The mineral element composition of *Imbrasia oyemensis* caterpillar powder and wheat flour is recorded in Table 5.

Statistical analysis reveals that the calcium (224.7 mg/100g), sodium (497.9 mg/100g), potassium (602.9 mg/100g) and magnesium (254.1 mg/100g) contents of *Imbrasia oyemensis* caterpillar powder were significantly higher ($p < 0, 05$) than those of wheat flour, estimated at 45 mg/100g, 2.5 mg/100g, 333.1 mg/100g and 145.2 mg/100g for calcium, sodium, potassium and magnesium respectively. In addition, the iron (64.97 mg/100g), zinc (13.54 mg/100g) and copper (4.257 mg/100g) contents of *Imbrasia oyemensis* caterpillar powder were approximately equal ($p > 0.05$) to those of wheat flour measured at 45.76 ± 0.28 mg/100g, 8.08 ± 0.086 mg/100g and 2.503 ± 0.18 mg/100g for iron, zinc and copper, respectively.

Table 5. Mineral content of caterpillar powder *(Imbrasia oyemensis)* and wheat flour

Parameters	Caterpillar powder *(Imbrasia oyemensis)*	Wheat flour
Calcium (mg/100g)	224,7 ± 0,54[a]	45 ± 1,31[b]
Sodium (mg/100g)	497,8 ± 5,72[a]	2,5 ± 0,27[b]
Potassium (mg/100g)	602,9 ± 10,98[a]	333,1 ± 18,36[b]
Magnesium (mg/100g)	254,1 ± 0,91[a]	145,2 ± 4,85[b]
Iron (mg/100g)	64,97 ± 0,96[a]	45,76 ± 0,28[a]
Zinc (mg/100g)	13,54 ± 0,06[a]	8,08 ± 0,086[a]
Copper (mg/100g)	4,257 ± 0,16[a]	2,503 ± 0,18[a]

Each value is the mean ± standard deviation of three determinations.
a, b: there is no significant difference ($p > 0.05$) between two values of the same line topped by the same letter.

3.2.5. Composition of Anti-nutritional Factors in Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

The composition of anti-nutritional factors indicated that the contents of phytates (18.05 mg/100g), tannins (45.33 mg/100g), flavonoids (8.94 mg/100g) and oxalates (46.97 mg/100g) in *Imbrasia oyemensis* caterpillar powder were significantly lower ($p < 0, 05$) than those of wheat flour which were 30.6 ± 0.045 mg/100g, 84.07 ± 0.783 mg/100g, 18.74 ± 0.33 mg/100g and 100.2 ± 0.9 mg/100g, respectively (Table 6).

Table 6. Antinutritional factors composition of caterpillar powder *(Imbrasia oyemensis)* and wheat flour

Parameters	Caterpillar powder *(Imbrasia oyemensis)*	Wheat flour
Phytates (mg/100g)	18,07 ± 0,037[a]	30,6 ± 0,045[b]
Tanins (mg/100g)	45,33 ± 0,806[a]	84,07 ± 0,783[b]
Flavonoïdes (mg/100g)	8,94 ± 0,106[a]	18,74 ± 0,33[b]
Oxalates (mg/100g)	46,97 ± 0,55[a]	100,2 ± 0,9[b]

Each value is the mean ± standard deviation of three determinations.
a, b: there is a significant difference ($p<0.05$) between two values of the same line topped by different letters

3.2.6. Molar Ratios of Caterpillar Powder *(Imbrasia oyemensis)* and Wheat Flour

The Phytate/Iron, Phytate/Zinc and Oxalate/Calcium molar ratios of caterpillar *(Imbrasia oyemensis)* powder and wheat flour are recorded in Table 7. Caterpillar *(Imbrasia oyemensis)* powder exhibited significantly lower ($p < 0.05$) Phytate/Fe (0.27 ± 0.015), Phytate/Zn (1.33 ± 0.02), and Oxalate/Ca (0.2± 0.02) molar ratios than wheat flour, which were 0.66 ± 0.01; 3.78 ± 0.1; and 2.227 ± 0.05 respectively.

Table 7. Molar ratios of caterpillar *(Imbrasia oyemensis)* powder and of wheat flour

Samples	Parameters		
	Phytate/Fe	Phytate/Zn	Oxalate/Ca
Caterpillars powder (*Imbrasia oyemensis*)	0,27 ± 0,015[a]	1,33 ± 0,02[a]	0,2 ± 0,02[a]
Wheat flour	0,66 ± 0,01[b]	3,78 ± 0,1[b]	2,227 ± 0,05[b]

Each value is the mean ± standard deviation of three determinations.
a, b: there is a significant difference ($p<0.05$) between two values in the same column surmounted by the same letter.

4. Discussion

Caterpillar powder *(Imbrasia oyemensis)* presents rich and varied macronutrient and micronutrient contents. Thus, the moisture content of 6.43% is close to that found by [4] (6.3%) on the same species. This low moisture content allows a good physical preservation of the caterpillars thus avoiding their decomposition [24]. It also allows for the conservation of most of the nutrients present in these caterpillars, as they are easily consumed and exported to other regions and Europe throughout the year [25].

The carbohydrate content of caterpillar *(Imbrasia Oyemensis)* powder evaluated in the present study is 17.24%. This result is close to that found by [26] (11.36%) on *Imbrasia oyemensis*. From this study, it is found that wheat flour has a significant carbohydrate content with 78.04 %. This result is in agreement with that obtained by [27] (76.53%) and confirms the priority energy function attributed to wheat flour. This high carbohydrate content of wheat flour can be optimized by substituting wheat flour with caterpillar *(Imbrasia oyemensis)* powder.

The present study indicates that caterpillar *(Imbrasia oyemensis)* ranks among the highest protein foods with 52.12%. This result is in agreement with those obtained by [4] (55.77%), [26] (55.49%) on *Imbrasia oyemensis*.

The high protein content of the caterpillar powder *(Imbrasia oyemensis)* gives it a favorable advantage for its incorporation into wheat flour rich in carbohydrates, as for the manufacture of cookies and or bakery or pastry products to fight against protein-energy malnutrition.

The present study reveals that the fiber content of caterpillar *(Imbrasia oyemensis)* powder is 3.2%, this result is slightly higher than that of [28] who obtained 2.68% on Cirina butyspermii vuillet caterpillars. Dietary fiber is considered essential for optimal digestive health, and also confers various functional benefits [29].

The amino acid profile of the caterpillar powder *(Imbrasia oyemensis)* indicates a total amino acid content of 1096.14 mg/g of protein, of which 572.56 mg/g of protein are essential amino acids and 523.58 mg/g of protein are non-essential amino acids. The essential amino acids present high concentrations and approximate to those of the [30] reference proteins except for methionine and cysteine, which in this study presents low concentrations of 3 and 1.47 mg/g respectively. These results are in agreement with those of [31] who obtained 2.9 mg/g protein on *Imbrasia Truncata* and by [26] (4.18 mg/g protein) on *Imbrasia oyemensis*. This low methionine concentration in the present study compared to the [30] reference (25 mg/g) could be the limiting factor of *Imbrasia oyemensis* protein. However, its incorporation into methionine-rich wheat flour (18.31 mg/g protein) may optimize this limiting factor.

From this study, it was found that *Imbrasia oyemensis* caterpillar powder has a chemical index of 17.88% and a high biological value of 82.12% which is included in the range [80 %; 100 %] in accordance with [32] recommendations, which attests to the good nutritional quality of these animals.

From these results, it appears that these caterpillars rank among the most protein-rich foods known such as meat and fish (82 % and 80 % respectively as biological value) but below eggs whose protein is 94 % complete [33].

The fat content of *Imbrasia oyemensis* caterpillar is 20.58 %. It is higher than that obtained by [31] (15.22 %) on *Imbrasia truncata*.

The proportion of lipids is equivalent to an energy value of 185.22 kcal and represents 40.03% of the total energy intake of this food, beyond the value advised by [34] between 20 and 35 %.

These excesses can be corrected by incorporating caterpillar powder *(Imbrasia oyemensis)* in wheat flour, which is low in lipids (1.26%). This moderate and controlled consumption prevents the development of various diseases such as cardiovascular diseases, cancers and various inflammatory and autoimmune diseases [35].

The acid indice contains little oleic acid (5.01%), thus little free fatty acids. This rate is higher than that of [36] on Macrotermes subhyalinus (1.25%). This rate would explain the beginning of alteration because it is higher than 4%, the threshold recommended by the Codex Alimentarius. In fact, oleic acid, which is a monounsaturated fatty acid, does not seem to have any harmful influence, it exerts favorable actions on health by promoting the increase of the “good” cholesterol; it is relatively insensitive to oxidation [37].

The saponification indice obtained in the present study (140.59 mg KOH/g fat) is lower than that of Macrotermes subhyalinus oil (193.40 ± 0.31) observed by [38]. Unsaponifiable matter (1.42%), consisting of bioactive substances including hydrocarbons, tocopherols, sterols, and terpene alcohols are present in minute quantities in this fat. The fat of the *Imbrasia oyemensis* caterpillar being richer in saturated fatty acids (53.34%) would explain its pasty or semi-solid appearance. Oleic acid represents the monounsaturated acid (37.55%). Linoleic acid (7.45%) and linolenic acid (1.66%) represent the polyunsaturated fatty acids. Palmitic acid, a saturated fatty acid, soft and white solid that melts at 63.1°C, represented in the composition at 42.71%, has thus conferred its properties to this fat. It is an excellent energy food (129 ATP), but its consumption in high proportion can increase the risk of cardiovascular disease and promote the formation of thrombosis [37].

The ashes from the incineration of the caterpillar powder *(Imbrasia oyemensis)* allowed the quantification of some mineral substances. Potassium recorded the highest content with 602.9 mg/100g, followed by sodium (497.8 mg/100g), and magnesium (254.1 mg/100g). These values are close to those found by [26] for potassium (610 mg/100g) and sodium (511.02 mg/100g) but higher for magnesium (208 mg/100g) on *Imbrasia oyemensis*.

Indeed, magnesium is a cofactor involved in more than 300 enzymatic reactions, making it essential for the synthesis of carbohydrates, lipids, nucleic acids and proteins, as well as for other actions in various organs of the cardiovascular and neuromuscular systems [39].

It appears from this study that *Imbrasia oyemensis* caterpillars have calcium and iron contents of 224.7 mg/100g and 64.97 mg/100g respectively.

These results are higher than those of [40] on Macrotermes bellicosus which obtained 210 mg/100g for calcium and 27 mg/100g for iron. Calcium is involved in bone formation, helps maintain acid-base balance in the body, and helps control energy metabolism [41]. Iron is an essential element for cell function and is a fundamental constituent of red blood cells. Its deficiency is common worldwide, especially in pregnant women and anemic people [32], but can be easily compensated by certain insect species such as *Imbrasia oyemensis* which are rich in iron [8].

The present study indicates that caterpillar *(Imbrasia oyemensis)* powder and wheat flour contain anti-nutritional factors in low proportions. Cooking is a common heat treatment used to reduce the amount of anti-nutritional factors [42].

Regardless of the absolute amounts of phytates or zinc, zinc uptake is considered high, moderate, or low when the phytate/zinc molar ratio is less than 5, between 5 and 15, or greater than 15, respectively [43].

The phytate/iron molar ratio above 0.5 could result in marginal iron deficiency resulting in low iron uptake [44]. Based on this assumption, the results indicate that the phytate content of the caterpillar powder *Imbrasia oyemensis*, could not interfere with the assimilation of zinc and iron as it has molar ratios Phytate/Zinc and Phytate/Iron respectively 1.33 and 0.27.

The molar ratios of Phytates/zinc (3.78) less than 5 and Phytates/iron (0.66) greater than 0.5 of wheat flour indicate that the phytate content of wheat flour may not interfere with zinc assimilation, but may interfere with iron assimilation.

Thus, the substitution of wheat flour with *Imbrasia oyemensis* caterpillar powder may contribute to improve the bioavailability of zinc and iron.

Taking into account the ratios of oxalate content to calcium content (TAO/TCa), it appears that the value of this ratio should be around 2 for oxalic acid to significantly interfere with calcium absorption [23]. Yet, the results indicate that the values of the ratios (TAO/TCa) of caterpillar *(Imbrasia oyemensis)* and wheat powder are 0.2 and 2.22, respectively, which would indicate that the oxalate content of caterpillar *(Imbrasia oyemensis)* powder could not interfere in the bioavailability of calcium.

However, the TAO/TCa content of wheat flour could interfere with calcium assimilation. But the incorporation of caterpillar powder *(Imbrasia oyemensis)* to wheat flour can improve calcium assimilation.

5. Conclusion

At the end of this study, it appears that the caterpillar powder *(Imbrasia oyemensis)* presents important nutritional potentialities. This food is a good source of protein of high nutritional value and contains satisfactory levels of amino acids and essential fatty acids close to the values recommended by the FAO.

On the other hand, the caterpillar powder *(Imbrasia oyemensis)* constitutes important reservoirs of minerals such as potassium, sodium, calcium, magnesium and iron.

Although the caterpillar powder *(Imbrasia oyemensis)* has good nutritional properties, it is however deficient in sulfur amino acid (methionine) and less rich in carbohydrates. However, its incorporation to wheat flour rich in carbohydrates and methionine for the manufacture of cookies or other bakery or pastry products, could be an alternative in the fight against protein-energy malnutrition in the world and especially in Africa.

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