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Original Paper

Potential of Dried Edible Caterpillars (Lepidoptera: Saturniidae) Vending on Local Markets to Improve Mineral Suitability in the Diet of the Population in Democratic Republic of the Congo

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***Abstract*— Insects, a traditional food in many parts of the world, are highly nutritious and especially rich in proteins and thus represent a potential food and protein source. They are rich in essential amino acids and unsaturated fatty acids and provide ample quantities of minerals such as Fe, Zn, Mn, Ca, and P essential for human health. The objective of this study was to assess the nutritional value of dried edible caterpillars with an exclusive focus on mineral content. Quantitative analysis of seven essential minerals for humans was analyzed for two dried edible caterpillars currently commercialized in Bukavu town, South Kivu province (eastern DR Congo) central market including *Bunaeopsis aurantiaca* (Lepidoptera: Saturniidae) and *Imbrasia oyemensis* (Lepidoptera: Saturniidae). Mineral content analysis of Ca, Mg, Na, Fe, Zn, and Mn were carried out using the Atomic Absorption Spectrophotometer (AAS) while the P content was analyzed using the Colorimetric method, then the mineral content was compared to the recommended daily intakes (mg/day). On a dry weight basis, we find that mineral content differed with type of caterpillar. *I. oyemensis* had the highest concentrations of most minerals tested compared to *B. aurantiaca*, which nevertheless had the greatest amount of phosphorus (P). P was significantly the most abundant mineral detected (605.70 ± 6.08 mg/100g; $p < 0.001$), followed by Mg and Na in *I. oyemensis* with 220.11 ± 6.10 mg/100g and 216.43 ± 1.08 mg/100g respectively. Oligo-minerals Zn and Fe, were the lowest in the caterpillar samples. All the edible caterpillars analyzed met the recommended daily mineral intake. The consumption of < 28 g and < 8 g of these caterpillars covers daily RNI in adults for Fe and Mn respectively. Thus, edible caterpillars in this study have shown that they can be excellent contributors to people's mineral requirements and should be sustainably utilized. Aside from direct consumption, there is a huge potential for using these caterpillars as raw material and food fortification. The mineral content of commonly eaten caterpillars was analyzed to inform consumers among indigenous populations in the Democratic Republic of Congo about the micro-nutritional quality of the insects.**

Keywords*— edible insect, mineral, micronutrient deficiency, anaemia, food fortification

I. INTRODUCTION

Entomophagy, which refers to the consumption of insects by humans, is an environmentally friendly approach to increasing food for consumption, and a good contributor to food security across the world [1] [2] [3]. According to the United Nations' Committee on World Food Security, food security is defined as physical and economic access to sufficient, safe and nutritious food by all people, at all times, fulfilling their dietary needs and food preferences for an active and healthy life.

Consumption of insects has recently received more attention since potentially promising for their nutritional contribution to livelihoods (economic and social factors), environmental and likely able to mitigate food insecurity around the world [4][1][5]. Insects are habitually consumed as food in Thailand [6][7], China [8][9], Mexico [10][11][12][13], Latin America [14], Japan [15], and Africa [16]. According to [4], approximately 2 billion people worldwide regularly consume insects as part of their diets. The consumption of insects is not a new phenomenon, as it dates back to before the development of agriculture when humans relied on gathering plants and hunting wild animals [17][18][9].

Edible insects provide satisfactory amounts of energy and protein, meet amino acid requirements for humans, are high in monounsaturated and/or polyunsaturated fatty acids, and are rich in micronutrients such as copper (Cu) , iron (Fe), magnesium (Mg), manganese (Mn), phosphorous (P), selenium (Se), and zinc (Zn) , as well as riboflavin (B_2), pantothenic acid (B_5), biotin (B_8) and, in some cases, folic acid (B_9) [19] [17]. Therefore, increasing their consumption could enrich diets of greater nutritional and help counteract malnutrition in developing countries with a more sustainable approach.

The need to feed a growing global population inevitably places continuous pressure on crop production, which in turn contributes further to the degradation of natural resources [20] [3]. Currently, FAO activities on sustainable diets explore linkages and synergies among food biodiversity, nutrition, food composition, food production, agriculture, urban agriculture (in the Food for the Cities program) and sustainability. The underlying objective is to improve food and nutritional security and provide more ecologically sound food recommendations to consumers and policymakers, including clarifying what is meant by an environmentally sustainable food system [21]. Consumption of insects fits comfortably within this environmentally sustainable food scenario and, by extension, should be considered prime food candidates as both food staples and supplements, as well as more generally for their role in sustainable diets [22].

Nowadays, edible insects play a key traditional role in diets of different countries in Africa [16][23]; [24] [25][26]. In addition, edible insects are an important natural resource that is used as a coping strategy, particularly in months of food shortage [27]; [28][29]. Unfavorable climatic conditions experienced in Africa affect small scale animal husbandry and reduce animal protein production, so dietary proteins are provided by edible insects [28], which have shown to offer significant socio-economic and ecological benefits for developing countries [30][31]. Insects form part of the traditional diets across different African cultures acknowledged for their cultural importance, and nutritive value, as well as supplementary food when staple food is limited [31][4][5] [26], [32][26]. In traditional cultures, insects are processed in a number of ways (steaming, roasting, smoking, frying, stewing, and curing, among others) to improve their sensory and nutritional qualities as well as their shelf-life [33]. However, in some African tribes, since entomophagy is heavily influenced by cultural and religious practices, people look at entomophagy with disgust and associate eating insects with primitive behavior. The reluctance to consume caterpillars, for example by some tribes can be attributed to a variety of factors such as taboos or religious beliefs [34], nutrition transition and adoption of western diets, psychological discomfort associated with eating insects, substantial decline in insect populations [35] and lack of knowledge on the possible benefits and nutrition value of this wild edible food [36][37] [38] [22].

On the other hand, prevalence of malnutrition is still high in most developing countries [39][40]. According to the Food security and nutrition report (FAO), Africa is the only region in the world where the number of stunted children has risen, shifting from 50 to 58 million of stunted children under the age of 5 [41][42], and the highest rates of malnutrition and under nutrition in the world have been reported in Central Africa (Ethiopia, Mozambique, DR Congo, Chad...) [43]. In the Democratic Republic of Congo, under nutrition is an important public health problem, as witnessed by 2013-2014 Demographic and Health Survey (EDS) results and 2017-2018 Multiple Indicator Cluster Surveys (MICS) data, which provided an overall description of observed practices, revealing that all provinces were hit by prevalence rates protruding the action level (SAM >10 %) [44] [45] [46].

To counteract malnutrition in developing countries macro and micronutrients intake needs to be improved, however the solution does not rely on conventional breeding water consuming and carbon producer. We must therefore turn to alternative solutions including harvest, and rearing of insects for human consumption [4]. Edible insects' nutritional value is widely recognized and depends not only on protein content, but also in lipid quality, and micronutrients including minerals (Fe, Zn, Ca and P) and vitamins [47] [48] [19]. [49][50][51][52][53] [54]. Similarly, [55] and [56] reported that human consumption of caterpillars (Lepidoptera) or "Lepideropterophagy" is experiencing a growing interest in Africa.

The Democratic Republic of the Congo (DRC) is considered one of the most important hotspots of entomophagy in Africa and the whole world. Over 200 species of insects are reported edible and are part of the traditional eating habits of the country, comprising caterpillars, beetles, crickets, etc. [16]. In Kinshasa, for example, more than 70% of the population consumes caterpillars throughout the year , which make up 5–10 percent of the protein intake [57]. The main supply provinces of the capital are Equateur (64%) and Bandundu (24%). Four main species of caterpillars are consumed: *Cirina Forda*, *Imbrasia epimethea*, *Imbrasia ertli*, *Imbrasia oyemensis* [58]. In the territory of Mwenga in South Kivu province, caterpillars are considered a delicacy. For local tribe (Barega), the caterpillar: *Bunaeopsis aurantiaca* locally called 'Milanga' is one of the major sources of macro and micronutrients of their diets. From an economic point of view, the trade of caterpillars to large urban centers such as South Kivu provides a source of income for the inhabitants of the region, particularly the most vulnerable [59] [60]. In eastern DRC in general and the South Kivu province in particular, caterpillars are the most common edible insects consumed as representative edible insects. Most nutrition research on edible insects has focused on lipid, carbohydrate, protein and mineral content of caterpillar *B. aurantiaca* and *I. oyemensis* [61] [59], as well as amino acids and fatty acids profile of *B. aurantiaca* [62].

Despite the healthy, livelihoods and environmental contribution of edible caterpillars in Bukavu town, South Kivu province, apparently no research on their mineral composition had been conducted [60], [63]. The persistence of such neglect will increase the erosion of their food resources with immediate consequences knowledge about the nutritional status and food security of populations, especially those in rural areas, hence the need for available analytical data in trace nutrient content of these caterpillars [64].

Faced with the challenge of underestimation of traditional foods by middle-class people in the Democratic Republic of Congo, the valorization of *Bunaeopsis aurantiaca* and *I. oyemensis* caterpillars through the publication of their nutritional value would be an unavoidable way to promote it consumption. In another hand, in order to enhance the marketability of edible insects as food industrialization materials through diverse development, it is critical to know better their nutritional content, since edible insects are used in addition to the foods rather than as a standalone food.

Thus, the objective of this study is to contribute to the knowledge of the mineral content of edible insects, including the caterpillars *B. aurantiaca* and *I. oyemensis*, for seeing the increased interest of other cultures besides local ones, to using insects as ingredients in a non-recognizable form, such as powders or flour, opening up to biotechnological research aimed at producing high value foods accessible to all and prevent malnutrition [65] [66] [67].

II. Material And Methods

A. Edible insect samples selection, purchase and treatment

In Bukavu town, South Kivu province (eastern DRC), nine species of insects from four orders are consumed, the order Lepidoptera (Saturniidae), more than anyone else, besides three highly valued caterpillars, namely *Bunaeopsis aurantiaca*, *Imbrasia forda* (a.k.a. *Cirina forda*) and *Imbrasia oyemensis* [60], [62]. In this study authors evaluated *Bunaeopsis aurantiaca* and *Imbrasia oyemensis* (Lepidoptera: Saturniidae) of stage 5 (Fig. 1A, B, and Fig. 2 respectively). These two species were selected because they are abundant during the period of harvest, are commonly commercialized at local markets and they are among the most widely consumed insects in the region.

The two types of the dried edible caterpillars were purchased from three vendors located in Kadutu central market, Bukavu, South Kivu province (eastern DRC) and each batch (300g each one) was taken for analysis.

Each batch was collected and transported by flight within 24 hours in plastic containers for analysis at General and Organic Chemistry Laboratory of Food Science and Technology Department, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya. The dried edible caterpillars were sorted to remove pebbles, other extraneous materials, the inedible portions and the edible portions of each sample were milled into fine powder using porcelain pestle and mortar within 24 hours of reception at the laboratory to obtain the caterpillar powders for chemical analysis. They were then stored at -20 oC until analysis. Therefore, seven essential minerals for human health (calcium, phosphorus, magnesium, sodium, iron, zinc and manganese) were analyzed for two representative edible insects (*Bunaeopsis aurantiaca* and *Imbrasia oyemensis*) consumed in South Kivu province.

Fig. 1A. Dried edible caterpillar *Bunaeopsis aurantiaca* collected from Kadutu central market, Bukavu in South Kivu province (DR Congo) © Justin Ombeni

Fig. 1B. Fresh edible caterpillar *B. aurantiaca* collected alive from their host plants during the period of abundance in Mwenga territory, South Kivu province (DRC) © Justin Ombeni

Fig. 2. Dried edible caterpillar *Imbrasia oyemensis* collected from Kadutu central market, Bukavu town in South Kivu province (DR Congo) © Justin Ombeni

B. Mineral content analysis

In order to conduct mineral content analysis for two types of edible caterpillars purchased, Atomic Absorption Spectrophotometer (AAS – model BUCK Scientific 205), as described by [68], was used and content of Ca, Mg, K, Na, Fe, Mn and Zn was determined. Phosphorus content was analyzed using the colorimetric method described by [69]. Minerals not measured during the analyses were not presented in the results. All values were expressed in mg/100g dry weight. The analytical procedures were done in triplicate and the mean data recorded.

C. Preparation of standard stock solutions

For calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na): A solution of 10,000 ppm K was prepared by dissolving 1.907 g of KCl dried in an oven. Into a volumetric flask of 100 mL, 5 mL of 1000 ppm K, 25 mL of 1000 ppm Ca, 5 ml of 1000 ppm Mg and 5 ml of 10,000 ppm Na were put, and the volume completed to the mark with Strontium chloride solution (5.75 g of SrCl2.6H2O dissolved in deionized water and made to 2 L with this water).

For iron (Fe), zinc (Zn) and manganese (Mn): 8 mL of 1000 ppm Fe, 2 ml of 1000 ppm Zn, 8 ml of 1000 ppm Mn were put into a 100 mL volumetric flask, and the volume was completed to the mark with aqua regia solution (400 mL of concentrated HCl and 133 mL of HNO3 70% dissolved in deionized water and made to 2 L with this water).

The phosphorus standard solution (1000 ppm) was prepared by dissolving 4.39 g of KH2PO4 in 1 L of deionized water. Using a diluter, volumes of 0, 1.25, 2.5, 3.75 and 5 mL of this KH2PO4 solution were introduced into five 50 mL propylene tubes, numbered 1 to 5 respectively. The volume in each tube was completed to 50 mL with the aqua regia solution. This was used for the preparation of the standard curve.

D. Preparation of standard working solutions

For calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na): 0.5 mL of aqua regia solution and 19.5 mL of strontium chloride solution were put into 25 mL tubes numbered 1 to 5 and homogenized. Volumes of 0, 0.25, 0.50, 0.75 and 1 mL of solution were removed from these tubes respectively and replaced by these same quantities of the stock solution and the mixture was vigorously stirred using IKA vortex (Genius 3)

For copper, iron, manganese and zinc: 10 mL of deionized water and 30 mL of aqua regia solution were put into 50 mL tubes numbered 1 to 5 and stirred. Volumes of 0, 0.5, 1, 1.5 and 2 mL of solution were removed from these tubes respectively and replaced by these same quantities of the standard solution and the mixture was stirred. These solutions were used for the determination of the standard curves.

For phosphorus, the slightly yellow standard solution was obtained by dissolving 1.056 g of ascorbic acid in 1 liter of deionized water containing 200 mL of Murphy - Riley stock solution (12 g of ammonium molybdate dissolved in 250 mL of deionized water and 0.291 g of tartaric potassium antimony dissolved in 100 mL of deionized water. Both solutions were put in a 2 L volumetric flask containing 140 mL of concentrated H2SO4 in 1 L of deionized water and the volume was completed to 2 L). Two porcelain capsules were washed, rinsed with 10% nitric acid, dried in an oven for 30 min and in a furnace at 500 °C for 3 hours. 0.5 g of defatted dry sample was placed in one capsule while the other empty capsule was used as a blank. Capsules were placed in the oven at 500 °C for 24 hours and then cooled in a desiccator. The residue obtained was whitish (ash). The capsules were rinsed with 15 mL of aqua regia solution into 50 mL propylene tubes, stirred for 10 min and centrifuged at 3000 rpm for 10 minutes. The supernatant of each sample was collected f or assays.

For the determination of Ca, Mg, K and Na, 0.5 mL of the supernatant was diluted in 19.5 mL strontium chloride solution, while for the determination of trace elements (Fe, Mn, Zn), 10 ml of undiluted supernatant were used. Two tubes containing the same quantities of reagents as all the other tubes and deionized water was added for each series of dosage. Standards, samples and blanks were taken to the flame atomic absorption spectrophotometer. The calibration curve of each standard solution was used to determine the concentration (mg/100 g DW) of each mineral by extrapolating the absorbance on the corresponding curves.

For phosphorus assay, 0.25 mL of each sample solution was introduced into 25 mL tubes and diluted with 19.75 mL of the working solution. The color of the solutions of all the tubes (samples, standards and blanks) were allowed to develop for 30 min and the absorbance was read at 860 nm against the blank using a spectrophotometer (GENESYS 10S UV-Vis). The phosphorus content of each sample was obtained by extrapolating its absorbance on the calibration curve.

E. Statistical analysis

SAS (Ver. 9.4, SAS Institute Inc., Cary, NC, USA) was used for statistical processing and analysis of DATA. Means and standard deviations were calculated for all analysis DATA. Mean differences in mineral concentration among the two types of insects were determined with one-way ANOVA test and Least Significant Differences LSD test and the correlation between the factors by the Pearson test. Verification on significance was conducted for all statistical analysis at level of $p < 0.05$.

III. RESULTS AND DISCUSSION

A. Mineral contents (mg/100g dry weight) of the two commonly commercialized edible caterpillars in South Kivu province local markets

The results in Table 1 show the mineral composition of two commonly commercialized dried edible caterpillars (*Bunaeopsis aurantiaca* and *Imbrasia oyemensis*) in Bukavu town, South Kivu province (eastern of the DRC). The tested minerals were classified into two groups: macro-minerals including calcium, phosphorus, sodium and magnesium and micro mineral/oligo-minerals: iron, zinc and manganese and the content was compared to the two studied caterpillars (Fig. 2), then, compared to the recommended daily intake (mg/day) (Table 2). *Imbrasia oyemensis* showed the highest content (5 over 7) of the minerals tested.

Phosphorus was significantly the most abundant mineral detected in the two caterpillar samples and the most abundant mineral of *Bunaeopsis aurantiaca* (605.70 ± 6.08 mg/100g; $p < 0.001$). According to [47], for edible caterpillars, those minerals range from 0-2300 mg/100g. The results in this study were similar to those obtained by [70] on *Imbrasia oyemensis* caterpillars from Ivory Coast.

Minerals are known to play important metabolic and physiologic roles in the living system. The macro-minerals: calcium, phosphorus, and magnesium play key role in both intra and extra skeletal systems. The calcium concentration of milk, the most common food source, is 90–130 mg/100g (Rural Development Administration, 2011; United States Department of Agriculture, 2015).

Imbrasia oyemensis resulted in the highest calcium content at 300.01 mg/100g dry weight had a much higher calcium concentration by threefold compared to that of milk, the most common food source, which is 90–130 mg/100g (Rural Development Administration, 2011; United States Department of Agriculture, 2015), while *B. aurantiaca* had the lowest Ca content to the level of 60.57 mg/100g. Calcium helps to maintain the acid-base balance in the body and promotes the control of energy metabolism [71] [72]. The Ca concentration of *I. oyemensis* in this study was higher than the one reported by [73] from Cameroun on the same caterpillar (27.96 mg/100g), similar (307.3 mg/100g) to those proposed by [74] on the dried powder of *Imbrasia oyemensis* from central-western Ivory Coast. This difference could be justified by the influence of several factors including geographic origin, maturity stage of caterpillars, condition and time of conditioning after collection and also interindividual laboratory technician expertise.

TABLE I. MINERAL CONTENTS (MG/100G DRY WEIGHT) OF TWO COMMONLY COMMERCIALIZED EDIBLE CATERPILLARS (*BUNAEOPSIS AURANTIACA* AND *IMBRASIA OYEMENSIS*) ON LOCAL MARKETS OF THE DEMOCRATIC REPUBLIC OF CONGO

Samples	**Mineral content (mg/100g dry weight of edible portion)**						
Caterpillar	**Calcium**	**Phosphorus**	**Magnesium**	**Sodium**	**Iron**	**Zinc**	**Manganese**
B. aurantiaca	$60.57^{b} \pm 1.61$	$605.70^{a} \pm 6.08$	$95.13^{b} \pm 1.18$	$185.40^{b} \pm 1.40$	$19.65^{b} \pm 1.17$	$8.70^{b} \pm 0.62$	$38.48^{b} \pm 2.10$
I. oyemensis	$300.01^{a} \pm 1.05$	$514.34^{b} \pm 4.93$	$220.11^{a} \pm 6.10$	$216.43^{a} \pm 1.08$	$69.10^{a} \pm 2.35$	$10.39^{a} \pm 0.73$	$141.67^{a} \pm 1.70$
				Statistics			
Total mean	180.29±131.15	560.02±50.29	157.62±68.57	200.92 ± 17.03	44.38±27.13	9.55 ± 1.11	90.08 ±56.54
***p*-value**	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0383	< 0.001
LSD	3.0800	12.547	9.9609	2.8329	4.2078	1.5446	4.3363
CV (%)	0.75	0.99	2.79	0.62	4.18	7.14	2.12

Mean (n=3) ± SD

[a, b] Values with different alphabets in each column of mineral analyzed are significantly different at $p < 0.05$ by LSD test

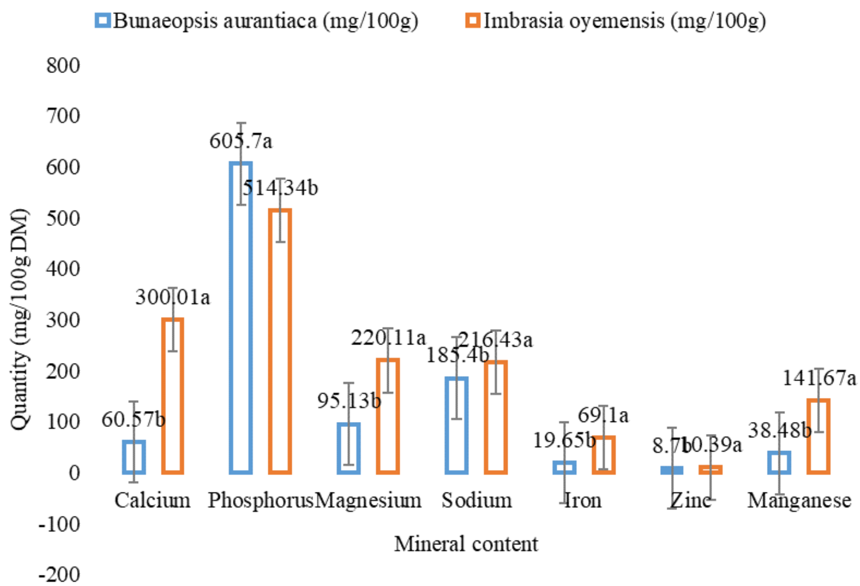

Fig. 3. Comparison of the mineral content of caterpillar's *B. aurantiaca* and *I. oyemensis* vended on local markets of the DR Congo (bars above each column are representing standard errors)

TABLE II. COMPARISON BETWEEN MINERALS COMPOSITION OF *BUNAEOPSIS AURANTIACA* AND *IMBRASIA OYEMENSIS* AND RECOMMENDED NUTRIENT INTAKE PER ADULT POPULATION

Minerals	**Quantities detected in *Bunaeopsis aurantiaca* (mg/100g)***	**Quantities detected in *Imbrasia oyemensis* (mg/100g)***	**Recommended Nutrient Intakes in Adult (19-65 year)**
Calcium	60.57	300.01	1000 mg/day
Phosphorus	605.70	514.34	550 mg/day
Magnesium	95.13	220.11	220 mg/day- Females 260 mg/day - Males
Sodium	185.40	216.43	< 2 g/day (200-500 mg/day) (< 5 g salt/day)
Iron	19.65	69.10	19.6 mg/day - Females 9.1 mg/day - Males
Zinc	8.70	10.39	8 mg – Females 11 mg – Males
Manganese	38.48	141.67	3.0 mg/day

B. Minerals content of caterpillar's Bunaeopsis aurantiaca and Imbrasia oyemensis compared to the recommended nutrient intake per adult population

Caterpillars *B. aurantiaca* and *I. oyemensis* had higher concentration in calcium than *I. dione* (20.26) and *R. phoenicis* (37.84 mg/100g edible portion) studied by [73] and caterpillars *Gonimbrasia belina* and *Gynanisa maja* with 127.8 and 166.4 mg/100g respectively reported by [51] in Zimbabwe. The studied edible caterpillars had highest calcium levels than unprocessed meat (5-15 mg/100g) and chicken (9mg), some species of fish, Mackerel (20 mg) and Tilapia (28 mg/100g edible portion). The consumption of only 100g of *I. oyemensis* can cover 1/3 of the Recommended Nutrient Intakes (RNI) for Calcium in adult equivalent to 1000 mg/day [75].

Phosphorus is involved in many physiological processes, such as cell's energy cycle, acid–base balance regulation, cell regulation and signaling, and bones and teeth mineralization, as cell structure. Phosphorus content was the highest macro-mineral in the quantitative analysis of the two commonly commercialized edible caterpillars. Phosphorus content of *B. aurantiaca* (605.70 mg/100g) and *I. oyemensis* (514.34 mg/100g) was highest to that of beef (170-182mg) and fish (210-281 mg/100g) [76]. Similar to those reported by [74] on *I. oyemensis* from Ivory Coast (514.01 mg/100g). Phosphorus content in both caterpillars was similar to the RNI for phosphorus recommended by [77].

Calcium and phosphorus as important minaret key minerals for bone and teeth formation and maintenance. All the samples examined presented a ratio less than 1/2, thus Ca is intended for rapid absorption in the gastrointestinal tract of children. In a study conducted by [78] in Congo-Brazzaville on edible caterpillar *Imbrasia truncata*, Ca/P ratio was much lower than 1 and resulted in low calcium absorption, indeed Ca/P ratio influences the absorption peak of these minerals in the gastrointestinal tract. A ratio of 1/2 for children and 1/1 for adults is equal to the maximum absorption for this mineral in the respective individuals. Therefore, these caterpillars may be recommended in children to prevent rickets and in older adults to prevent osteoporosis [79] [80].

Magnesium contents of caterpillars *Bunaeopsis aurantiaca* (95.13) and *Imbrasia oyemensis* (220.11 mg/100g) dry weight were about 2 to 4 times richer than those of raw cow meat (22-25), chicken (28 mg/100g) and fish (33-36 mg) [76]. Those insects could therefore be considered as excellent sources of Mg. Magnesium is indispensable in the metabolism of calcium, but is also necessary for the proper functioning of the heart, it is a cofactor of many enzymes involved in energy production in the body [81] and plays an important role in insulin sensitivity [82].

Indeed, magnesium is a cofactor participating in more than 300 enzymatic reactions, which makes it an essential element for the synthesis of carbohydrates, lipids, nucleic acids and proteins, as well as for other actions in different organs of the cardiovascular and neuromuscular systems [75]. It helps to maintain normal muscle and nerve function, keeps heart rhythm steady, supports a healthy immune blood and regulates blood sugar levels [83].

Edible caterpillar *I. oyemensis* showed provides a sufficient quantity of Mg to the body (220.11 mg/100g), as the RNI by [75] and [77], recommending magnesium intake around 220 mg/day for females and 260 mg/day for males.

Sodium content of the samples *B. aurantiaca* (185.40 mg/100g) and *I. oyemensis* (216.43 mg/100g edible portion) dry weight were comparable to those of animal sources foods which range from 50-221 mg/100g edible portion [76]. The high content of sodium observed could be attributed to addition of seasonings such as bouillon cubes, sodium chloride (NaCl), or table salt during processing. The sodium amount in the two edible caterpillar samples were comparable to RNI for sodium by [80] and more recently by [84] recommending a reduction in sodium intake to < 2 g of NaCl/day (200-500 mg/100g) in order to regulate blood pressure and reduce the risk of stroke and coronary heart disease in adults, hence, the addition of table salt during cooking of these caterpillars should be restricted..

Within the two types of commonly commercialized caterpillars here analyzed, iron and manganese concentration were the highest of all minerals in the samples, while zinc was the lowest, as detected in a proportion of 8.70 and 10.39 mg/100g respectively. The high content of iron in *B. aurantiaca* (19.65) and *I. oyemensis* (69.10 mg/100g) dry weight is of particular interest. The content for *I. oyemensis* (69.10 mg/100g) is similar to those of [74] in the same caterpillar, but less quantitatively important than *Imbrasia truncata* of [85] with 81 mg/100g dry weight, 2.6 times higher than the content obtained by [86] on *Macrotermes bellicosus* form Nigeria. The iron amount in *I. oyemensis* in this study is 3.5 times higher than the RNI for iron by [75] which is 9.1 mg/day for males and 19.6 mg/day for females (Table 2).

Iron is a component of hemoglobin and myoglobin which has oxygen carrier function and acts as a cofactor of various enzymes [87]. Micronutrient deficiency, which is referred to as hidden hunger, reduced physical activity and increased maternal morbidity and mortality, are of great concern particularly among pregnant women and children in poor urban and rural dwellers. Iron deficiency often manifests as sideropenic anemia [75], and could be easily counteracted by consumption of some iron rich insect species such as *Imbrasia oyemensis* [88]. Bearing in mind that iron content of beef liver, a good food source for iron, is 5–8 mg/100g (Rural Development Administration, 2011; United States Department of Agriculture, 2015), iron content of the two edible caterpillars considered in this study was slightly higher. [89] reported that iron content of edible insects *Lethocerus indicus* and *Hydrophilus olivaceous* was 410 and 461 mg/100g, respectively.

Thus, some edible insects may be an important source of iron. The high levels of Fe present in the studied samples indicated that they are good sources of iron for target populations with high requirements of iron, including youth, pregnant and lactating women.

Zinc is a component of about 100 enzymes which catalyze activation, cell division, and immune action [90]. Major dietary sources of zinc include red meat, poultry and oysters. Zinc content of oyster is 13.2 mg/100g (Rural Development Administration, 2011). Zinc deficiency causes impaired growth and contributes considerably to the high infectious disease burden [91] Zinc deficiency has also been known to cause poor growth and impairment of sexual development [92].

Comparing zinc content of the edible caterpillars analyzed *B. aurantiaca* and *I. oyemensis* with 8.70 mg/100g and 10.39 mg/100g dry weight respectively with the dietary refence values for zinc in adults as recommended by [93], the two edible caterpillars cover the daily needs (Table 2). Zinc content of those species was lower than the one of edible insects *Verlarifictorus aspersus* (18.91 mg/100g dry weight) from Korea [94] and of *Laccotrephes maculatus* from India (23.2 mg/100g) and was similar to that of oysters and beef liver [89].

Vegetarians are at risk of zinc deficiency [95] although baked beans, chickpeas, also contain zinc [96] [online only]. Iron and zinc deficiency is widespread in developing countries, especially in children and women of reproductive age [97]. Therefore, the cereal-based diets for feeding infants and young children observed in most of those countries could receive a boost with the addition of these caterpillars to the diet.

Lastly, in this study the manganese (Mn) as oligo-mineral was also detected in the caterpillar samples at 38.48 ± 2.10 mg/100g and 141.67 ± 1.70 mg/100g for *B. autrantiaca* and *I. oyemensis* respectively. It is well known that Mn is component of various enzymes which contributes to activation of several enzymes, including a number of kinases, transferases, hydrolases, and decarboxylases [98]. The manganese content of both analyzed caterpillars in this study is higher than the one reported by [99] in palm weevil larvae *Rhynchophorus phoenicis* from Nigeria, revealing that the Mn content of *R. phoenicis* in early larvae stage and adult were 0.49 mg/kg and 0.50 mg/kg respectively while late larvae stage recorded 0.30 mg/kg. The consumption of < 8 g of the edible caterpillars could cover daily RNI for manganese in adult as recommended by [100] and [101].

It should be noted that a few different studies in Africa have analyzed the mineral content of some caterpillars consumed in the studied country [102]–[106]; [107] however, the data obtained are not always comparable because of the variations between caterpillars, and because of the different methods used to analyze these compounds. The mineral content of the studied insects could be altered prior by the laboratory analysis, as for most foods, preparation and production methods (e.g., drying and boiling for our case) applied prior to consumption influence the nutritional composition.

IV. CONCLUSION

In this study, the minerals' bioavailability was not evaluated, only a quantitative mineral component analysis of two dried edible caterpillars commonly commercialized on local markets of eastern Democratic Republic of Congo including *Bunaeopsis aurantiaca* and *Imbrasia oyemensis* were analyzed. The authors provided the quantitative analysis of seven (7) essential minerals for human health: calcium, phosphorus, magnesium, sodium, iron, zinc and manganese showing that mineral content differed within type of edible caterpillar. *Imbrasia oyemensis* provided the highest content (5 over 7) of the minerals tested. Phosphorus was significantly the most abundant mineral detected in the two samples and the highest mineral of *Bunaeopsis aurantiaca* compared to other ones, suggesting that those edible insects are a useful mineral-rich food sources as well as insect-based ingredients for food enrichment, fulfilling daily requirements of essential minerals, as for iron amount in *I. oyemensis*, that was 3.5 times higher than the RNI of iron in adults. The consumption of < 8 g of the edible caterpillars could cover the daily RNI for manganese in adults. The content in other measured minerals per 100g of edible caterpillar portion was in the range of the daily RNI in adult 19-65 year.

Even if minerals are inorganic nutrients, usually required in small amounts from less than 1 to 2500 mg/day, they are very essential for the normal development and functioning of the body systems of organisms and their deficiencies cause major health problems. Therefore, edible caterpillars in this study can supply necessary nutritive elements for human body functions and could be consumed along with other food rich in other essential minerals to further complement the diet, especially of most vulnerable groups as those in pediatric age, women of childbearing age and elderly.

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