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RESEARCH ARTICLE

Nutritional composition of three edible caterpillars in the Democratic Republic of Congo

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Abstract

The role of edible caterpillars in human nutrition is increasingly undeniable, given their contribution to food security, especially in sub-Saharan Africa. However, some local species are almost unknown and the lack of data on their nutritional composition limits the integration of consumption in consumer diets. This article therefore focuses on the nutritional profiles of three edible caterpillar species from DR-Congo: *Aegocera rectilinea*, *Epidonta* sp and *Imbrasia truncata*. Data on protein content and amino acid profiles were discussed, with particular emphasis on threonine, lysine, methionine, cysteine and histidine; fat content and fatty acid profiles were examined, with particular attention to omega-6 and omega-3 fatty acids and the PUFA/SFA ratio; Finally a discussion of essential minerals in insects, with particular emphasis on Fe and Zn, as well as anti-nutritional factors such as phytic acid, oxalates and tannins, which may have a negative effect on the bioavailability of these trace elements were discussed. The results of this study should induce a change in behavior in terms of the valorization of these edible insects as food in DR-Congo, via their popularization through workshops carried out in their production and consumption areas, while encouraging rational harvesting practices with a view to their sustainable use.

Keywords

Aegocera rectilinea – *Epidonata* sp. – food security – *Imbrasia truncata* – insect consumption

1 Introduction

Widespread undernutrition and poverty are major challenges to global development (*Griggs et al.*, 2013). By 2050, the world's population is expected to increase by one-quarter and the population of Sub-Saharan Africa is expected to double (Gnana *et al.*, 2022; Naumovski, 2022). This demographic growthwill lead to increases in food demand and production, especially in developing countries where undernourishment is rampant, creating an urgent need to identify new sustainable production methods. Edible insects appear to be a solution for the future that can contribute to the fight against food insecurity (Belluco *et al.*, 2015; Liceaga, 2021; Rodrigues *et al.*, 2021). Insects are very nutritious, rich in proteins, lipids, minerals, and vitamins, and have amino- and fatty-acid compositions that are well balanced for human needs (Gnana *et al.*, 2022; Kelemu *et al.*, 2015). Recent studies have shown that insects are rich sources of antioxidants and are beneficial to the human gut microbiota (Babarinde *et al.*, 2021; Raubenheimer and Rothman, 2013; Stull, 2021). In parallel, insects have

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high food conversion efficiency, and some species show excellent potential for rearing using organic byproducts; they have high fecundity, short development cycles, and low land and water requirements for their mass production (Paul *et al.*, 2016; van Huis, 2013).

Caterpillar consumption is very popular in Sub-Saharan Africa, representing about 31% of the species consumed among the 472 insect species identified as edible (Mariod, 2020). In the Democratic Republic of Congo (DRC), edible caterpillars represent 46.7% of all edible insect species inventoried in Kinshasa (Kelemu *et al.*, 2015; Nsevolo *et al.*, 2016). Caterpillars are an alternative protein sources (their main components), with an essential amino-acid profile comparable to those of soy and fish meal (Rumpold and Schlüter, 2013). Some species meet human nutritional needs for vitamins (e.g. thiamine/B1, riboflavin/B2, pyridoxine/B6, pantothenic acid, and niacin) and minerals (e.g. K, Ca, Mg, Zn, P, and Fe) (Vantomme *et al.*, 2004; Womeni *et al.*, 2009). Edible caterpillars are also sources of income for those who harvest them seasonally and those who trade them. For example, in Kinshasa, the sale of insects would bring in an average of €100 per month, whereas the average public administration salary is €85.93 per month (Leleup and Daems, 2014; Nsevolo *et al.*, 2016).

The caterpillars consumed most in the DRC belong to the Saturniidae family, notably *Cirina forda* (Westwood 1849), *Imbrasia epimethea* (Drury, 1773), *Imbrasia ertli* (Rebel, 1904), and *Imbrasia oyemensis* (Rougeot, 1955), and are collected mainly in savannahs and forests (Balinga *et al.*, 2004). Nutritional information for these edible caterpillars is generally known. For example, *C. forda* caterpillars contain 12-74.4 g/100 g protein, 5.3-20.2 g/100 g fat, 1.7-7 g/100 g carbohydrates, and 1.5-11.5 g/100 g ash. They also contain essential amino acids such as lysine, histidine, and threonine; essential fatty acids such as α-linolenic acid (C18:3n3) and linolenic acid (C18:1n9c); 1.3-64 mg/100 g Fe; and 3.7-24.2 mg/100 g Zn (Numbi *et al.*, 2022). Little or no nutritional information is available for other caterpillar species consumed (e.g. *Aegocera rectilinea* (Boisduval, 1836), *Epidonta* sp. (Bethune-Baker, 1911), and *Imbrasia truncata* (Aurivillius, 1909); Figure 1), although they may be significant food resources for consumers (Bocquet *et al.*, 2020; Malasi *et al.*, 2022; Muya *et al.*, 2021). The dissemination of information about the nutritional composition of these locally available species would contribute to their value enhancement and thereby the fight against malnutrition in certain regions of the country (Mabossy-Mobouna *et al.*, 2022).

FIGURE 1 Edible caterpillars. (A) *Aegocera rectilinea*; (B) *Epidonta* sp.; (C) *Imbrasia truncata*.

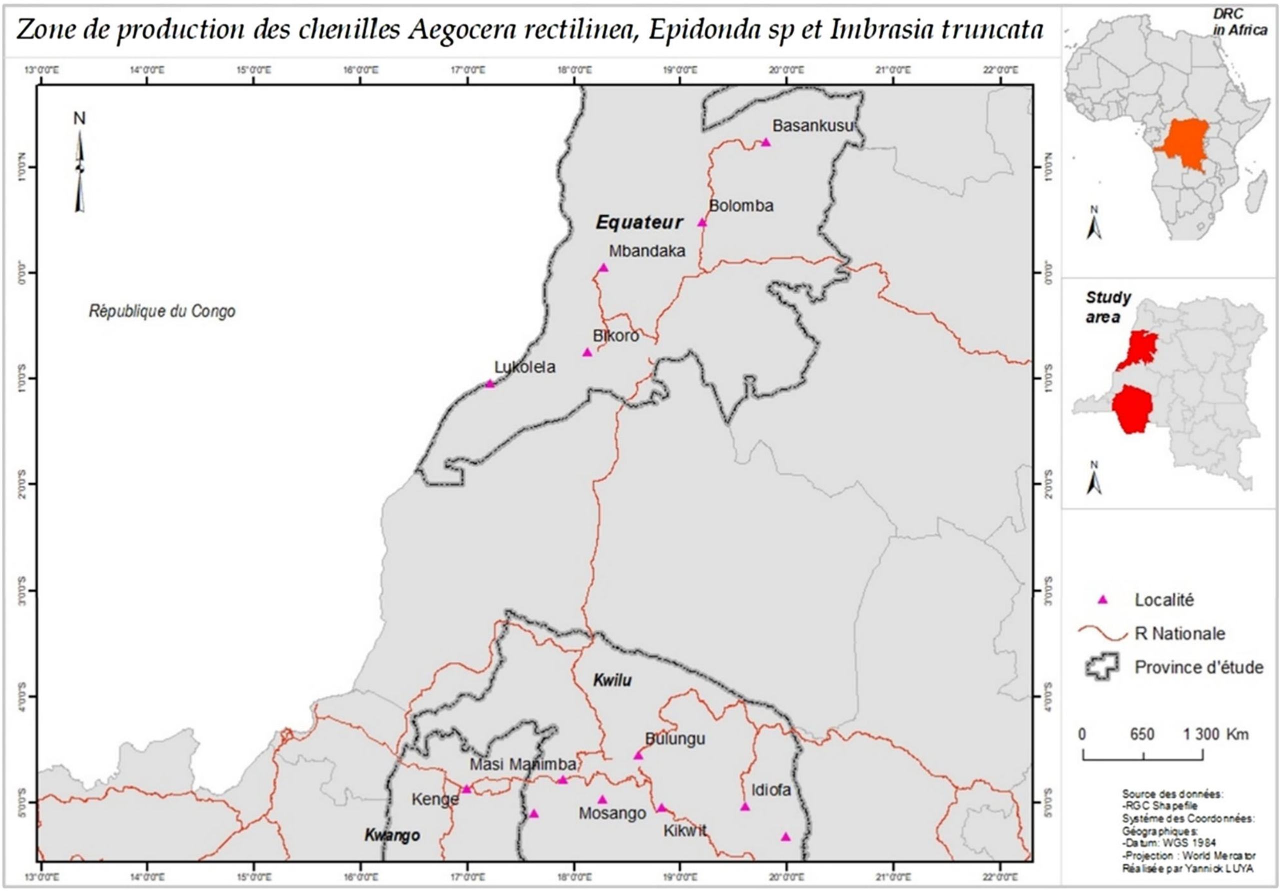

FIGURE 2 Map showing study sites in the Republic of Congo: Edible caterpillar production zone.

A. rectilinea, commonly called "*mikombidila*" in Kikongo, Kimbala, Kisuku, and Kiyaka, is consumed by the local population of the former Bandundu Province; Figure 2). This caterpillar feeds mainly on the leaves of *Boerhavia diffusa* L., a pantropical annual with a creeping or erect glabrous stem that grows around houses, in deserted villages, and on wastelands and fallow land (Mbuta *et al.*, 2012; Figure 3). It feeds secondarily on the leaves of other plants with food value, such as *Arachis hypogaea* L., *Brassica oleracea* L., *Lagenaria sicerana* (Molina) Standl., *Lycopersicon* sp. Mill, *Manihot esculenta* Crantz, *Phaseolus vulgaris* L., *Vigna unguiculata* (L.) Walp, and *Zea mays* L. (AfroMoth, nd). It appears at the beginning of the rainy season, i.e. in September, and its season ends in January. However, it can be harvested in very small quantities throughout the year in some regions (Numbi *et al.*, 2022).

Epidonta sp. belongs to the Notodontidae family. It is consumed in the western portion of the DRC by the Yansi ethnic group. It appears from November to January in the Masi-Manimba region (Figure 2). It is a defoliator of the plant *Millettia laurentii* De Wild, which belongs to the Fabacae family (Malasi *et al.*, 2022; Figure 3).

I. truncata belongs to the Saturniidae family. It is called "*poso*" in Equateur (northern DRC) and "yellow *bikubala*" in Lubumbashi (southeastern DRC; Figure 2). It feeds on the foliage of several plants, including *Amphimas pterocarpoides* Harms. 1913, *Petertianthus macrocarpus* (P. Beauv.) Liben, and *Piptadeniastrum africanum* (Hook.f.) Brenan 1955 (Mabossy-Mobouna *et al.*, 2013; Numbi *et al.*, 2022; Figure 3).

The objective of the present study was to determine the nutritional composition of the caterpillars *A. rectilinea*, *Epidonta* sp. and *I. truncate*. We provide new data on their protein and lipid contents, amino- and fatty-acid profiles, and some micronutrient contents.

2 Materials and methods

Sample collection and preparation

A. rectilinea caterpillars were obtained from mass rearing in cages (BugDorm-4D, 47.5 × 47.5 × 93 cm; NHBS – Wildlife, Ecology & Conservation, Totnes, UK) placed in a breeding room with uncontrolled environmental conditions (26 ± 2 °C, 77 ± 6% relative humidity) at the Laboratory of the Faculty of Agronomic Sciences, Uni-

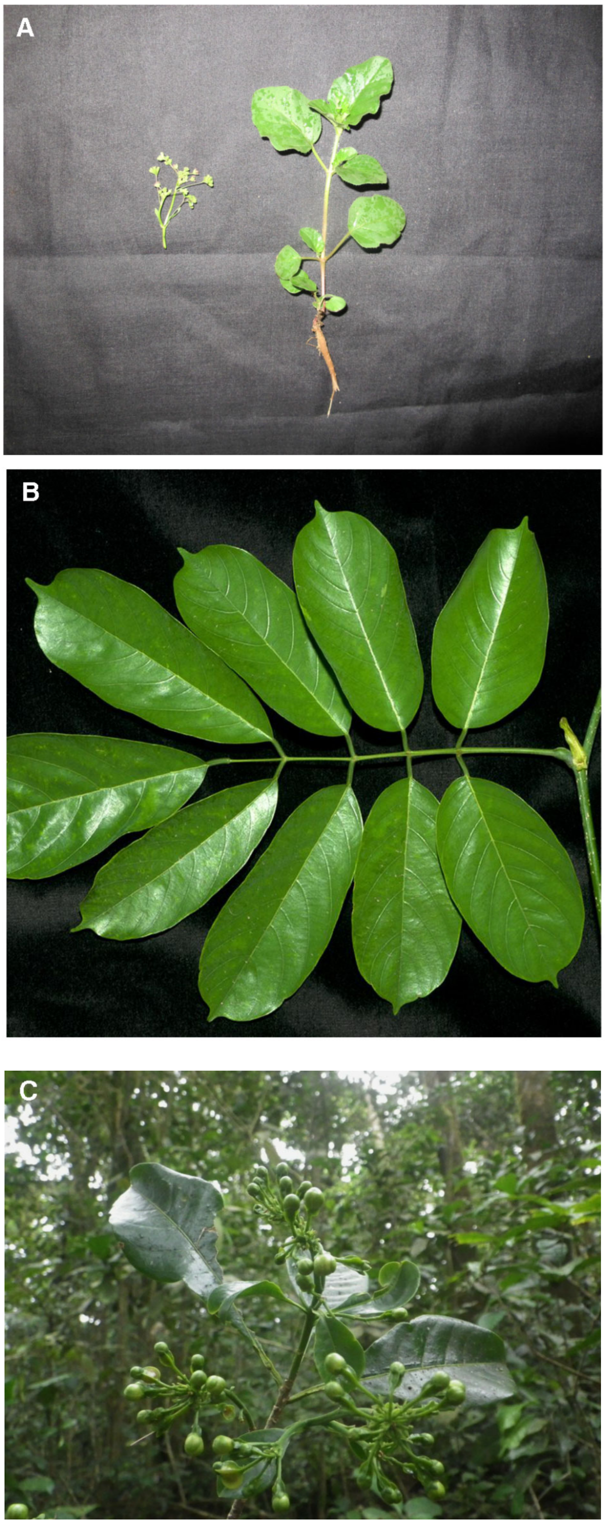

FIGURE 3 Host plants of edible caterpillars. (A) *Boerhavia diffusa*; (B) *Millettia laurentii*; (C) *Petertianthus macrocarpus*.

versity of Kinshasa, Kinshasa, Democratic Republic of Congo. The caterpillars completed larval development in growth cages, where they fed on locally grown *B. diffusa* leaves. The pupae were collected and placed in emergence cages, and adult mating and oviposition took place in breeding cages containing *B. diffusa*. Each plant had 11 leaves on 6 branches. The mean total life-cycle duration, from egg to adult emergence, was 36.2 ± 2.3 days with developmental phase durations of 19.8 ± 1.6 and 12.5 ± 1.9 days were observed for the larval and pupal stages, respectively (Muya *et al.*, 2021).

One (1) kg of each caterpillar species: dried *I. truncata* and boiled *Epidonta*. sp. were bought on the markets of Kinshasa in August (2021). They were sorted and cleaned of all kinds of waste and stored at −20 °C. Each sample was freeze-dried and milled for about 1 min in a grinder (IKA-Werke GmbH & Company, Staufen im Breisgau, Germany) before using. The insect powder was then recovered for nutritional analysis. Sampling consisted of identifying all caterpillar species sold in four key markets in the city of Kinshasa. On the basis of a literature review on the nutritional composition of the caterpillars identified, those whose chemical composition was under-documented or non-existent were selected for analysis.

Nutritional analysis

The samples' dry matter (DM) content was determined by dehydrating them in a drying oven at 105 °C overnight. The ash content was determined by incinerating the samples in a muffle furnace heated to 550 °C at a constant rate of 50 °C every 30 min for 4 h, followed by cooling in a desiccator using the methods of the Association of official Analytical Chemist (AOAC, 2005). The crude protein content was determined by the Dumas method (Rapid N Cube Elementary, Hanau, Germany) with an N-protein conversion factor of 4.76 (Janssen *et al.*, 2017). Amino acid profiles were determined by ion chromatography with ultraviolet detection (ISO 13903:2005 mod Laboratoire Euraceta SA, Villers-le-Bouillet, Belgium). The fat content was determined by the Folch extraction method described by Paul *et al.* (2017). Fatty acids from 10 mg lipids were converted to 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 hexane (VWR) and were then analyzed by gas chromatography-mass spectrometry (GCMS: Trace GC Ultra, Thermo Scientific Interscience; Asse, Belgium). The following parameters were used: column (Restek Stabilwax-DA30 m 0.25 mm ID 0.25 µm df); gases (He:1 ml/min, H2: 35 ml/min, air: 350 ml/min, N2: 30 ml/min); injection (Splitless 0.85 min); Detector (FID 2050 °C); Temperature program: 40 °C(1′) – (30 °C/′)00150 °C – (4 °C/′) – 240 °C(18′). 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 mixture, Sigma-Aldrich, St Louis, MO, USA).

The relative percentage of each fatty acid was obtained by comparing the area of the individual peak to the sum of the areas of the peaks of all identified compounds using Chemstation software (Agilent Technologies, Palo Alto, CA, USA). The Fe and Zn contents were determined by wet mineralization of the samples (HNO_3/HCl = 1/3) and atomic absorption measurement (Buck Scientific, Norwalk, UK).

Data analysis

The data collected was analyzed using descriptive statistics with the computation of means and standard deviations.

3 Results and discussion

Protein contents

The crude protein contents of the three caterpillars analyzed ranged from 42.3% (*Epidonta* sp.) to 53.82% (*A. rectilinea*) dm (Table 1). These values are similar to the range reported by Nsevolo *et al.* (2022) (40-50%) for nine species of edible caterpillar belonging to two main families (Notodontidae and Saturniidae). The analytical method used, rearing conditions or origin (farmed or wild caught), stage at harvest, diet, and natural or biological variation are the main contributors to the variation in edible insects' nutritional profiles (Anankware *et al.*, 2021).

Epidonta species belong to the same family as *Anaphe infracta* and *Anaphe recticulata*, but have a higher protein content, closer to that of "*tunkobio*" caterpillars. In the Saturniidae family, *I. truncata* has a higher protein content than *C. forda*, but this content was lower in this study than previously reported for *I. truncata* and *Imbrasia obscura* (Table 1). *A. rectilinea*, the only Noctuidae, has a higher protein content than some species of the family Saturniidae, such as *I. oyemensis* and *C. forda*; this content is closer to that of caterpillars of *Bunaea alcinoe* (Table 1). The differences in protein content between this study and others are due in part to the use of the N-protein conversion factor of 6.25 in most studies (Finke and Oonincx, 2014); we applied the factor of 4.76, following Janssen *et al.* (2017), to our values and those reported previously, as the use of 6.25 tends to lead to overestimation due to the non-protein N fraction present in the exoskeleton (Hawkey *et al.*, 2021; Jonas-Levi and Martinez, 2017; Mariotti *et al.*, 2008). However, the protein content calculated with the 4.76 conversion factor is not always accurate due to the variable chitin content of the insect cuticle. Hard cuticles have high (70-85% dry weight) protein and low (15-30%) chitin contents, whereas soft cuticles contain about 50% chitin and protein. Thus, the amount of protein can vary greatly among species and among life cycle stages of the same insect (Jonas-Levi and Martinez, 2017). Thus, the determination of the protein content by amino acid analysis would be of interest, although this method would lead to the destruction of certain amino acids, such as tryptophan and cysteine

TABLE 1 Chemical composition of three edible caterpillars (%DM)

Edible insects	Family	Protein	Lipids	Ash
Aegocera rectilinea	*Noctuidae*	53.82 ± 0.11	5.1 ± 0.27	9.07 ± 0.04
Anaphe infracta	*Notodontidae*	15.2[*a]	–	–
Anaphe recticulata	*Notodontidae*	17.5[*a]	–	–
Bunaea alcinoe	*Saturniidae*	42[*b]	–	–
Cirina forda	*Saturniidae*	38.1[*c]	–	–
Epidonta sp	*Notodontidae*	42.3 ± 0.40	27 ± 0.70	10.29 ± 0.4
Imbrasia belina	*Saturniidae*	41.1[*d]	–	–
Imbrasia obscura	*Saturniidae*	55[*e]	–	–
Imbrasia truncata	*Saturniidae*	49.95 ± 0.53	25.3 ± 2.15	4.34 ± 0.00
Imbrasia truncata	*Saturniidae*	54.1[f]	–	–
Imbrasia oyemensis	*Saturniidae*	40[*c]	–	–
Tunkobio	*Notodontidae*	41.1[*c]	–	–

Results are expressed as an average ± standard deviation (n = 3).

Sources: Hlongwane *et al.* (2020)[a], Amadi and Kiin Kabari (2016)[b], Kanga-Kanga *et al.* (2018)[c], Moyo *et al.* (2019)[d], Mabossy-Mobouna *et al.* (2018)[e], Mabossy-Mobouna *et al.* (2017)[f].

* The values obtained were recalculated using 4.76 as the N-protein conversion factor.

(Anankware *et al.*, 2021). For example, Fogang Mba *et al.* (2019) calculated specific N conversion factors for *Imbrasia* caterpillars by determining the amounts of N in total amino acid residues from the amino acid composition and dividing them by the total N content. The percentages of protein N content calculated from the amino acid residue compositions for *I. truncata* and *I. epimethea* (92.1 and 97.8 g/100 g N, respectively) confirmed that small percentages of N are not from protein, but are from elements such as chitin, nucleic acids, and phospholipids. Because of these variations, the assessment of the digestible protein content of insects should involve the subtraction of the fraction of non-digestible N in chitin from the total N, and the multiplication of this value by the appropriate conversion factor for each insect species category. In addition, certain cooking processes could contribute significantly to the observed differences in protein content among species. For example, the removal of the intestinal contents of some edible caterpillars significantly increases their protein content due to the loss of carbohydrate plant material in the gut (from 68.5 ± 0.7 to 73.1 ± 0.3 g/100 g dm for *I. epimethea*) (Lautenschläger *et al.*, 2017). In this study, the intestinal contents were not removed from *A. rectilinea* samples and details of the transformation processes of *Epidonta* and *I. truncata* were lacking, which prevented the establishment of a link between the observed protein level and the elimination of the intestinal contents.

The protein digestibility and/or bioavailability of these edible caterpillars could also be taken into account by indicators such as amino acid scores (including the protein digestibility-corrected and digestible indispensable scores), the chemical score, biological value, net protein utilization, and *in-vitro* or *in-vivo* protein digestibility (Miankeba *et al.*, 2022). In this study, we assessed the content of the five essential amino acids (EAA) methionine, cystine, lysine, threonine and histidine in *A. rectilinea* caterpillars. Indeed, some insect proteins are low in methionine and cystine but high in lysine and threonine (Womeni *et al.*, 2009). At the same time, given that histidine is an indispensable amino acid in adults and children (Gibbs, 2020; Moro *et al.*, 2020), these five EAA were analyzed in this study to verify whether edible caterpillars could be a potential source of it for the benefit of consumers.

The amino acid concentrations in *A. rectilinea*, quantified per 100 g protein, meet the United Nations' Food and Agriculture Organization's (FAO) recommendations (Table 2). These caterpillars have an interesting lysine content and can be mixed with cereal flour, which is often low in this essential amino acid. In addition, increasing the quantity of caterpillars ingested could help balance the nitrogen balance to cover amino acid requirements (Foua Bi *et al.*, 2015). The consumption of these caterpillars in combination with other energy- and protein-providing foods (to maximize the health benefits of entomophagy) could be expected to meet human needs.

The edible caterpillar flours analyzed in this study could be mixed with those of certain cereals (i.e. sorghum and corn) and incorporated into porridges fed to children, fragile individuals, and pregnant women for breakfast (Numbi *et al.*, 2022; Ombeni and Munyuli, 2019). These edible caterpillars can also replace nutritional inputs (F75 and F100 milk) used in the management of pediatric malnourishment, because of their high protein and energy content in the same way as with other edible caterpillar species (*Bunaeopsis aurantiaca* (Rothschild, 1895), *C. forda*, and *I. oyemensis*) (Ombeni and Munyuli, 2019).

Lipid contents

The lipid contents of the caterpillars analyzed ranged from 5.1% (*A. rectilinea*) to 27% (*Epidonta* sp.; Table 1), within the range of 5-77% reported for most edible caterpillars (Rumpold and Schlüter, 2013). The lipid contents of *Epidonta* sp. and *I. truncata* are similar to the average of 28% reported by Rumpold and Schlüter (2013) for Lepidoptera larvae and greater than that of *A. rectilinea*, which in turn is similar to that reported by the same authors for *C. forda*. They are therefore a potential source of lipids for human consumption (Foua Bi *et al.*, 2015). The low lipid content of *A. rectilinea* larvae is due to their collection before the pupal stage, when these larvae accumulate the energy reserves needed for main-

TABLE 2 Amino acid compositions of three edible caterpillars (g/100 g of protein)

Edible caterpillars	Threonine	Cystine	Methionine	Histidine	Lysine
Aegocera rectilinea	3.6	1.1	1.5	2.2	6.4
PR-FAO (g/100 g of protein)	2.3	–	–	1.5	3.3

Sources: Atowa *et al.* (2021), Mabossy-Mobouna *et al.* (2017), Nsevolo *et al.* (2022).

tenance during metamorphosis (10-15 days) (Downer and Matthews, 1976).

Fatty acid contents

All caterpillars analyzed contained palmitic (C16:0) and stearic (C18:0) acids, the main saturated fatty acids (SFAs) found in insects. *Epidonta* sp. had the highest SFA content (70.15%), represented mainly (50.38%) by palmitic acid, and *A. rectilinea* had the lowest content (23.15%), represented largely (16%) by stearic acid. The SFA content of *I. truncata* was 33%, with palmitic acid being the major component (17.3%; Table 3).

Palmitoleic (C16:1) and oleic (C18:1n9cis) acids are among the main monounsaturated fatty acids (MUFAs) in insects (Caparros Megido *et al.*, 2015). The caterpillars analyzed in this study contained little palmitoleic acid, whereas oleic acid was among the predominant MUFAs (Table 3). *A. rectilinea* and *I. truncata* had the highest and lowest MUFA contents (14% and 10%, respectively), and the MUFA content of *Epidonta* sp. was 12%; in all cases, the oleic/elaidic acid group was the major component. The oleic acid values obtained in this study (10-13.2%) are higher than that reported for *I. epimethea* (8.4%) and within the range reported for *Cirina butyrospermi* (Vuillet 1911), *C. forda*, *Imbrasia belina*, *I. obscura*, and *I. truncata* (0.4-40.3%) (Numbi *et al.*, 2022).

Polyunsaturated fatty acids (PUFAs) were most represented in the three caterpillar species analyzed (Table 3). The highest proportion (67.3%) of PUFAs was found in *I. truncata* and the lowest proportion (28%) was found in *Epidonta* sp. *A. rectilinea* had 56% PUFAs. PUFAs in all species were predominantly α-linolenic acids (27%, 32%, 12%, respectively).

The fatty acid profiles of these caterpillars make them suitable for human consumption and beneficial to health. For example, PUFAs have been shown to reduce low-density lipoprotein cholesterol levels by preventing atherosclerosis and are considered to be essential for healthy childhood development (Anankware *et al.*, 2021). Dietary deficiencies in PUFAs appear to inhibit growth and slow wound healing (Anankware *et al.*, 2021). On the other hand, the high SFA level in *Epidonta* sp. due to the palmitic acid content is a potential risk factor for increased blood pressure, low-density lipopro-

TABLE 3 Fatty acid profiles of three edible caterpillars

% Fatty acids (n = 3)	*Aegocera rectilinea*	*Epidonta* sp.	*Imbrasia truncata*
Myristic acid (C14:0) SFA	–	0.15 ± 0.07	–
Myristoleic acid (C14:1) MUFA	–	0.09 ± 0.01	–
Pentadecanoic acid (C15:0) SFA	–	2.06 ± 017	–
Pentadecenoic acid (C15:1) MUFA	–	2.37 ± 0.07	–
Palmitic acid (C16:0) SFA	2.25 ± 0.9	50.38 ± 2.35	17.3 ± 1.3
Palmitoleic acid (C16:1) MUFA	0.4 ± 0.3	1.79 ± 0.13	–
Margaric acid (C17:0) SFA	0.5 ± 0.5	0.77 ± 0.13	–
Heptadecenoic acid (C17:1) SFA	0.4 ± 0.3	–	–
Steric acid (C18:0) SFA	16 ± 1.4	15.89 ± 0.92	15.5 ± 1.3
Oleic / elaidic acid C18:1n9cis + trans MUFA	13.2 ± 4.6	10 ± 1.12	9.6 ± 0.9
Linoleic acid (C18:2n6c) PUFA	15.8 ± 1.0	2.90 ± 0.64	20.4 ± 1.5
α-linolenic acid (C18:3n3) PUFA	27 ± 1.4	12 ± 0.36	32 ± 3.2
Arachidic acid (C20:0) SFA	1.9 ± 1.7	0.37 ± 0.06	–
Behenic acid (C22:0) SFA	1.3 ± 0.1	0.53 ± 0.13	–
Docosadienoic acid (C22:2n6) PUFA	0	1.20 ± 0.84	5.6 ± 4.7
Lignoceric acid (C24:0) SFA	1.2 ± 0.9	–	–
Total			
SFA	23.15	70.15	33
MUFA	14	12	10
PUFA	56	28	67.3
Ratios			
PUFA/SFA	1.8	0.4	4
n6/n3	0.58	0.3	0.64

Data are mean values with standard deviations.

tein levels, and atherosclerosis. However, the hypercholesterolemic action of palmitic acid could be mitigated by the presence of oleic and stearic acids, which contribute to the increase of blood high-density lipoprotein cholesterol levels (Mabossy-Mobouna *et al.*, 2017.).

The PUFA/SFA ratios of *A. rectilinea* (1.8) and *Epidonta* sp. (0.4) are more beneficial to human consumers' health and well-being than is that of *I. truncata* (Table 3). This ratio is a good indicator of the health-benefitting (e.g. cholesterol- and cardiovascular disease-reducing) qualities of dietary lipids, and the consumption of foods with PUFA/SFA ratios close to 0 is recommended (Anankware *et al.*, 2021; Paul *et al.*, 2017). PUFA/SFA ratios ≥ 3 confer a risk of cardiovascular disease development and those ≤0.33 may be atherogenic (Paul *et al.*, 2017). Although the PUFA/SFA ratio for *I. truncata* is >3, this species can be used in the same way as other caterpillars in coronary heart disease prevention and treatment in patients with desirable cholesterol levels (Womeni *et al.*, 2009). Moreover, the consumption of these caterpillars would compensate the lack of essential fatty acids, which are provided mainly by tropical vegetable oils (Womeni *et al.*, 2009). The ratio of omega-6 to omega-3 (n6/n3) fatty acids is another indicator of dietary fat quality. The n6/n3 ratios of the analyzed caterpillars ranged from 0.24 to 0.64, fulfilling published recommendations (Milićević *et al.*, 2014). N6/n3 ratios < 4 reduce the risk of developing diseases such as cancer and coronary heart disease (Milićević *et al.*, 2014).

Mineral contents

The three caterpillar species studied had Fe contents of 84-362 mg/kg and Zn contents of 82-150 mg/kg (Table 4), meeting the European Food Safety Authority's and FAO's Fe (9-20 mg/kg/day) and Zn (30-140 mg/kg/day) requirements for adults. The highest and lowest Fe and Zn concentrations were found *A. rectilinea* and *Epidonta* sp., respectively. The concentrations in *A. rectilinea* are similar to those in *I. belina* (310 and 140 mg/kg, respectively), one of the most widely consumed caterpillar species (Numbi *et al.*, 2022).

The caterpillars analyzed contain more of these micronutrients than certain cereals (wheat, corn, and rice), cassava leaves, and tubers (Table 4). Deficiency in these minerals prevails in areas where diets are very often monotonous, energy rich, and micronutrient poor, generally made up of cereals and tubers with little consumption of animal products (Mwangi *et al.*, 2018). In addition, cereals, nuts, and legumes contain antinutritional compounds, such as phytic acid, oxalates, and tannins, that tend to reduce Fe and Zn absorption and bioavailability by forming soluble and insoluble complexes (Mwangi *et al.*, 2018). The addition of caterpillars to starchy diets could improve the intake of these minerals and reduce the incidence of anemia (Kanga-Kanga *et al.*, 2018; Mwangi *et al.*, 2018). However, a better understanding of the bioavailability of Fe and Zn from edible insects is urgently needed to provide scientific data on their effectiveness in improving diets.

TABLE 4 Fe and Zn contents of the caterpillars analyzed and other food sources

Species	Fe (mg/kg)	Zn (mg/kg)
Aegocera rectilinea	362	150
Epidonta sp	84	82
Imbrasia truncata	317	96
Wheat	11.7	7
Maize	5.2-27.1	4.5-22.1
Rice	8	11.6
Cassava leaf	4-83	71
Cassava tubers	17	7.5

Sources: Abdulrahman and Omoniyi (2016), Chávez *et al.* (2005), Montagnac *et al.* (2009).

4 Conclusion

The present analysis demonstrated that *A. rectilinea*, *Epidonta* sp. and *I. truncata* have great potential as dietary protein and lipid sources. These caterpillars have favorable nutritional profiles in terms of amino acids, fatty acids, and minerals. However, the digestibility of nutrients and bioavailability of minerals from edible caterpillars need to be investigated to ensure these insects' effective and efficient use as human food. At the same time, the health risks (biological agents and chemical contaminants) associated with edible insects must also be taken into account in order to guarantee consumer safety.

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Conflict of interest

The authors declare no conflict of interest.

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