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Imbrasia truncata caterpillars' nutritive composition and food value-adding pathways: A review

Germain Mabossy-Mobouna[1,2*], Justin B. Ombeni[3,5], Louis Looli B.[5], Théodore Munyuli B. M.[3,4] & François Malaisse[6,7]

[1]Laboratoire de Nutrition et d'Alimentation Humaines, Faculté des Sciences et Techniques, Université Marien Ngouabi, Congo Brazzaville.
[2]Unité de Recherche en Nutrition, Santé et Motricité Humaine, Institut Supérieur d'Education Physique et Sportive, Université Marien Ngouabi, Congo Brazzaville.
[3]Département de Nutrition et Diététique, Institut Supérieur de Techniques Médicales de Bukavu, Sud-Kivu, D.R. Congo.
[4]Laboraroire d'Entomologie, Centre de Recherche en Sciences Naturelles de Lwiro, CRSN, Bukavu, Sud-Kivu, D.R. Congo.
[5]Laboratoire d'Entomologie Appliquée et Fonctionnelle (LENAF), Institut Facultaire des Sciences Agronomiques de Yangambi-Kisangani, D.R. Congo.
[6]Biodiversity and Landscape Unit, Gembloux Agro-Bio Tech, University of Liège, Belgium.
[7]Meise Botanical Garden, Belgium.

**Corresponding author*, E-mail: *bossylsmabmobger@gmail.com*

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ABSTRACT

The world's population is rapidly increasing and could reach 10 billion by 2050. This situation is expected to increase global food demand by up to 70% over current levels. The goal of this study was to demonstrate the potential of *Imbrasia truncata* caterpillars harvested in the equatorial forest as an alternative food resource that could fill the food gap in the future and alleviate certain nutritional pathologies. To accomplish this, documentary research was conducted on the nutritional value of *I. truncata* caterpillars and the importance of the nutrients that comprise this value on the proper functioning of the human organism and the prevention of certain pathologies. As a result, *I. truncata* caterpillars are high in proteins, lipids, vitamins, minerals, and oligo-elements. They are high in all essential amino acids, including threonine, tryptophan, and aromatic amino acids. Essential fatty acids (linoleic acid C18:2 ω6 and α-linolenic acid C18:3 ω3) are abundant in the lipids. The ratio ω6/ω3 is less than 0.5, which is good from a nutritional standpoint for improving this ratio, which is frequently greater than 5 in the current human diet. The ash contain calcium, magnesium, phosphorus, potassium, sodium, iron, zinc, and copper, as well as a good potassium/sodium nutritional ratio and a very low calcium/phosphorus nutritional ratio. Almost all of the B-complex vitamins are present in amounts that are frequently far in excess of the body's nutritional requirements, both for infants and pregnant or nursing women. Thus, *I. truncata* caterpillars are an important source of macro and micro-nutrients that can help the human body develop in a balanced manner.

Keywords: Edible caterpillars, *Imbrasia truncata*, nutritional composition, food valorisation, recommended daily intake, daily requirement, human nutrition, Africa.

RESUME

Composition nutritive et voies de valorisation alimentaire des chenilles d'*Imbrasia truncata*

La population mondiale en cours d'accroissement exponentiel pourrait atteindre 10 milliards d'habitants d'ici 2050. Cette situation devrait entraîner une augmentation de la demande alimentaire mondiale jusqu'à 70% par rapport aux besoins actuels. L'objectif de cette étude était de montrer les potentialités des chenilles *d'Imbrasia truncata,* récoltées dans le massif forestier équatorial, comme une ressource alimentaire alternative pouvant être la solution susceptible de combler le déficit alimentaire en perspective et de palier à certaines pathologies nutritionnelles. Pour y parvenir, les recherches documentaires relatives à la valeur nutritive des chenilles d'*I. truncata* et l'importance de nutriments composant cette valeur sur le bon fonctionnement de l'organisme humain et la prévention de certaines pathologies ont été menées. Il en résulte que, les chenilles *d'I. truncata* sont riches en protéines, en lipides, en vitamines, minéraux et en oligo-éléments. Elles contiennent en quantité appréciable tous les acides aminés essentiels dont la thréonine, le tryptophane et les acides aminés aromatiques. Les lipides sont riches en acides gras essentiels (acides linoléique C18 :2 ω6 et α- linolénique C18 :3 ω3). Le rapport ω6/ω3 est inférieur à 0,5, ce qui est bon du point de vue nutritionnel pour l'amélioration de ce rapport qui, dans l'alimentation humaine actuelle, est souvent supérieur à 5. Les cendres contiennent entre autres du calcium, du magnésium, du phosphore, du potassium, du sodium, du fer, du zinc et du cuivre avec un bon rapport nutritionnel potassium/sodium et un rapport calcium/phosphore très faible. Presque toutes les vitamines du groupe B-complexe sont présentes en quantité parfois largement supérieures aux besoins nutritionnels de l'organisme tant pour les nourrissons que pour les femmes enceintes ou allaitantes. D'où, les chenilles *d'I. truncata* sont une source importante en nutriments susceptibles de contribuer au développement harmonieux de l'organisme humain.

Mots-clés : Chenilles comestibles, *Imbrasia truncata*, composition nutritive, valorisation alimentaire, apport journalier recommandé, besoin journalier, nutrition humaine, Afrique.

INTRODUCTION

The main nutritional issues in Africa are associated with protein-energy malnutrition, to which specific micronutrient deficiencies are added (iron, vitamin A, iodine, etc.) (Mabossy-Mobouna, 2017; FAO, 2013). They are the result of low local agro-pastoral and fisheries production, insufficient reserves, lack of a conservation, processing, and storage culture, and the seasonal nature of product supply. They are also caused by the population's lack of nutritional knowledge and the use of unhealthy eating habits (Mabossy-Mobouna, 2017).

Thus, as the Congolese population grows, as does the demand for food, it is clear that agriculture is incapable of ensuring this population's food security (Mabossy-Mobouna, 2017). As a result, other alternative solutions to filling the food gap are required. The alternative resource must allow for a sustainable, culturally and economically accessible, and nutritionally adequate diet. Given this socioeconomic situation and its impact on the nutritional status of the Congolese population, it seems appropriate to highlight local foods that are already consumed and have undeniable nutritional value. Nutritionists argue that eating insects is one of the potential solutions to the world's malnutrition problem (FAO, 2004; 2013; Adegbola, 2013; Van Huis et al., 2013).

Many protein deficiency problems could be solved by the nutritional quality of insects and the ability to produce them at a low cost. Various insect species contain more protein than fish and soybeans (Anand et al., 2008). In fact, amino acids derived from most insect proteins have higher levels than amino acids found in poultry supplement formulations (Bukkens, 2005). Caterpillars, among the insects consumed, are becoming increasingly important in improving Central Africa's food situation. Caterpillars have very high protein contents that are rich in lysine and threonine, according to studies on their nutritional value (DeFoliart, 1992).This could be a more important source of protein than beef and fish (Malaisse, 1997), which are sold at exorbitant prices in markets, or it could have a nutritional value comparable to cattle meat (Kelemu et al., 2015).

This important protein source may aid in the fight against protein-energy malnutrition, ensure the healthy development of the foetus and child, and protect pregnant women from certain nutritional deficiencies. Among the many caterpillar species sold and consumed in the Congo, *Imbrasia truncata*, primarily from the northern part of the Congo, is the most important morphologically and qualitatively. Large-scale development and promotion of this species' caterpillar consumption could be one of the solutions to combat malnutrition and micronutrient deficiencies, as well as ensure household food security in the Republic of the Congo.

As a result, operations to promote its consumption are critical. Furthermore, a food may be readily available but have low nutritional value. Before considering potential pathways for its valorisation, it is necessary to understand the nutritional value of *I. truncata* caterpillars, specifically their composition in essential amino acids, essential fatty acids, and micronutrients. To that end, a study on the nutritional value of *I. truncata* caterpillars must be conducted in order to determine their nutritional value. As a result, we must assess the nutritional potential of *I. truncata* caterpillars in order to identify their chemical characteristics and demonstrate the importance of consuming these caterpillars in the prevention of certain pathologies caused by nutritional deficiencies. This research will allow supplementation to improve the nutritional value of the food rations of people suffering from various nutritional deficiencies.

SEARCH PROCEDURE

The information presented in this study (*viz.* nutritional value of *I. truncata* caterpillars and the importance of the nutrients that comprise this value for the proper functioning of the human organism, as well as the nutritional potential of these caterpillars in the prevention of certain pathologies) were based on information compiled from a literature review.

As a result of the literature search, we were able to learn about the various studies and publications pertaining to the nutritional value of *I. truncata* caterpillars. Therefore, three articles on the nutritional value of *I. truncata* were consulted, including Kodondi et al. (1987a,b), Mabossy-Mobouna et al. (2017a), and Fogang Mba et al. (2019). We then consulted various human nutrition publications, specifically on the essential nutrients required by the organism, their respective quantities, and the thresholds below which the organism could manifest physiological disorders. These findings were then compared to the nutritional values of *I. truncata* to estimate its potential to solve certain nutritional problems and diseases associated with malnutrition. This data was used to consider the various applications for these caterpillars.

Data analysis and Value conversion methods

The arithmetic averaging procedure was used to compute the averages (Mean). We converted the values obtained by Kodondi et al. (1987), which were in g/g N, to mg/16g N because the essential amino acid values of the FAO 2007 reference protein are given in g/16g N or g/100g protein (knowing that 100g protein contains 16g N). Similarly, because the FAO 2007 reference protein essential acid values are given in g/16g N or g/100g protein (knowing that 100g protein contains 16g N), we converted the values obtained by Kodondi et al. (1987) using the following equation:

$$X=16Y/1000$$

With X= value obtained after conversion (g/16g d'N) ; Y= value obtained by Kodondi (mg/g d'N)

Because the amino acid values for Fogang Mba et al. (2019) were obtained from 100g of fresh material, we deduced the same values in 100g of dry matter using the protein contents in both materials (62.9g of protein in 100g of dry matter; 19.1g of protein in 100g of fresh matter) using the following relationship:

$$X=62.9Z/1000\times19.1$$

With X= value obtained after conversion (g/16g d'N) , Z= value obtained by Fogang Mba (mg/100g of fresh matter)

NUTRITIONAL VALUE OF *Imbrasia truncata* CATERPILLARS

Overall nutritive composition of *I. truncata* caterpillars

The composition of *I. truncata* caterpillars (Table 1) was determined by analysing smoked samples (mean and standard deviation) by Kodondi et al. (1987a), dried samples by Mabossy-Mobouna et al. (2017a), and dried samples by Fogang Mba et al. (2019). These analyses show that *I. truncata* caterpillars have a high protein content (60 to 70.63%) with an average of 64.51±5.50% and lipids (15.2 to 22.6%) with an average of 17.67±4.27%. Mineral elements range from 2.75 to 3.7% in these caterpillars, with an average of 3.29±0.49%.

Table1. Comparison of the nutritional value of *I. truncata* caterpillars

Composition of caterpillars	(g /100g of dry matter)			
	Kodondi et al. (1987a)	Mabossy-Mobouna et al. (2017a)	Fogang Mba et al. (2019)	Mean
Protein	60.0 ± 1.0	70.63	62.9±2.1	64.51±5.50
Total fat	15.2 ± 1.5	15.22	22.6±2.1	17.67±4.27
Total ash	3.7 ± 0.2	2.75	3.41±0.03	3.29±0.49

Pagezy (1988) presents additional chemical analysis results of *I. truncata* caterpillars. The relative humidity of the sample is 75%, the ash content is 3.48%, the lipid content is 17.86%, and the protein content is 63.67%. Finke (2005) presents a slew of analytical findings on the chemical composition of insects. These include *I. truncata* caterpillar analysis results. They are related to the overall composition of smoked and dried caterpillars. The protein content of the caterpillars is 61% of their dry mass, and the lipid content is 16%. Selenium (32mg/kg dry mass) is a powerful antioxidant among the trace elements obtained.

Amino acid composition of *I. truncata* caterpillar

The average amino acid composition (Table 2) shows that all essential amino acids are present, with tyrosine, lysine, valine, leucine, phenylalanine, and threonine being the most abundant; isoleucine, methionine, and tryptophan being the least abundant. There is also a significant amount of arginine and a fair amount of histidine, both of which are necessary for a child's growth. The amino acid glutamine is the most abundant in these caterpillars.

Table 2. Composition in amino acids of *I. truncata* caterpillars

Amino acids	Imbrasia truncata (g/16g d'N)			
	Kodondi et al. (1987a)*	Mabossy-Mobouna et al. (2017)	Fogang Mba et al. (2019)*	Mean
Aspartic acid	8.7	4.76± 0.16	5.49	6.32±2.10
Threonine	4.68	3.1± 0.03	3.41	3.73±0.84
Serine	4.86	3.05± 0.07	2.75	3.55±1.14
Glutamine	13.58	6.32± 0.16	9.13	9.68±3.66
Proline	2.14	3.50± 0.08	3.35	2.99±0.75
Glycine	3.65	2.68± 0.06	2.77	3.03±0.54
Alanine	3.95	2.65± 0.04	2.36	2.99±0.85
Valine	10.18	2.79± 0.07	2.84	5.27±4.25
Cystine	1.65	_	0.78	1.22±0.62
Methionine	2.22	1.0± 0.014	1.07	1.43±0.69
Cystine +methionine	3.87	1.0± 0.014	1.85	2.24±1.47
Isoleucine	2.41	2.41	2.70	2.51±0.17
Leucine	7.31	3.33± 0.06	3.78	4.81±2.18
Tyrosine	7.65	4.34± 0.02	8.72	6.90±2.28
Phenylalanine	6.22	3.13	2.63	3.99±1.94
Tyrosine + phenylalanine	13.87	7.47	11.35	10.90±3.22
Lysine	7.89	3.42± 0.14	4.77	5.36±2.29
Histidine	1.68	2.10± 0.03	2.19	1.99±0.27
Tryptophan	1.65	1.10	0.81	1.19±0.43
Arginine	5.5	2.92 ± 0.007	3.20	3.87±1.42
Total amino acids	96.06	52.45	62.75	70.42±22.79
Total essentiel amino acids	51.87	26.72	27.32	35.30±14.35

***Converted values Italicized amino acids are essential*

However, when compared the amino acids composition of *I. truncata* caterpillars to the reference protein composition (FAO/UNU/WHO, 2007) (Table 3), *I. truncata* caterpillar proteins have three limiting amino acids (chemical index <100). This is true for the amino acids leucine, isoleucine, and methionine. The primary limiting factor is leucine, and the secondary limiting factor is isoleucine. Furthermore, these proteins contain more amino acids than the reference protein. Threonine, aromatic amino acids, valine, and tryptophan are examples.

Table 3. Comparison of the protein composition of *I. truncata* and the FAO reference values (2007)

Amino acids	Imbrasia truncata (g/16g d'N)*	Adult protein of reference (FAO, 2007)	Chemical index
Threonine	3.73 ± 0.84	2.3	162.17
Valine	5.27 ± 4.25	3.9	135.13
Cystine	1.22 ± 0.62	0.6	203.33
Methionine	1.43 ± 0.69	1.6	89.38
Cystine +methionine	2.24 ± 1.47	2.2	101.81
Isoleucine	2.51 ± 0.17	3	83.66
Leucine	4.81 ± 2.18	5.9	81.53
Tyrosine + phenylal.	10.90 ± 3.22	3.8	286.84
Tryptophan	1.19 ± 0.43	0.6	198.33

*Average values from Kodondi et al. (1987ab), Mabossy-Mobouna et al. (2017a) and Fogang Mba et al. (2019)

I. truncata caterpillar proteins are generally higher in essential amino acids than plant proteins. In comparison to plant protein materials, animal protein materials contain almost no anti-nutritional substances. As a result, they outperform plant proteins (Antoun &Baracos, 2008).

Thus, the nutritional quality of proteins is determined by two factors: their ability to supply nitrogen to the organism, which is determined by digestibility, and their ability to supply essential amino acids to the organism, which is determined by composition (Mourey, 2004). *I. truncata* caterpillars have very high protein digestibility (76-98%), which is higher than that of leguminous grains such as *Phaseolus vulgaris* (78.5%), *Lens culinaris* (80.3%), *Cajanus cajan* (59.9%), fishmeal (74.7%), and casein of milk (78.4%). Insects are low in anti-nutritional substances.

Fatty acid composition of *I. truncata* caterpillars

Caterpillars of *I. truncata* contain two essential fatty acid precursors (linoleic acid and α-linolenic acid). They are high in α-linolenic acid, followed by palmitic and stearic acids. Linoleic and oleic acids are then added. Myristic acid, arachidic acid, and palmitoleic acid have extremely low concentrations (<1%). As a result, the lipids extracted from *Imbrasia truncata* caterpillars have high α-linolenic acid and linoleic acid contents. In terms of saturation, these caterpillars have more polyunsaturated fatty acids than saturated fatty acids. These caterpillars have a high polyunsaturated fatty acid content and a high essential unsaturated fatty acid content (C18:3n ω3 and C18:2n ω6). Fresh caterpillars have a high concentration of eicosapentaenoic acid (5%). Furthermore, the fatty acid content varies depending on the stage of the caterpillars (smoked or fresh). In all cases, the essential fatty acid content exceeds 50% of the total fatty acid content.

Table 4. Compositioninfatty acids of *I. Truncata* caterpillars

Fatty acids		**Composition in fatty acids (g/100g of lipids)**		
		Kodondi et al. (1987a)	**Mabossy-Mobouna et al. (2017a)**	**Mean**
Lauric acid	12 :0	Traces	nd	
Myristic acid	14 :0	0.2 ± 0.1	0.31	0.25±0.07
Pantadecanoic acid	15 :0	Trace	nd	
Palmitic acid	16 :0	24.6 ± 2.0	20.63± 0.71	22.61±2.81
Palmitoleic acid	16 :1 n-7	0.2 ± 0.1	0,33± 0.01	0.265±0.09
Stearic acid	18 :0	21.7 ± 0.3	16.44± 0.13	19.07±3.72
Oleic acid	18 :1 n-9	7.4 ± 0.8	7.68± 0.03	7.54±0.20
Linoleic acid	18 :2 n-6	7.6 ± 0.6	8.67± 0.1	8.13±0.76
Linolenic acid	18 :3 n-3	36.8 ± 1.3	42.63± 0.33	39.71±4.12
Arachidic acid	20 :0	nd	0.33	0.33
Eicosadienoic acid	20 :2 n-6			
Arachidonic acid	20 :4 n-6			
Eicosapentaenoic acid	20 :5 n-3	5 (fresh caterpillars)		
SFA				42.27
MUFA				7.81
PUFA				49.92
PUFA/SFA				1.18
ω6/ω30.23				0.20

The PUFA/SFA ratio is 1.18, which is beneficial for the health and well-being of people who eat these insects as food. Indeed, a PUFA/SFA ratio >0.20 is associated with low cholesterol levels and a low risk of coronary heart disease (Banjo et al., 2005; Mabossy-Mobouna et al., 2020; Kinyuru et al., 2013). The ω6/ω3 ratio is less than 0.5, which is nutritionally good for improving this ratio, which in the current human diet is often higher than 5.

In terms of fatty acids, Pagezy (1988) assigns a relative importance of 59.8 for saturated fatty acids, 15.7 for monounsaturated fatty acids, and 21.5 for polyunsaturated fatty acids in *I. truncata* caterpillar lipids. Pagezy's findings contradict those of Mabossy-Mobouna et al. (2017a) and Kodondi et al. (1987b) where the unsaturated fatty acid content was above 50%. Because these caterpillars are polyphagous, this could explain the observed differences.

According to Finke (2005), the major fatty acids constituting the 16% lipid content are as follows: myristic acid (14:0): 0.03%; palmitic acid (16:0): 4.03%; palmitoleic acid (16:1): 0.03%; stearic acid

(18:0): 3.56%; oleic acid (18:1): 1.21%; linoleic acid (18:2): 1.25%; and linolenic acid (18:3) : 6.04%. According to Kodondi et al. (1987a) and Mabossy-Mobouna et al. (2017a), linolenic acid is also dominant, followed by palmitic and stearic acids.

Mineral element composition of *I. truncata* caterpillars

Mineral element content was also obtained and published (Table 5). With a dry matter content of 1.39%, potassium is the most abundant mineral in *I. truncata* caterpillars. The phosphate content is 0.70% dry matter, with an average calcium/phosphorus ratio of 0.22. Sodium levels are extremely low (0.099%). Zinc, iron, magnesium, phosphorus, potassium, and copper levels are far above what is considered adequate for infants (>100%). Furthermore, 100 g of *I. truncata* caterpillar dry matter meets 116% of the average nutritional requirement for iron in pregnant and lactating women, 131% of the average nutritional requirement for zinc in pregnant women and 115% in lactating women, 93.67% of the magnesium intake in female categories, 39.8% of the potassium intake in pregnant women and 34.85% in lactating women, and 93.67% of the magnesium intake in male categories. However, zinc bioavailability is highly dependent on a variety of dietary factors that can interfere with its absorption, such as phytates (found in cereals and legumes).

Manganese levels are within the range of the recommended daily allowance. *I. truncata* caterpillars contain 90% of the acceptable sodium intake for infants under 6 months of age, 27% for those 6 months and older, and 6.6% for pregnant or lactating women. In terms of calcium, they cover 76.5% of the adequate intake for infants under 6 months, 55% for those over 6 months, and 20% of the average nutritional needs of pregnant or breastfeeding women.

Pagezy (2008) determined the following soluble ion contents (in mg/100 g DM): Ca= 185, Cl= 41, Mg= 142, SO4= 107, K= 911, and Na= 9

Table 5. Mineral element composition of *Imbrasia truncata*caterpillars

Ash and mineral elements	**Unit**	**Values for 100g DM**		
		Kodondi et al.(1987a)	**Mabossy-Mobouna et al. (2017a)**	**Mean**
Total ash	g	3.7 ± 0.2	2.75	3.22±0.61
Potassium	mg	1.250 ± 10	1538± 55	1394±203.65
Phosphate	mg	780 ± 30	621± 1.4	700.5±112.43
Magnesium	mg	178 ± 2	384± 2.1	281±145.65
Calcium	mg	122 ± 6	184± 5.6	153±43.84
Sodium	mg	170 ± 40	28± 1.4	99±100.41
Zinc	mg	10.3 ± 0.6	13.57± 0.12	11.93±2.31
Ion	mg	8.1 ± 0.6		8.1±0.6
Manganese	mg	3.0 ± 0.1		3±0.1
Copper	µg	1.30 ± 250	1280± 140	1290±14.14
Selenium	mg/kg	32		
Sodium/potassium				0.07
Calcium/phosphorus				0.22
Calcium/magnesium				0.54

The potassium/sodium ratio of *I. truncata* ash is good, and the calcium/phosphorus ratio is very low. A sodium/potassium ratio less than one is beneficial to the body's proper functioning. Indeed, He and Mac Gregor (2008) discovered that when a food's sodium/potassium ratio is less than one, it lowers blood pressure, cardiovascular mortality, protects renal function, and prevents urinary lithiasis and osteoporosis. People with high blood pressure may benefit from the low sodium content. Nonetheless, potassium-rich foods are generally lacking in the diets of people suffering from renal failure (Mc Cay et al., 1975; Soudy, 2011).

Because the calcium/phosphorus ratio is much lower than one, calcium absorption is low (Comelade, 1995). Similarly, because the Ca/Mg ratio is less than 2, its fixation is less important in the organism (Gayet & Cazel, 2002). To compensate for the calcium deficit, the food consumed with the caterpillars in the meal must contain more calcium.

Oligo-elements are present in very small amounts in the body, and it is these minute amounts that are required for the body to function properly. Copper, zinc, manganese, iodine, chromium, fluorine, iron, cobalt, and selenium are among them. Zinc, fluorine, copper, iron, and chromium are the most abundant trace elements in *I. truncata* caterpillars. Chromium enhances the action of insulin, influencing carbohydrate, lipid, and protein metabolism. Copper is involved in a variety of redox reactions, including collagen protein synthesis, myelin synthesis and maintenance, neurotransmitter synthesis, iron metabolism, and protection against oxidative damage (Mourey, 2004). Zinc is an antioxidant that also plays a role in protein synthesis.

Table 6. Composition in mineral of *Imbrasia truncata* caterpillars compared to recommended daily allowance for infant, pregnant and breastfeeding women

Mineral elements	*Imbrasia truncata* (mg/100g DM)*	Nutritional references (Anses, 2021) : Recommended daily allowances (mg)			
		Infant <6 month old	**Infant >6 month old**	**Pregnant woman**	**Breastfeeding woman**
Potassium	1394 ± 203.65	400	750	3500	4000
Phosphate	700.5 ± 112.43	100	160		550
Magnesium	281 ± 145.65	25	80		300
Calcium	153 ± 43.84	200	280		750
Sodium	99 ± 100.41	110	370		1500
Zinc	11.935 ± 2.31	2	2.9	9.1	10.4
Ion	8.1 ± 0.6	0.3	8	7	7
Manganese	3 ± 0.1				
Copper	1290 ± 14.14	0.3	0.5	1.7	1.7

*Average values from Kodondi et al. (1987a,b), Mabossy-Mobouna et al. (2017a) and Fogang Mba et al. (2019)

It lowers cholesterol levels and lowers the risk of atherosclerosis (Salonen et al., 1995).

Composition in vitamins

Table 7 shows an estimate of the vitamin content published (Kodondi et al., 1987b). Caterpillars of *I. truncata* are high in vitamins. Nicotinic acid, with a content of 10.9±0.5 mg/100 g crude matter, is the most abundant water-soluble vitamin in *I. truncata* caterpillars. Riboflavin concentration is 5.1 mg/100g crude weight. With a content of 31µg/100g of raw matter, retinol was the only fat-soluble vitamin discovered. However, Fogang Mba et al. (2019) discovered four isomers of vitamin E in *I. truncata* caterpillars in Cameroon, with a total content of 119.7 ± 16.5 µg/g lipid, i.e. 0.82 ± 0.11mg/100g of fresh material. In both infants and pregnant and lactating women, 100gDM from *I. truncata* caterpillars are more than meets satisfactory and/or average nutritional requirements for niacin, riboflavin, thiamine, and biotin. This confirms the findings of Malaisse (1997).

Tableau 7. Vitamin content estimates of smoked and dried *Imbrasia truncata* caterpillars (Kodondi et al., 1987b)

Vitamins	Content per 100 g DM	Nutritional references (Anses, 2021) Recommended daily allowance			
		Infant <6 month old	**Infant >6 month old**	**Pregnant woman**	**Breastfeeding woman**
Niacin(mg)-Vit. B3 (PP)	10.9 ± 0.5	2 (SS)	1.3mg/MJ (ANR)	1.3mg/MJ (ANR)	1.3mg/MJ (ANR)
Riboflavin (mg) - Vit. B2	5.1 ± 0.3	0.3 (SS)	0.4 (SS)	1.5 (ANR)	1.7 (ANR)
Thiamine (mg) -Vit. B1	0.27 ± 0.07	0.2 (SS)	0.072 mg/MJ (ANR)	0.072mg/MJ (ANR)	0.072 mg/MJ (ANR)
Pyridoxine (µg) - Vit. B6	37 ± 5	0.1mg (SS)	0.3 mg (SS)	1.5mg (ANR)	1.4mg (ANR)
Folic acid (µg) Vit. B9	37 ± 5	65 (SS)	80 (SS)	600 (SS)	380 (ANR)
Biotine (µg) -Vit. B8	45 ± 1	4 (SS)	6(SS)	40(SS)	45(SS)
Retinol (µg) -Vit. A	31 ± 1.5	350(SS)	190(ANR)	540(ANR)	1020(ANR)
Pantothenic acid (µg) -Vit. B5	10.2 ± 0.1	2mg(SS)	3mg(SS)	5mg(SS)	7mg(SS)
β-carotene (µg) Pro-Vit. A	6.6 ± 0.3				
Cyanocobalamin (µg x 10^{-3}) -Vit. B12	25	0.4(SS)	1.5(SS)	4.5(SS)	5(SS)

¶SS: Sufficient Supply , MJ: Megajoule , ANR: Average Nutrient Requirement

Vitamins are organic substances that act in small doses and are necessary for the body's proper functioning. The body, however, is unable to synthesise them and must obtain them through diet. Avitaminoses are diseases caused by a vitamin deficiency (Martin, 2001; Mourey, 2004). Vitamins play a variety of roles, but the most important one is to transfer an electron from one molecule to another, from one atom (or a limited group of atoms) to another, via cellular redox reactions (Mourey, 2004). Caterpillars of *I. truncata* are a good source of vitamins, which are necessary for the proper functioning and growth of the human body. Almost every vitamin is present. For children aged 0-6 months, as well as pregnant and breastfeeding women, 100 g DM from these caterpillars provides the recommended daily amount of riboflavin.

Antioxidants like ascorbic acid, vitamin A, and tocopherol-Vit. E (highlighted in the work of Fogang Mba et al., 2019), when combined with dietary fibre, help to prevent nutrition-related diseases like cancer, diabetes, coronary heart disease, and obesity (Larrauri et al., 1996; Mc Dougall et al., 1996; Adepoju & Omotayo, 2014). Vitamins E and C are important in lowering the prevalence of degenerative diseases (Halliwell, 1997; Adepoju & Omotayo, 2014). Furthermore, the presence of vitamins A and E in significant amounts in *I. truncata* caterpillars, combined with the presence of selenium, indicates that these have good antioxidant properties (Adepoju & Omotayo, 2014).

FOOD VALUE-ADDING PATHWAYS FOR *Imbrasia truncata* CATERPILLARS

The nutritional value of *I. truncata* caterpillars, the trend in their demand, and the ecological constraints associated with their harvesting must all be considered when valorizing them. Caterpillars of *I. truncata* can be added to weaning porridges made from local foods and used in the formulation of dietary feeds tailored to specific physiological and pathological conditions. They can also be used in the industrial production of certain human and animal foods.

Fighting against childhood malnutrition

Mother's milk is the best food for the baby because it protects from infection. However, after the age of six months, infants require complementary foods because breastmilk no longer meets all of their nutritional needs. During this period of complementary feeding, which lasts from about six months to 18 months, the child should have a meal that is high in energy and nutrients and easy to digest at least four times per day. Weaning porridges are made in Sub-Saharan Africa from cereals or tubers that are deficient in certain essential nutrients, resulting in infant malnutrition. The nutritional value of *I. truncata* as above described can help to solve this problem by supplementing the various food dishes that these children consume. Ombeni and Munyuli's (2019) recent publication reveals that developed complementary food products-based on edible caterpillars (*Bunaeopsis aurantiaca*, *Imbrasia oyemensis*, and *Cirina forda*) consumed in South Kivu province, eastern DR Congo can cover the daily needs of malnourished bodies and ensure the sustainable decentralised countries reliance on exported food aid products accommodated the dietary management of malnutrition for young children.

Improvement of weaning slurries

The maize and cassava flours used to make weaning porridges in Congo are low in α-linolenic acid (Nitou et al., 2012; Mabossy-Mobouna et al., 2017b). Infants who only eat these porridges are deficient in this fatty acid, which has serious consequences. Appropriate complementary foods to meet the nutritional needs of infants and older children should be included in their general ration to avoid deficiencies of α-linolenic acid and its long-chain derivatives and to allow normal infant development during the weaning period. Most traditional Congolese staple foods are supplemented with milk powder to improve the nutritional quality of the porridge. This food is frequently imported, which complicates its availability. Furthermore, because of the high cost, it is generally out of reach for low-income mothers. As a result, it is critical to use locally available, easily accessible foods with high nutritional value to improve weaning baby's porridges (Ombeni & Munyuli, 2019).

I. truncata caterpillars have a high nutritional value and can be mixed with maize or cassava flour to supplement infant porridges to combat protein-energy malnutrition and certain micronutrient deficiencies. *I. truncata* caterpillars have several advantages that allow for the development of a nutritional strategy that includes using them to fight against these scourges. Indeed, these caterpillars are high in proteins that contain all of the essential amino acids, essential fatty acids (α-linolenic acid and linoleic acid), and minerals.

Weaning food supplementation with fermented maize meal

Maize has a low protein (8.5%) and lipid (4%) content, with a Ca/P ratio <1; the limiting amino acids are lysine and tryptophan. Supplementing the maize slurry with *I. truncata* caterpillar flour will improve the nutritional value of its protein. Furthermore, the amino acids histidine and arginine, which are required by infants, are abundant in *I. truncata* caterpillar protein. α-linolenic acid is found in trace amounts in maize. Its abundance in *I. truncata* caterpillars (42.63%) will allow corn porridge to be supplemented and the infant to receive essential fatty acids from the ω3 family. The zinc content of *I. truncata* caterpillars is sufficient to meet a child's daily requirements of 5 to 10 mg. Indeed, zinc deficiency is common in mother's milk after 6 months, causing growth to stall. The zinc content of the porridge can be increased by combining maize flour with *I. truncata* caterpillar flour. *I. truncata* caterpillars, on the other hand, are high in copper, an oligo element involved in bone mineralization. Because this supplement does not provide a Ca/P ratio ≥1, it must be combined with a calcium-rich food such as spinach or orange juice (*Citrus sinensis*) (Adrian et al., 1995).

Weaning porridge supplementation with fermented cassava flour

Because maize production is low in Congo, weaning porridge is frequently made from fermented cassava flour. Cassava is low in protein (1.2%) and lipids are in trace amounts, exposing the infant who consumes it to malnutrition. The addition of *I. truncata* caterpillar flour to cassava porridge increases the protein content and provides essential fatty acids; the nutritional value of the porridge is improved, and the infant is protected from protein-energy malnutrition. Sulphur amino acids, on the other hand, are 52% deficient in cassava (Adrian et al., 1995) and 37.5% deficient in *I. truncata* caterpillars. As a result, they will be the limiting factor in this formulation.

Pregnant and breastfeeding women's nutrition

An adequate intake of ω3 fatty acids during pregnancy is required for optimal brain and visual development of the foetus. Indeed, ω3 fatty acids accelerate neuronal differentiation from embryonic stem cells, neuronal maturation, and neuronal extension development. They allow for the storage and release of neurotransmitters, which are responsible for the transmission of nerve impulses from one neuron to another (Lavialle & Layé, 2010). They maintain the plasticity of astrocytes (glial cells organised in a syncytium that contribute to neuronal function) by modifying their morphology and communication between these cells. They also promote children's psychomotor development and visual performance (Bourre, 2004). ω3 fatty acid (primarily DHA) are essential for foetal and infant development due to their effect on gene regulation (Geiser, 2008). It turns out that ω3 fatty acid intake is naturally provided by placental transfer during foetal life, and then by breast milk after birth (AFSSA, 2010; Gould et al., 2013). At the end of the third trimester of pregnancy, the foetus deposits 30mg of ω fatty acids in its brain each week (Bourre, 2004). An adequate intake of ω3 fatty acid during this cerebral phase allows for visual and cognitive development (Geiser, 2008). Furthermore, polyunsaturated fatty acid accumulation and incorporation in the brain occurs primarily during the first 6 months of a child's life (Cunnane et al., 2000). A pregnant woman's α-linolenic acid deficiency can result in a low birth weight and reduced head circumference, which can lead to later mental and developmental problems (Richardson, 2004). During the first months of life, breast milk meets the ω3 fatty acid requirement. The infant's ω3 fatty acid status is thus dependent on that of the mother, because the accumulation of ω3 fatty acid in the brain during pregnancy and lactation is proportional to their quantities in the diet (Bourre et al., 1989). Because the third trimester of pregnancy is a critical stage in the transfer of DHA from the mother to the developing foetus, preterm infants will benefit from ω3 fatty acid supplementation (Gould et al., 2013).

Thus, pregnant and breastfeeding women should consume foods high in ω3 fatty acid in moderation for proper foetal and infant development.

Pregnant women should consume 2g of α-linolenic acid per day, while nursing mothers should consume 2.2g (LeGrand et al., 2001). *I. truncata* caterpillars contain approximately 6.5g of α-linolenic acid, which more than meets these women's daily requirements for this fatty acid. Consumption of these caterpillars should be encouraged to compensate for ω3 fatty acid deficiencies that are frequently observed in pregnant and breastfeeding women who do not consume oily fish or do not have easy access to this type of fish.

Prevention of certain nutritional diseases and the ageing process

I. truncata caterpillars can also be used in the formulation of meals for people suffering from certain pathologies, the effects of which can be mitigated by the consumption of ω3 fatty acid and/or other micronutrients.

Diabetes and obesity

A diet high in ω3 fatty acid can reduce adipose tissue expression. Indeed, ω3 fatty acid increase cell sensitivity to insulin action. To that end, ω3 fatty acid supplementation has an anti-adipogenic effect by decreasing adipocyte proliferation and fat storage as a result of increased ß-oxidation and decreased fatty acid synthetase activity (Coulhon, 2015).

Caterpillars of *Imbrasia truncata* are high in zinc and arginine. Zinc regulates insulin secretion, plays an important role in its circulation, and allows it to be stored. Furthermore, zinc regulates blood sugar levels in diabetics by reactivating insulin production (Niewoehner et al., 1986). Arginine can reduce insulin resistance, increasing cell receptivity to this hormone (Williams et al., 2002). Glutamine also contributes to the production of energy, which helps to prevent insulin-induced fat storage, as well as the storage of dietary fat, which helps to regulate body weight (Prada et al., 2007).

Cardiovascular diseases

A diet high in omega-3 fatty acid lowers blood triglycerides and VLDL while increasing HDL. It also reduces the risk of clot formation (due to the presence of prostacyclin 3 (PGI3) and thromboxane 3 (TXa3), both of which have a fluidifying effect) and the amount of fibrinogen (Coulhon, 2015). Arginine improves blood vessel elasticity. Thus, a sufficient dietary intake of arginine aids in the prevention of endothelial dysfunction by promoting vasodilation and, as a result, improved vessel elasticity (Sekhon & Agarwal, 2013).

Ageing process

Forette et al. (1996) define ageing as the accumulation of anatomical, histological, and physiological changes (alterations) that occur over time in various cell types, organs, and systems. It is distinguished by changes in tissue biochemical composition, a progressive decline in physiological capacities, a steady loss of the organism's ability to adapt to changing environmental conditions, and an increased susceptibility to disease and death (Troen, 2003). It causes a decrease in neuronal activity, a loss of brain plasticity, and an increase in low-level neuroinflammation (activation of microglial cells and the release of inflammatory cytokines) (Lavialle & Layé, 2010). Burke and Barnes (2006) found that neuronal reorganisation occurs with brain ageing in humans and animals, particularly in the prefrontal cortex and the hippocampal region. During ageing, the hippocampus's polyunsaturated fatty acid content decreases (Carver et al., 2001). Furthermore, long-chain polyunsaturated fatty acid consumption reduces neuroinflammation associated with an increase in inflammatory cytokines in elderly subjects (Lavialle & Layé, 2010).

It should be noted that α-linolenic acid deficiency specifically affects monoaminergic neurotransmission, particularly in the frontal lobe of the brain (Chalon et al., 2001). This deficiency hastens the loss of hearing, specifically at the level of brain structures (Bourre et al., 1989). It significantly reduces pleasure perception by altering the efficiency of sensory organs (Bourre, 2004).

As we age, we experience an increase in oxidative stress due to a decrease in free radical protection, which can lead to a decrease in ω3 fatty acids in brain structures. This drop in ω3 fatty acids is accompanied by cognitive decline (Heude et al., 2003). As a result, an adequate supply of ω3 fatty acid ensures proper membrane renewal and protects against brain ageing by exhibiting anti-oxidant properties (Martin et al., 2002).

Thus, *I. truncata* caterpillars can be used in the formulation of elderly-friendly meals to boost their ω3 fatty acid content and fight against the effects of ageing process. *I. truncata* caterpillars are also high in zinc, a mineral that reduces the effects of free radicals and aids in the treatment of osteoarthritis and osteoporosis. The presence of magnesium in these caterpillars also provides effective free radical protection. *I. truncata* caterpillars are also high in glutamine, an anti-aging supplement (Bowtell et al., 1999).

CONCLUSION

Imbrasia truncata caterpillars can be processed and preserved in cans for human consumption in a relatively simple manner. These caterpillars can be eaten whole, as pastes, or ground into flour, and their protein and oil can be extracted. By incorporating their flour into biscuits or food flours, they will become more acceptable to the majority of the population, particularly those who are not accustomed to eating them. They could also be added to the diets of pregnant and breastfeeding women, the elderly, and people suffering from certain nutritional disorders.

Conflict of interest

The authors declare they have no conflict of interest.

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