**International Journal of Food Science and Biotechnology**
2021; 6(4): 96-106
http://www.sciencepublishinggroup.com/j/ijfsb
doi: 10.11648/j.ijfsb.20210604.12
ISSN: 2578-9635 (Print); ISSN: 2578-9643 (Online)

# Nutritional Quality of Six African Edible Insects

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**To cite this article:**
Boko Adjoua Christiane Eunice, Angaman Djédoux Maxime. Nutritional Quality of Six African Edible Insects. *International Journal of Food Science and Biotechnology*. Vol. 6, No. 4, 2021, pp. 96-106. doi: 10.11648/j.ijfsb.20210604.12

**Received**: September 29, 2021; **Accepted**: October 22, 2021; **Published**: November 5, 2021

**Abstract:** Protein-energy malnutrition affects approximately 170 million children under 5, with a prevalence of 40% in South Asia and 50% in sub-Saharan Africa. In Côte d'Ivoire nearly 30% of children suffer from chronic malnutrition, 8% are wasted and 15% are underweight. FAO sees insects as a sustainable alternative to animal protein in the face of dwindling natural resources and environmental pressures. Thus, insects appear more and more as a solution of the future. To date, the consumption of insects indicated by the term entomophagy has generated enormous interest. In such a context, an evaluation of nutritional parameters of insects seems essential. To do this, laboratory analyzes for the physicochemical and functional characterizations were performed. The nutritional profile established on six species of insects collected confirms that they are real sources of nutrients (proteins, lipids and minerals) capable of compensating for the nutritional deficiencies of populations, especially pregnant women and children. These insects are very rich in magnesium, calcium, potassium, sodium. Apart from their nutritional potential, the functional properties such as water and oil absorption capacity observed make them suitable for the formulation of foods.

**Keywords:** Edible Insects, Physicochemical Parameters, Minerals, Fatty Acid Profile, Functional Properties

## 1. Introduction

The State of Food Security and Nutrition in the World, jointly released by FAO, IFAD, UNICEF, WFP and WHO in 2019, puts the number of people in food insecurity situation in the world [1]. The most serious form of these nutritional problems is protein-energy malnutrition, which currently affects over one billion people [2]. It is currently very present in poor countries, especially on the African continent, where it affects about one in five people. In Côte d'Ivoire for example, the results of the SMART 2011-2012 survey reveal 29.8% of children suffering from chronic malnutrition and 7.5% of children suffering from wasting [3]. The main cause of this malnutrition is linked to an imbalance in energy, protein and/or nutrient intake. In fact, the diet is not very diversified, essentially based on tubers, roots and cereals which contribute more than 65% to daily dietary energy intake [3]. These foods are generally poor in certain nutrients such as proteins, fats, minerals and vitamins which are essential to ensure the nutritional balance of the body. One of the most viable ways to meet these nutritional needs is to fortify the energy foods with complementary ones rich in protein, fat, vitamins and minerals. Among these complementary foods, the edible insects recommended by the FAO to feed the world by 2050 are proving to be a suitable alternative.

Edible insects are generally described as being a true source of nutritional elements such as fat, protein, calories, vitamins and minerals [4-6]. These nutritional elements are very variable in particular because of the great variety of species of edible insects, their stage of development but also external factors such as climate, food, habitat, method of preparation [7]. Insects are often described as being low in carbohydrates [7]. In Côte d'Ivoire, insects are consumed by a segment of the population as a replacement for meat and fish [8]. The objective of this study is to assess the nutritional properties of edible insects from Côte d'Ivoire.

## 2. Material and Methods

### *2.1. Sample Collection*

Insects were collected from the wild and identified with the

entomologists of Jean Lorougnon Guédé University (Côte d'Ivoire). Samples were at larval stage for *Rhynchophorus phoenicis (*Coleoptera, Curculionidae) *Oryctes owariensis* (Coleoptera, Scarabaeidae), *Imbrasia oyemensis* (Lepidoptera, Saturniidae), *Cirina byturospermi* (Lepidoptera, Saturniidae), *Nudaurelia dione* (Lepidoptera, Saturniidae), excepting those of *Macrotermes subhyalinus* (Isoptera, Termitidae) and *Zonocerus variegatus* (Orthoptera, Pyrgomorphidae) which were at adult form. Samples were freeze-dried and ground in the lab with the aid of a mortar before using.

### *2.2. Chemical Composition*

#### *2.2.1. pH*

The pH was determined according to AOAC [9]. Five grams of sample were weighed into a 50 ml tube and then added with 20 ml of distilled water. The whole was centrifuged and then 10 ml of the supernatant was taken into a beaker for pH measurement by pHmeter SevenEasy S20 (Mississauga, Canada).

#### *2.2.2. Titratable Acidity*

The titratable acidity (mEq/100g) was determined according to the colorimetric method described by the French standard NF V05-101 [10]. A quantity of 5 g of sample was weighed into a 50 ml tube and then added with 20 ml of distilled water. The whole was centrifuged and then 5 ml of the supernatant was taken. A titration was carried out with sodium hydroxide (NaOH at N1=0.1N) after adding 2 drops of phenolphthalein.

$$A^{\circ}\left(\frac{mEq}{100g}\right) = \frac{N_1.V_1.10^5}{m \times V_0} \quad (1)$$

#### *2.2.3. Brix Degree*

The determination of the soluble solids content was carried out according to Dadzie [11]. using a refractometer. One drop of filtrate temperate at 20°C was placed on the prism of a refractometer Atago N-1α, model N (Saitama, Japan) which was then pointed in the direction of a light source for the reading of the degree Brix corresponding to the rate of dry extract of the sample. The value read was multiplied by the dilution factor of this solution.

$$RI = M \times f \quad (2)$$

*M* is the value read on the refractometer and *f* is the dilution factor, *RI* is the refractive index.

#### *2.2.4. Moisture*

The moisture was determined according to the method of AACC [12]. The vacuum crucible was first cleaned, dried and weighed (M0). Then, the crucible containing the sample (1g) was weighed again (M1) and then placed in an oven at 105°C for 24 h. After this drying time, the crucible is taken out of the oven, then cooled before being weighed (M2) again.

$$\text{Moisture}(\%) = (M1 - M2)/(M1 - M0) \times 100 \quad (3)$$

#### *2.2.5. Dry Matter*

Dry matter (DM) was obtained by the method described by [13]. Knowing the percentage of the water content, the dry matter was deduced.

#### *2.2.6. Ashes and Minerals*

The ash constitutes the total quantity of mineral matter obtained after incineration of the samples in an oven according [13]. To do this, 1 g of insect flour was put in a porcelain crucible of mass M0 and was placed in a muffle furnace at 550° C for 8 hours then removed and weighed after cooling.

$$\text{Ashes}(\%) = (M2 - M0)/(M1 - M0) \quad (4)$$

Minerals (copper, zinc, iron, selenium, manganese, molybdenum, calcium, potassium, magnesium and sodium) were quantified by mineralizing 0.5 g of dry samples in 5 mL of aqua regia [1:3 v:v (nitric acid: chloridric acid)] for 2 h under reflux. A dilution of 1% was made (0.5 g in 50 ml) before analyzing the samples. Concentrations were obtained with an atomic absorption spectrometer (AAS) (Perkinelmer AAnalyst2001, Waltham, Massachusetts, USA). All dosages were performed from calibration curves.

#### *2.2.7. Vitamin C*

Vitamin C content was determined by colorimetric assay of Kolthoff [14] with small modifications. For each sample 5 g were weighed into a 50 ml tube and then added with 20 ml of distilled water. The homogenate was centrifuged and then 5 ml of the supernatant was taken and supplemented with 5 ml of a iodine solution at $5.10^{-3}$ N. After stirring, this blackish blue solution with the addition of a few drops of starch. starch was titrated with sodium thiosulfate at $5.10^{-3}$ N to equivalence.

$$m = (C_{I2}V_{I2} - \frac{1}{2}C_{th}V_E)M \quad (5)$$

m: Mass of vitamin C contained in 5 mL of solution; CI2: Concentration of iodine used; VI2: Volume of diode added to the solution; Cth: Concentration of sodium thiosulfate used; VE: Volume of sodium thiosulfate poured in; M: Molecular weight of ascorbic acid

#### *2.2.8. Carbohydrates*

Carbohydrate content was described by Antia [15] method. The percentage is deduced after calculating the sum of the percentage of lipids, protein, ash, humidity.

$$\text{Carbohydrates}(\%) = 100 - (\text{Proteins}(\%) + \text{Lipids}(\%) + \text{Ashes}(\%) + \text{Moisture}(\%)) \quad (6)$$

#### *2.2.9. Lipid Extraction*

##### *(i) Determination of Total Lipids*

Insect samples (larvae and adult) have been freeze-dried (LABFREEZ FD 12-R, BeiJing, China) and ground in a mortar. Fat content was extracted by the method of Folch [16].

##### *(ii) Chemical Characterization of the Extracted Fat*

*a. Peroxide Index*

The principle of determining this index is based on the oxidation of the iodide by the active oxygen of the peroxides

contained in the oils, in an acidic medium. The iodine released is then dosed back with the titrated sodium thiosulphate. One (01) g of fat was weighed in an Erlenmeyer flask and 10 ml of chloroform is added thereto. Then, 15 ml of acetic acid and then 1 ml of a solution of potassium iodide (KI) were introduced. After this step, the Erlenmeyer flask is stoppered and placed in the dark for 5 min and at a temperature between 15 and 25°C. Finally, 75 ml of distilled water was added and the iodine was titrated with stirring with sodium thiosulfate in the presence of starch as an indicator. A blank test was carried out in the same way. The peroxide number (PI) expressed in mEq of oxygen/kg of fat was calculated by the mathematical expression:

$$PI = \frac{(V-V_0)\times C}{P} \times 100 \quad (7)$$

V0: Volume of sodium thiosulfate (mL) required for the blank test; V: Volume of sodium thiosulfate (mL) for the sample; C: Exact concentration, in moles per liter, of the standard sodium thiosulphate solution used; P: Test portion (g).

*b. Iodine index*

A test portion of 1 g of the fat was weighed and placed in a flask. Fifteen (15) mL of the carbon tetrachloride and 25 mL of the Wijs reagent were added thereto. After capping and shaking, the flask was wrapped with aluminum foil and allowed to stand for one hour. Then, 20 mL of instantaneously prepared 10% potassium iodide and 150 mL of distilled water were added to the solution. Titration was carried out with 0.1 N sodium thiosulfate solution until the yellow color due to iodine had almost disappeared. Then a few drops of starch were added before continuing the titration until the blue-violet color disappeared; the solution then became transparent. A blank test was carried out in the same way. The iodine number (II) is given by formula (8):

$$II(\text{g iodine}/100\text{ g}) = \frac{V_0-V}{P} \times 126{,}9 \times N \quad (8)$$

V0: Volume in (mL) of (0.1 N) sodium thiosulfate required to titrate the blank test; V: Volume in (mL) (0.1 N) sodium thiosulfate required to titrate the sample; P: Test portion (g); 126.9: Molar mass of iodine (g / mol); N: Normality of sodium thiosulfate is 0.1.

*c. Acid Index*

The acid index of an oil measures the amount of free fatty acids (FFA) present in that body. This involves dissolving the fat in hot neutralized ethanol, then titrating the GLA present by means of a standard solution of KOH in the presence of phenolphthalein as indicator. Therefore, 1 g of fatty substance was introduced into a glass Erlenmeyer flask. Five milliliters (5 ml) of 95% ethanol and 5 drops of 0.2% phenolphthalein were added and neutralized with an ethanoic KOH solution (0.1 M) until a color was obtained. persistent pink.

$$AI = \frac{V\times 56{,}1\times N}{P}(mg\ KOH\ /g) \quad (9)$$

V: Volume of KOH (0.1 M) in ml; N: Normality of the KOH solution (0.1 M); P: Weight of the test sample in g; 56.1: Relative molecular mass of KOH (g /mol)

***(iii) Determination of Fatty Acids Profile***

Fatty acid composition was determined by GC–MS. Fatty acids of 10.0 mg of lipids were converted into fatty acid methyl esters with boron trifluoride (Sigma-Aldrich, Overijse, Belgium) and methanol (VWR, Oud-Heverlee, Belgium). Fatty acid methyl esters were diluted in 8 mL of hexane (VWR) and analysed with a model 6890n GC System/5973 Mass Selective Detector (Agilent Technologies, Santa Clara, USA), which was fitted with a split/splitless injector (240.0°C) in splitless mode (splitless time: 0.85 min) and a flame ionization detector (250.0°C). A Carbowax DA column (Restek Corp., Bellefonte, PA, USA) (30.00 m × 0.25 µm × 0.25 mm in length × thickness × diameter) was used for the analysis. The temperature program was as follows: hold at 55.0°C for 1 min, increase to 250.0°C at 10.0°C/min and hold at 250.0°C for 5 min. As chromatographic conditions were similar, fatty acid methyl esters were identified based on their retention data compared to a reference mixture of 37 key fatty acid methyl esters (Supelco 37 component FAME mix, Sigma-Aldrich, Overijse, Belgium). Fatty acids were also identified by their retention index and their recorded mass spectra, which were compared with the National Institute of Standards and Technology (NIST) and Wiley spectral databases. The relative percentage of each compound was realized by comparing individual peak area with the sum of peak areas of all identified compounds, using Chemstation software (Agilent Technologies, Palo Alto, CA, USA). Non-deuterated methyl esters were identified on the basis of their retention index, according to their mass spectrum in comparison with a library and according to their mass fragments.

The representation of fatty acid abundance was performed in RStudio with ade4 package by table. value function.

***2.2.10. Protein and Energy value***

Protein content was determined using a Dumas Elementar Rapid N cube (Donaustrasse, Germany). A quantity of 200 mg of insect flour sample were protected in paper and pressed in pellet form. The wrapped samples were placed onto a carousel. Samples were then transferred to the combustion tube and the nitrogen determination was based on the quantitative digestion of the sample at approximately 960°C, in presence of excess oxygen [17]. The bound nitrogen was converted into nitric oxides and molecular nitrogen. The gases were transmitted with $CO_2$, by way of a catalytic post combustion zone, to a reduction zone. At this stage, the nitric oxides were transformed into nitrogen. The gas mixture flows to the thermo conductivity detector via an electronic flow controller. Through a connected personal computer (PC), the nitrogen concentration was determined from the thermo conductivity detector signal of the $N_2$ in the $CO_2$ and from the sample weight.

The energy value was calculated multiplying the average values of carbohydrates, lipids and proteins by the Atwater factors of 4; 9 and 4 respectively [18].

### *2.3. Functional Properties*

#### *2.3.1. Water Absorption Capacity*

The water absorption capacity (WAC) of flours was measured by the centrifugation method of Sosulski [19]. An amount of one (1) gram of flour is weighed per sample and placed in a centrifuge tube. The tubes containing the flour were weighed. Afterwards 10 mL of water were added to each tube and were stirred for 30 min. A Final centrifugation was carried out for 25 min at 3000 rpm (SIGMA 2-16P, Germany). The supernatant was poured and water absorption capacity was calculated according to the formula (10):

$$WAC\ (\%)=[(M'-M)/Ms] \times 100 \quad (10)$$

M: Mass of the tube containing the flour before centrifugation (g), M': New mass from the tube containing the flour after centrifugation (g), Ms: mass of the sample (g).

#### *2.3.2. Oil Absorption Capacity*

The determination of oil absorption capacity (OAC) was performed according to the method of Lin [20] with a slight modification. An amount of 0.5 g of flour is weighed and introduced into a centrifuge tube. Afterwards 6 mL of sunflower oil was added and stirred for 30 min. Finally, the centrifugation was carried out for 25 minutes at 5000 rpm (SIGMA 2-16P, Germany). The supernatant was poured. The tubes are oven-dried (at 50°C) for 45 min. The OAC was calculated according to the formula:

$$OAC\ (\%)=[(M'-M)/Ms] \times 100 \quad (11)$$

M: Mass of the tube containing the flour before centrifugation (g), M'': New mass from the tube containing the flour after centrifugation (g), Ms: mass of the sample (g).

#### *2.3.3. Foaming Properties*

The foaming capacity (FC) and foam stability (FS) were determined according to the method of Guo [21]. A quantity of 20 mL of a 1% sample was homogenized in a high shear homogenizer mixer (Binatone BLG 452, UK) at a speed of 14,000 rpm for 2 min. The whipped sample was immediately transferred into a cylinder. The total volume was read at time zero and 30 min after homogenization. The foaming capacity and foam stability were calculated from the formula (12) and (13):

$$\text{Foaming capacity (FC) } (\%)=[(V_0-V)/V] \times 100 \quad (12)$$

$$\text{Foam stability (FS) } (\%)=(V_{30}/V0) \times 100 \quad (13)$$

V: volume before whipping (ml), $V_0$: volume after whipping (ml), $V_{30}$: volume after standing (ml).

#### *2.3.4. Emulsifying Properties*

Emulsifying properties were determined according to the method of Wu [22] with a slight modification. The samples were dispersed in distilled water (1% w/v) and 15 ml of the dispersion were homogenized (Binatone BLG 452, UK) with 15 ml of vegetable oil at a speed of 15,000 rpm for 3 min. Afterwards, the samples were centrifuged at 3000 g for 5 min and the volume of the individual layers were read. Emulsion stability was evaluated by heating the emulsion for 30 min at 80°C. Then, the samples were centrifuged at 3000 g for 5 min. Emulsion activity and emulsion stability were calculated from the formula (14) and (15):

$$\text{Emulsion capacity or activity (EC) } (\%)=(Ve/V) \times 100 \quad (14)$$

$$\text{Emulsion stability (ES) } (\%)=(V30/Ve) \times 100 \quad (15)$$

V: total volume of tube contents, Ve: volume of the emulsified layer, V30: volume of the emulsified layer after heating.

### *2.4. Principal Component Analysis*

The results of Physiscochemical and functional properties were assessed using PCA Biplot with R. 4.1.0. with FactomineR and factoextra packages (R core team, 2021).

### *2.5. Kohonen Self-Organizing Map (SOM)*

The results of minerals were performed by MATLAB 6.1 for classifying density of mineral in species (map size: 8x6, final quantization error: 0.002, final topographic error: 0.000).

### *2.6. Statistical Analysis*

All experiments and/or measurements were replicated three times. The analyses were conducted with RStudio from R (Version 4.1.0, Boston, USA). The results were presented as the mean and the standard error of the mean (±SE). The accepted level of significance was 5% in all analyses. As data were not normally distributed and/or did not have homogeneous variances, Welch's ANOVA were used to evaluate the influence of species on the physicochemical, functional properties and fatty acid composition.

## 3. Results and Discussion

### *3.1. Nutritional Potential of Edible Insects*

The analysis highlighted the potential and nutritional quality of edible insects collected in different cities of Côte d'Ivoire (Table 1). Relatively low moisture contents were obtained in the samples [4, 23] except *Zonocerus variegatus* (55.09%). A low moisture content is desirable in order to facilitate storage and avoid the risk of microbial deterioration of edible insects over a long period [24, 25]. Carbohydrates were the main source of energy, besides fat, to fuel muscle and organs. Carbohydrates varied from 1.70 to 32.13 g/100g DM [26, 27]. Edible insects are true sources of protein [28-30]. The high protein content could help fight protein deficiency in Africa [31]. Indeed, the fat content was in the range from 8.944 to 46.065 g/100g DM and *M. subhyalinus* displayed the higher amount [32].

According to PCA Biplot analysis of the physicochemical parameters the first two dimensions expressed 69.91% of the total dataset inertia; that means that 69.91% of the individuals (or variables) cloud total variability is explained by the plane

(Figure 1). This percentage is relatively high and thus the first plane well represents the data variability. This value is strongly greater than the reference value that equals to 42.08%, the variability explained by this plane is thus highly significant (the reference value is the 0.95-quantile of the inertia percentages distribution obtained by simulating 2168 data tables of equivalent size on the basis of a normal distribution).

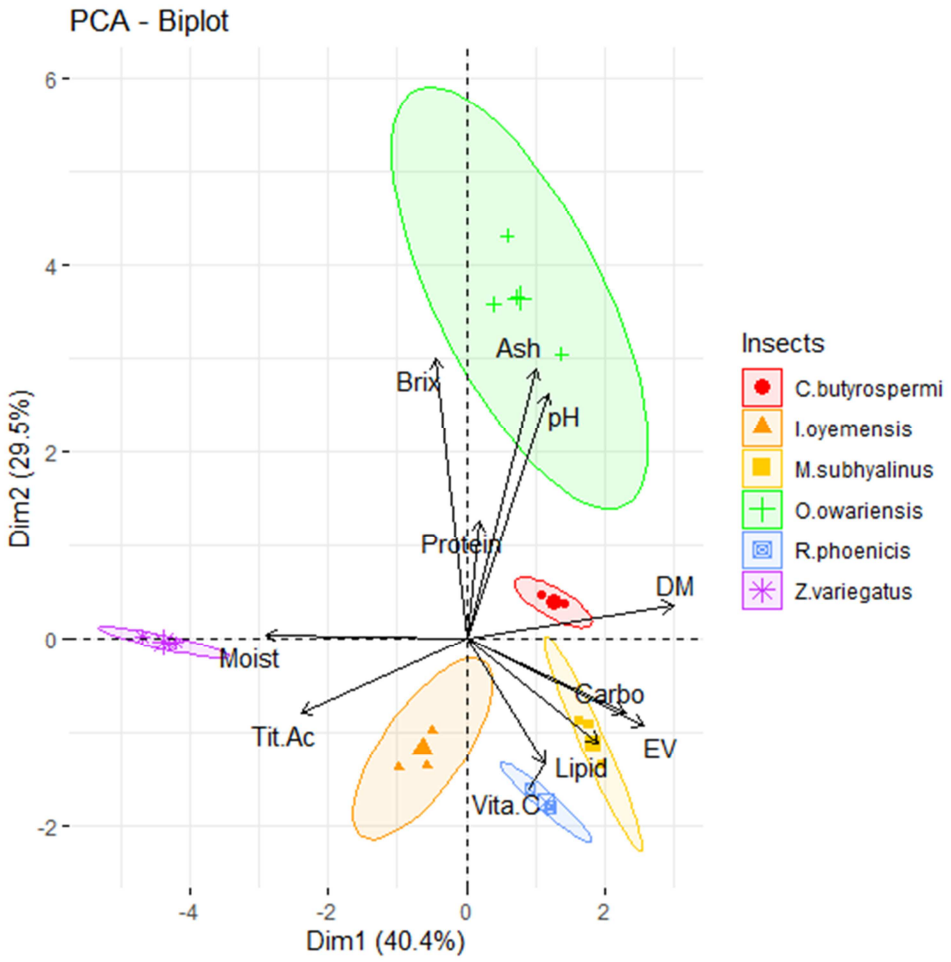


***Figure 1.*** *Biplot PCA between the physicochemical composition and the edible insects.*

***Table 1.*** *Physicochemical parameters of edible insects lyophilized.*

| Physicochemical Parameters | *C. butyrospermi* | *I. oyemensis* | *M. subhyalinus* | *O. owariensis* | *R. phoenicis* | *Z. variegatus* |
|---|---|---|---|---|---|---|
| pH | 6.18±0.01$^{c}$ | 5.41±0.01$^{a}$ | 6.36±0.01$^{d}$ | 7.41±0.03$^{e}$ | 5.83±0.03$^{b}$ | 5.80±0.01$^{b}$ |
| Titratable acidity (meq/L) | 3.07±0.83$^{a}$ | 43.60±3.47$^{d}$ | 19.33±0.11$^{c}$ | 10.80±1.42$^{b}$ | 6.93±0.92$^{ab}$ | 42.67±1.15$^{d}$ |
| Brix degree (°B) | 5.90±0.10$^{b}$ | 4.13±0.15$^{a}$ | 4.33±0.21$^{a}$ | 8.87±0.26$^{c}$ | 3.97±0.06$^{a}$ | 6.23±0.06$^{b}$ |
| Dry matter (%) | 92.86±0.55$^{c}$ | 74.85±11.96$^{b}$ | 94.03±2.71$^{c}$ | 90.89±2.27$^{c}$ | 86.97±2.04$^{bc}$ | 44.89±5.20$^{a}$ |
| Moisture (%) | 7.14±0.55$^{b}$ | 7.48±0.80$^{b}$ | 0.88±0.20$^{a}$ | 9.11±2.27$^{bc}$ | 13.02±2.04$^{c}$ | 55.09±1.85$^{d}$ |
| Vitamin C (mg/100gDM) | 267.52±12.32$^{b}$ | 136.67±3.72$^{a}$ | 138.13±3.79$^{a}$ | 114.84±10.02$^{a}$ | 415.07±22.58$^{c}$ | 126.00±6.81$^{a}$ |
| Ash (g/100g DM) | 4.73±0.83$^{b}$ | 1.26±0.59$^{a}$ | 2.57±0.58$^{ab}$ | 10.98±1.37$^{c}$ | 1.46±0.93$^{a}$ | 0.96±0.01$^{a}$ |
| Lipid (g/100g DM) | 17.94±0.18$^{ab}$ | 33.40±7.07$^{cd}$ | 46.06±8.32$^{d}$ | 23.31±1.97$^{bc}$ | 29.79±6.59$^{bc}$ | 8.94±2.86$^{a}$ |
| Protein (g/100g DM) | 44.49±4.72$^{bc}$ | 51.55±0.03$^{c}$ | 32.75±2.38$^{a}$ | 47.31±7.07$^{c}$ | 35.64±0.14$^{ab}$ | 34.59±0.51$^{ab}$ |
| Carbohydrate (g/100g DM) | 25.69±3.89$^{c}$ | 6.41±0.03$^{ab}$ | 19.11±2.38$^{bc}$ | 9.32±3.60$^{ab}$ | 20.08±3.94$^{bc}$ | 1.71±0.51$^{a}$ |
| Energy value (kcal/100g DM) | 442.19±5.00$^{b}$ | 533.11±1.53$^{d}$ | 619.86±2.08$^{e}$ | 436.20±19.17$^{b}$ | 490.99±25.03$^{c}$ | 216.46±1.00$^{a}$ |

Values with different alphabetic letters on the same row are statistically different (p-value <0.05).
C. butyrospermi=Cirina butyrospermi; I. oyemensis=Imbrasia oyemensis; M. subhyalinus=Macrotermes subhyalinus; O. owariensis=Oryctes owariensis; R. phoenicis=Rhynchophorus phoenicis; Z. variegatus=Zonocerus variegatus

The Wilks test p-value indicates that insect species are variable which one explain the best the distance between individuals. The dimension 1 opposes *O. owariensis* to *Z. variegatus*. *Oryctes owariensis* had high values for Ash, pH, Brix degree, protein and dry matter and low values for titratable acidity. However the dry matter and *Z.variegatus* are highly correlated with this dimension (respective correlation of 0.94, 0.96). These variables could therefore summarize

themselve the dimension 1.

The dimension 2 opposes *O. owariensis* to *R. phoenicis*. The *R.phoenicis* species shared high values for lipid, vitamin C, carbohydrate and Energy values. The dimension 3 opposes *I. oyemensis* to *C. butyrospermi*. *Imbrasia oyemensis* showed high values for titratable acidity and protein while *C. butyrospermi* was characterized by a negative coordinate on the axis with high values for vitamin C, carbohydrate, Brix degree and moisture.

### *3.2. Fat Indices*

These differences are also observed at the level of the principal component analysis carried out from dimensions 1 and 2. The first 2 axes of the analysis express 93.99% of the total inertia. This is a very high percentage, so the foreground represents extremely well the variability contained in the whole dataset. Dimension 1 opposes the species *Imbrasia oyemensis* (on the right of the graph) characterized by strongly positive coordinates on the axis to the species *Rhynchophorus phoenicis* (on the left) which has strongly negative coordinates on the axis. The *I. oyemensis* species has high values for peroxide and acid indices and low values for iodine index. In contrast, *R. phoenicis* is characterized by a high iodine index and a low acid value. *Cirina butyrospermi* is extremely correlated with dimension 1 (correlation of 0.9) and could summarize this axis on its own. The species *R. phoenicis, O. owariensis* and *C. butyrospermi* formed a group around a common component which is the iodine index.

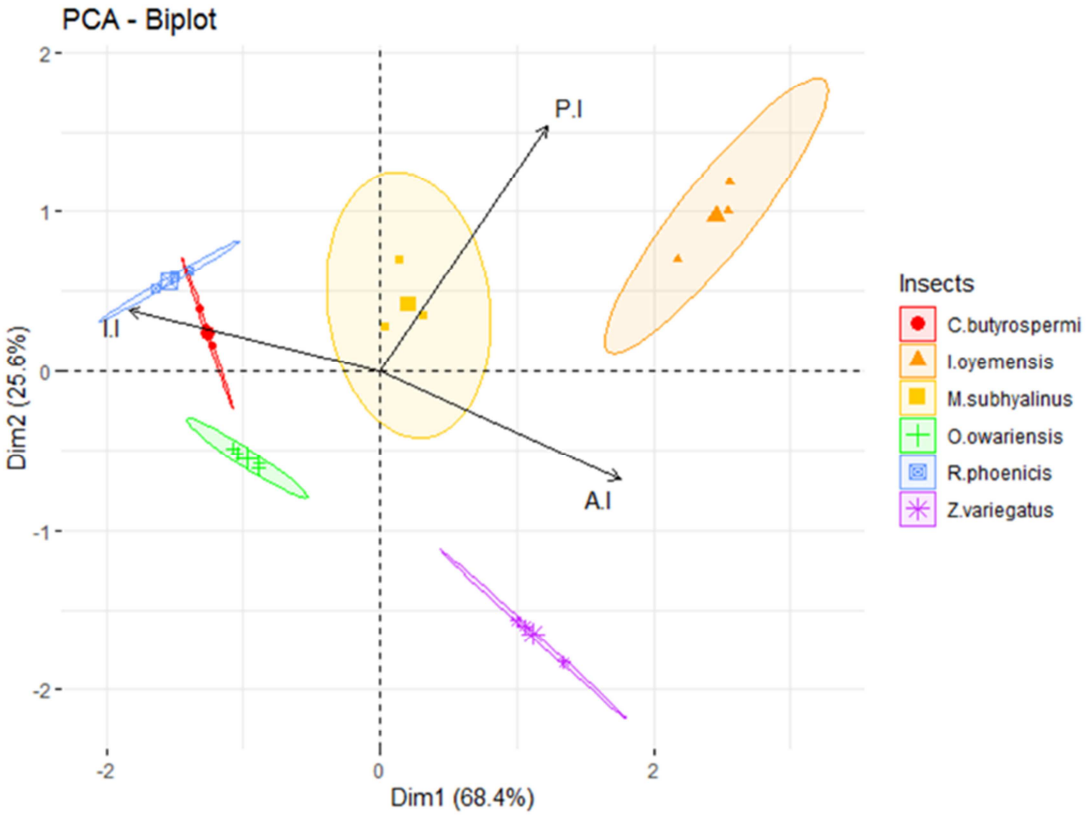


***Figure 2.*** *Biplot PCA between the fat parameters and the edible insects.*

### *3.3. Characterization of Fatty Acids*

The profile of fatty acids in the lipids of insects is presented in Table 3. In total, 23 fatty acids belonging to three different categories, including saturated, monounsaturated and polyunsaturated have been identified. Among the saturated fatty acids in the lipids of insects the highest share was palmitic acid (C16:0), and was followed by stearic acid (C18:0). The predominant monounsaturated fatty acid was oleic acid (C18:1) and polyunsaturated with high amounts was α-linolenic acid (C18:3) followed by linoleic acid (C18:2). The recommended amount of PUFA/SFA ratio in the diet should be higher than 0.40. Lepidoptera (*I. oyemensis*, *C. butyrospermi)* and *Z. variegatus* have therefore a better fat quality than *R. phoenicis, O. owariensis* and *M. subhyalinus*.

The quality of the fat depends on the fatty acid composition. In general, the insects analyzed had a level of saturated fatty acid (SFA) higher than unsaturated fatty acids (UFA) *except Z. variegatus* which evolved in the opposite direction (Table 3) [30]. Figure 3 is a great representation of fatty acids in the samples. Alpha-linolenic acid (up to 28.08 g/100g DM in *C. butyrospermi*) is the most important polyunsaturated fatty acids (PUFA) and present in all of Lepidoptera of this study [33]. Coleoptera (*R. phoenicis, O.owariensis,)*, Isoptera (*Macrotermes subhyalinus*) were characterized by oleic acid as monounsaturated fatty acid (MUFA). Palmitic acid is the most saturated fatty acid (SFA) in all species.

***Table 2.*** *Fat indices of edible insects lyophilized.*

| Index | C. butyrospermi | I. oyemensis | M. subhyalinus | O. owariensis | R. phoenicis | Z. variegatus |
|---|---|---|---|---|---|---|
| Peroxyde (meq $O_2$/kg fat) | 3,07±0,22a | 10,77±1,04b | 5,70±0,75c | 1,06±0,06d | 4,12±0,40a | 0,99±0,14d |
| Acidity (KOH/g fat) | 1,65±0,58a | 8,45±0,36b | 4,08±0,19c | 3,21±0,51d | 3,133±0,37e | 67,60±3,15f |
| Iodine ($I_2$/100g fat) | 112,28±3,26a | 55,76±2,28b | 85,97±5,04c | 102,12±1,37d | 142,49±1,07e | 67.60±3,15f |

Values with different alphabetic letters on the same row are statistically different (p-value <0.05).
C. butyrospermi: Cirina butyrospermi; I. oyemensis: Imbrasia oyemensis; M. subhyalinus: Macrotermes subhyalinus; O. owariensis: Oryctes owariensis; R. phoenicis: Rhynchophorus phoenicis; Z. variegatus: Zonocerus variegatus

***Table 3.*** *Functional properties of edible insects.*

| | *C. butyrospermi* | *I. oyemensis* | *M. subhyalinus* | *O. owariensis* | *R. phoenicis* | *Z. variegatus* |
|---|---|---|---|---|---|---|
| WAC (%) | 71.16±0.93$^{b}$ | 170.87±14.71c | 155.39±6.84c | 176.18±9.17c | 6.67±1.65a | 177.66±25.90c |
| OAC (%) | 121.36±2.95$^{a}$ | 128.46±3.63$^{a}$ | 135.79±4.78$^{a}$ | 210.73±1.02$^{b}$ | 129.74±20.63$^{a}$ | 235.14±22.79$^{b}$ |
| FC (%) | 2.56±0.46$^{a}$ | 6.93±0.62$^{ab}$ | 9.51±0.70$^{ab}$ | 16.55±3.58$^{c}$ | 12.77±0.01$^{bc}$ | 27.76±4.95$^{d}$ |
| FS (%) | 2.13±0.19$^{a}$ | 2.02±0.16$^{a}$ | 8.46±1.53$^{a}$ | 601.12±37.19$^{b}$ | 766.79±0.18$^{b}$ | 31.47±1.47a |
| EC (%) | 25.02±3.71$^{a}$ | 66.04±4.20$^{a}$ | 39.63±3.58$^{a}$ | 21±0.95$^{a}$ | 21.50±1.92$^{a}$ | 49.28±4.58$^{a}$ |
| ES (%) | 102.29±0.78$^{d}$ | 103.32±0.61$^{d}$ | 89.47±4.14$^{bc}$ | 91.48±6.81$^{c}$ | 81.12±3.89$^{b}$ | 12.57±1.7$^{a}$ |

Values with different alphabetic letters on the same row are statistically different (P <0.05).
C. butyrospermi=Cirina butyrospermi; I. oyemensis=Imbrasia oyemensis; M. subhyalinus=Macrotermes subhyalinus; O. owariensis=Oryctes owariensis; R. phoenicis=Rhynchophorus phoenicis; Z. variegatus=Zonocerus variegatus; N. dione=Nudaurelia dione; WAC: Water absorption capacity; OAC: Oil absorption capacity; FC: Foaminf capacity; FS: Foam stability; EC: Emsulsifying capacity, ES: Emulsion stability

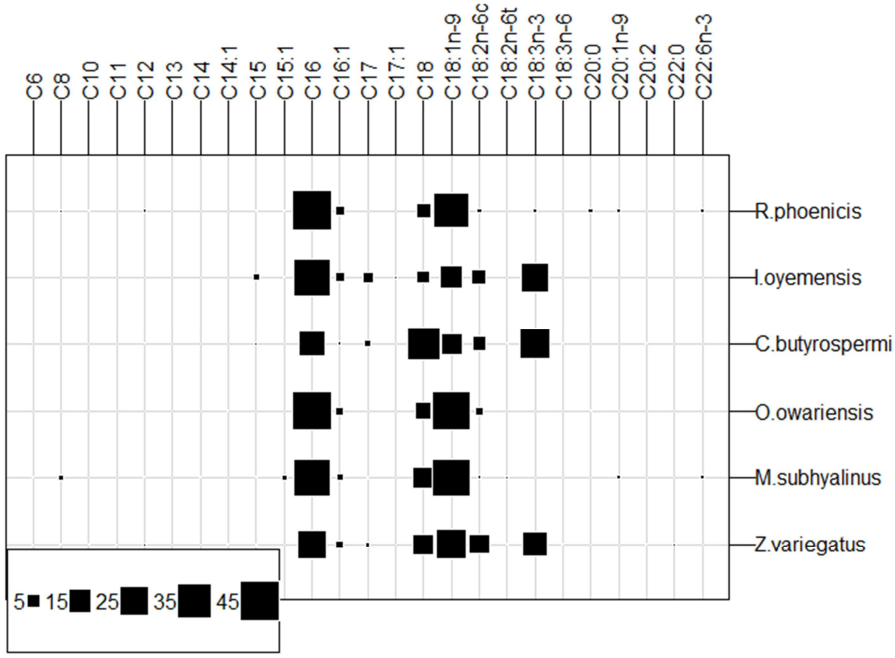


***Figure 3.*** *Abundance of Fatty acids (g/100 g DM) of six edible insects.*

Unsaturated fatty acids play an important role in human nutrition as it considerably reduces the occurrence and effects of cardiovascular, hypertensive, inflammatory, auto-inflammatory disorders. immune systems, depression and certain neurological functions [34, 35]. Oleic acid made *Macrotermes subhyalinus* (40.71±1.119g / 100g MS); *Oryctes owariensis* (43.915±0.918g / 100g DM) and *Rhynchophorus phoenicis* (39.524±0.869) ideal candidates in the formulation of food for people with hypercholesterolemia or a report of cholesterol imbalance [36, 37].

### *3.4. Micronutrients of Edible Insects*

The high ash content (0.96±0.01 to 10.98±1.37%) observed reflects the large quantity of minerals that constitute the species analyzed. Indeed, 10 minerals including Ca, Mg, K, Na, Cu, Zn, Fe, Mn, Mo and Se were determined from ashes of insects. Hence, potassium (6658.20 to 32527.24 mg/kg DM), calcium (2305.4 to 8669.33 mg/kg DM), magnesium (977.18 to 4879.89 mg/kg DM) and sodium (415.46 to 4350.11 mg/kg DM) which have been proven to be the most abundant micronutrients. In addition, the abundance of potassium is beneficial for the proper functioning of the organism, according to [38], potassium is the main cation of the intracellular fluid and participates in the acid-base balance, in the regulation of the pressure osmotic, conduction of nerve impulses, muscle contraction, as well as in the reduction of kidney stones. In addition, the high levels of

calcium and magnesium in the insects analyzed could satisfy the appetites compared to the reference values [39] whose needs are recommended in adults at 10 mg/kg/day for calcium and 5 to 7 mg/kg/day for magnesium. From a medical point of view, calcium is important in the fight against osteoporosis and several other chronic diseases such as hypertension and colon cancer [40]. It helps maintain acid-base balance in the body and helps control energy metabolism [41]. Its abundance in *Oryctes owariensis* (3559,206) makes it a food of choice. Like calcium, magnesium acts on various organs of the cardiovascular and neuromuscular systems [42]. It is a cofactor that participates in more than 300 enzymatic reactions, making it an essential element for the synthesis of carbohydrates, fats, nucleic acids and proteins. It should also be noted that micronutrients are beneficial for the body, in fact they are involved in strengthening the bones of adults. Also, they play a role of bio-activator and osmotic balance in cell metabolism. They also promote the growth of children [43]. Zinc is an integral part of many enzymes and is important for the human body [44]. Zinc deficiency is a major public health problem, especially for children and nursing mothers. Thus, *Rhynchophorus phoenicis* (209 mg/kg DM); *Oryctes owariensis* (147 mg/kg DM) richer in zinc would be adequate to reduce growth retardation and skin lesions as well as its increased susceptibility to infections mediated by immune system defects linked to zinc deficiency [45]. Zinc is a component of about 100 enzymes which catalyze activation, cell division, and immune action [46]. Zinc content of oyster is 132 mg/kg, *R. phoenicis* and *O. owariensis* were higher that of oyster [47]. Copper is a component of various oxidizing enzymes which contributes to oxidation–reduction reactions. Major dietary copper content of beef liver is 53 mg/kg [48]. Copper concentrations of M. subhyalinus (60 g/kg DM) and Z. variegatus (67 g/kg DM) were slighty higher than that of beef liver [49]. Likewise, the high iron content for these species, particularly for *Zonocerus variegatus* [4], is useful for the proper functioning of cells (especially in anemic people) because iron is an essential constituent for red blood cells [50]. Some chemical analyses [51, 52] obtained significant amounts of iron for *Zonocerus variegatus* (910 mg/100g); *Imbrasia oyemensis* (70.21 mg/100g); *Cirina butyrospermi* (13 mg/100g) and *Oryctes owariensis* (20,26 mg/100g). Considering the fact that iron content of beef liver, a good food source for iron, is 50–80 mg/kg [53]., iron content of *Z. variegatus* was higher at 432 mg/kg dry weight. Thus, all edible insects studied may be a main source of iron. This study found that mineral content differed with type of edible insects.

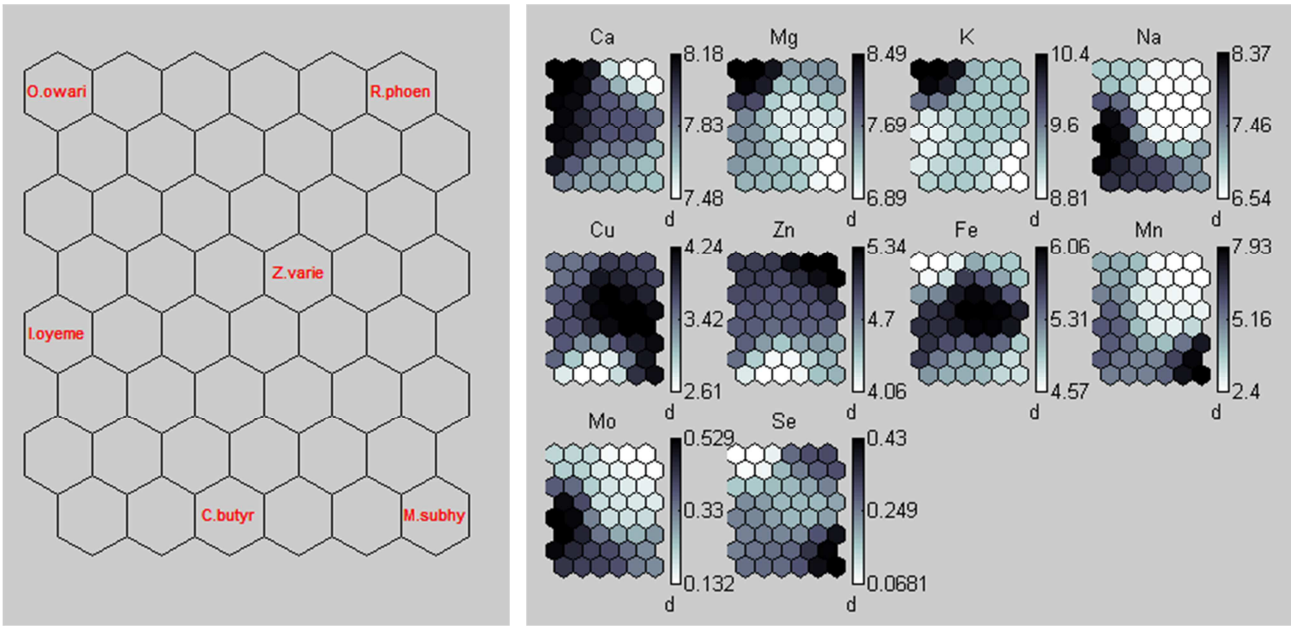


***Figure 4.*** *Relative abundance of minerals in six edible insects.*

### *3.5. Functional Properties*

Apart from the nutritional quality, the functional properties of insects were also determined (Table 3). Indeed, water absorption capacity (WAC) is an important property in food products that require water binding to improve the thickening as well as the viscosity of the food [54]. In addition, oil absorption capacity (OAC) is important in food applications with the aim of improving palatability and mouthfeel, as well as flavor preservation [55, 56]. Foam capacity (FC) and foam stability (FS) were in the respective ranges of 2.55 to 27.757% and 2.02 to 76.67%. The highest values of FP and FS were detected respectively in *Z. variegatus* and *R. phoenicis*. However, FS in *Z. variegatus* remains much higher [57]. The first two dimensions of Figure 5 related to the functional properties express 74.91% of the total dataset inertia. This percentage is high and thus the first plane represents an important part of the data variability. This value is greater than the reference value that equals 57.7%, the variability explained by this plane is thus significant (the reference value is the 0.95-quantile of the inertia percentages distribution obtained by simulating 2221 data tables of equivalent size on the basis of a normal distribution).

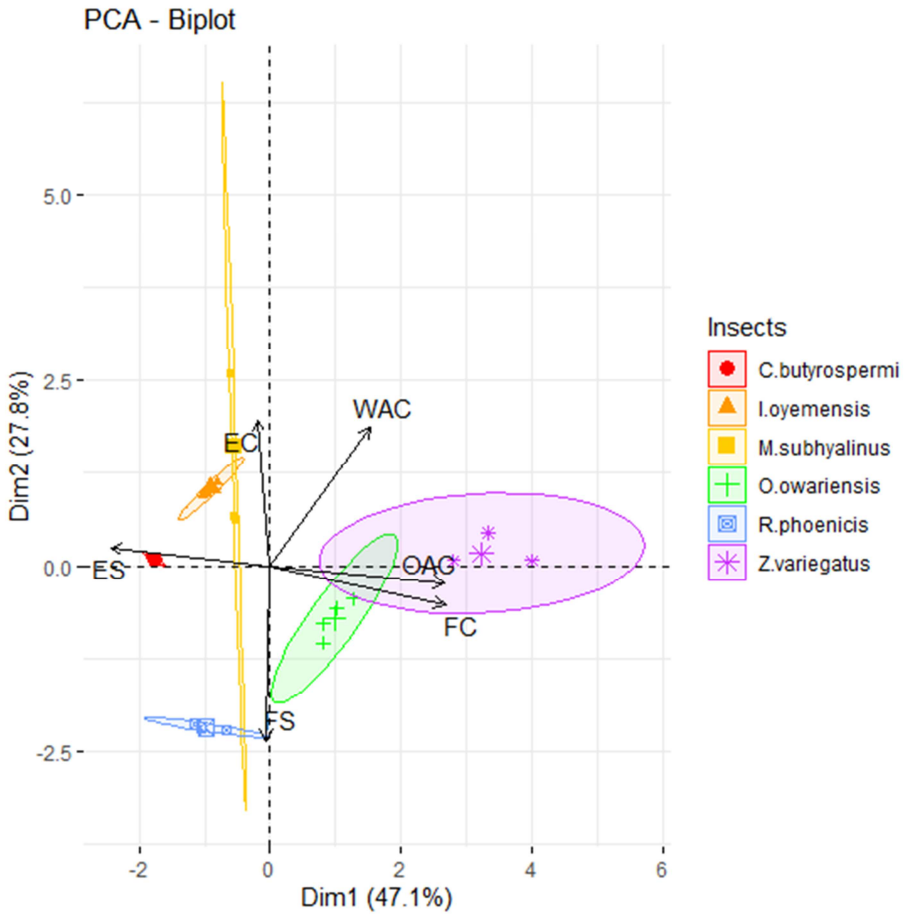


***Figure 5.*** *Biplot PCA between the functional properties and the edible insects.*

## 4. Conclusion

The nutritional profile established on six species of insects collected confirms that they are real sources of nutrients (proteins, lipids and minerals) capable of compensating for the nutritional deficiencies of populations, especially pregnant women and children. Having regard to the protein content which varied from 32.75g/100g DM to 51.55g/100g DM in *Imbrasia oyemensis*. In addition, lipid contents observed in *Macrotermes subhyalinus* were up to 46.06 g/100g DM. The recorded energy value was between 216.46±1.00 kcal/100g DM to 619.86±2.08 kcal/100g DM for the species analyzed. Regarding minerals, these insects are very rich in magnesium, calcium, potassium, sodium. Apart from their nutritional potential, the functional properties such as water and oil absorption capacity observed make them suitable for the formulation of certain foods and in many other.

## Acknowledgements

The authors thank Prof. Frédéric Francis, the Dean of Gembloux Agro Bio Tech-University of liege (Belgium) for his precious assistance in the analyses performed. We also thank Prof. Philippe Maesen for his help in minerals analysis.

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