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RESEARCH ARTICLE

Anthropo-entomophagy: quantitatively chemical assessment of some edible arthropods, bought from an e-shop

Zeynep Aydoğan [1]

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Abstract

Eating edible arthropods is not associated with rural life anymore. The emerging industry of edible arthropods is trying to change that. The best shopping spot to buy well-known edible arthropods is online today. Consumers can find numerous outlet options to buy edible arthropods from the Internet. With worldwide growing threats to food security, today, gastronomy, especially in western countries, is trying to develop a more positive view to arthropods' nutritional value. In this paper, non-crustacean arthropods (armor tail scorpion, black scorpion, black ant, flying termites, giant waterbug, June beetle, diving beetles, rhino beetles, silkworm pupae, sago worm, bamboo worm), bought from online edible insect market, were evaluated in terms of availability of some hazardous chemical. Energy Dispersive X-Ray Fluorescence (EDXRF) spectroscopy was used for determining the concentrations of heavy metals/metalloids in the total body of the arthropods. Concentration of the elements (Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Pb) were measured quantitatively in all samples. The results showed that the chemicals like Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, and Pb have highly been measured in the black scorpion, black ant, flying termites, giant waterbug, June beetle, sago worm, and bamboo worm.

Keywords Anthropo-entomophagy · Entopreneurs · Online insect markets · Heavy metals/metalloids

Introduction

Scorpions, spiders, centipedes, termites, worms, and insects have been consumed as food and food complement in poor and developed countries from the time immemorial (Hope 1842; Holt 1885). Today, many cultures still keep on eating these animals. Consuming arthropods is becoming increasingly popular around the world, but it is a novelty for most western countries and remains taboo or disgusting things in some cultures in the developed world such as Turks, Europeans, non-Aboriginal Americans, and Canadians.

Anthropo-entomophagy, like any other bizarre or exotic foods, is a cultural phenomenon. Eating a slice of horse meat is considered normal in Kazakhstan and Belgium; many cultures regard it as strange. Similarly, adding a tarantula in a sandwich is very delicious for Cambodians. As in some cases, cultural habits can also change like in decreasing entomophagy in aborigines' diet due to settlements of Europeans. As in sushi, lobster, or crustacean acceptance in developed countries, nutritional preference, cultural norms, and consumer preferences may change over time.

Throughout history, majority of arthropods have been harvested in the wild like freshwater ecosystems, forests, agricultural fields, or farms. The uncontrolled and unsustainable wild collection has led to over-collecting, destruction of the nature, and extinction of species (Mitsuhashi 2010). In recent times, the rearing and mass production of the arthropods have been growing. Anthropo-entomophagy has become global and now is a growing trend in the food industry. At first, the majority of the western countries refused to eat arthropods, but now with a several campaigns, their food preference are changing, and consumers are curious about its taste and willing to try arthropods in the future (Sogari et al. 2017). Their increased curiosity mainly depends on the ecological, nutritional, economic, global, and culinary aspect of arthropods. In addition, "Green product" issues may be main motivation for eating insects.

Several academic studies have been investigated the nutritional value of arthropods (Gmuer et al. 2016; Piha et al.

Responsible Editor: Philippe Garrigues

✉ Zeynep Aydoğan
zeynep.aydogan@atauni.edu.tr

[1] Narman Vocational School, Atatürk University, Narman, Erzurum, Turkey

2018). In addition to academic studies, mass media, travel documentaries, cooking books, popular magazines, and entrepreneurs have been working to increase the advantage of this new, nutritious, and environmentally friendly food sector. However, there is also increasing academic interest in anthropo-entomophagy. Considering the term "edible insects" searched on the Web of Science publication in number 59, 167, 1213 records in the year 1970-2000, 2000-2010 and 2010-2020 respectively. Only in one year, 2020–2021, 265 articles were published. With all these changing opinions about anthropo-entomophagy, some countries such as Belgium, Switzerland, and the Netherlands have regulated their food legislation and have started to sell edible insects and other arthropods in supermarkets and online markets (Sogari et al. 2017).

Anthropo-entomophagy is a brand new sector, and it is growing fast. This means a different line of business; innovative entopreneurs or ento-business are emerging. Here, entopreneurs or ento-business means; companies, organizations, insect farming and individuals who are farming, working or other related business on edible insects, arthropods and their products. According to a report by Meticulous Research™, the valuation of edible insect markets will be USD 7.96 billion by 2030 (Anonymous 2018). This new industry is working on producing, marketing, commercializing, farming, and cooking and trying to develop new products from one of the largest and most diverse groups of organisms: arthropods. As a new sector, the main obstacles of this field are people's acceptance, regulation, and rearing-commercializing process. Increasing population and decreasing food resources pave the way for the increasing demand for nutrient-rich foods. These food innovators are ready to invest and launch a business to produce, farm, and commercialize the arthropod and arthropod-based products.

The list of entopreneurs around the world was given by the Bugburger website to honor of World Edible Insect Day on October 23, 2015, and new companies have been adding to the list every year (Bugburger 2019). In total, there are 257 entomo-companies/brands around the world on the list from Australia, Belgium, Canada, China, Colombia, DR Congo, Czech Republic, Denmark, Finland, France, Germany, Indonesia, Italy, Israel, Japan, Mexico, the Netherlands, New Zealand, Norway, Peru, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, the UK, and the USA. Consumers can find insects and other arthropod based products on that list and also can order vast amount of different kinds of worldwide popular arthropod products such as insect flour, insect pasta, oil, crackers, lollipops, entomilk, energy bars, bitters, burgers, nutrition supplements, noodles, protein shake, smoothies, insect infused beer or whisky, and more unique products. Such products reduce the visibility of arthropods and look less disgusting and may increase arthropods edibility. Many of these entopreneurs have their shops, marketed directly to their worldwide clients.

Not all arthropods are edible. Certain arthropods are vectors of disease (such as mosquitoes); others can produce venom or contain naturally or anthropogenically driven toxic substances. If arthropods are not controlled, like other kinds of food sources, all of them are likely to have some hazard to their consumers as allergically, microbially, parasitically, and chemically. This study was performed to assess the level of some hazardous chemicals in 12 online marketed edible non-crustacean arthropod species (armor tail scorpion, black scorpion, black ant, flying termites, giant waterbug, June beetle, diving beetles, male rhino beetles, rhino beetles, silkworm pupae, sago worm, bamboo worm).

Materials and methods

Twelve edible arthropods (Fig. 1) were purchased via the Internet from the same internationally popular online entomophagy market. Arthropods were shipped in sealed plastic bag packages of variable weight, by international express courier, and stored at an ambient temperature until analyses. The arthropods were processed (boiled, dried, and salted) by manufacturers and hence ready to be consumed. The arthropods were originated from Thailand. A total of 12 arthropods including 7 adult beetles (*Belostomatidae*, *Macrotermes bellicosus*, *Polyrhachis*, *Phyllophaga*, *Dytiscidae*, and male-female *Xylotrupes gideon*), 2 scorpion (*Heterometrus* longimanus and *Mesobuthus martensii*), 1 beetle pupae (*Bombyx mori*), and 2 beetle worm (*Rhynchophorus ferrugineus* and *Omphisa fuscidentalis*) were examined for determining their heavy metal/metalloid content. Single packets of each insect type were purchased and tested. Their element levels were analyzed by EDXRF spectrometry at Atatürk University High Energy Spectrometer Research Laboratory, as described in Aydoğan et al. (2017). Purchased specimens were oven-dried at 80 °C for 36 h to remove inherent water molecules and were pulverized into powdery forms; then cellulose was added as a binder. Cellulose helps to gain better pellet/tablet shape. Five tons of pressure were applied to make 13-mm diameter pellet of each species. The 13-mm diameter pellet was done for every arthropod. Before starting to the measurement of the metals, blank samples were prepared for the correction of measured signals. Every arthropod samples were irradiated with photons at 59.5 keV, emitted from 5 Ci ^{241}Am radioactive source. The characteristic X-rays released from the samples were measured with an HPGe detector, with resolution ~ 180 eV. In experiment geometry, sample, source, and detector were on the same plane. The distance between the radioactive source and the sample was determined by measuring nine different positions, where X-rays were measured most severe, and was

found as 35,5 mm. Irradiation time for the samples was 24 h. The measurement was carried out under vacuum for the elimination of the elements on the air. The element concentration of each sample was determined with the WinQXAS program that performed quantitative analysis. The model parameters are then optimized using a non-linear least squares strategy, using a modified Marquardt algorithm to minimize the weighted (optional choice) sum of differences $\chi 2$ between the experimental data and the mathematical model. The concentrations of heavy elements have some uncertainties due to EDXRF (maximum ~ 5%). Possible error sources for these uncertainties are as follows: statistical error (~ 1%), systematic errors (~ 2%), errors arisen from the peak evaluation procedure (3%), and fundamental parameter methods (3%).

Identification of arthropods was made according to the names on the packages and checked by the author. Experiences of people who bought online and tasted them were also given below.

Scorpion (Arachnida: Scorpionida)

Like insects, scorpions belong to Arthropoda, but a scorpion is an eight-legged arthropod and is not an insect. It has been long used in traditional Chinese medicines due to anti-cancer, anti-coagulation, and anti-epileptic functions. In addition, many people in China, Korea, Japan, Mongolia, Thailand, and Vietnam are familiar with a variety of scorpions on sticks and are eating scorpions regularly. Consumers are using it as topping material from salads to the main dish. After death, the poison in the tail become harmless, and cooking or drying also makes the poison harmless. Eating the tail depends on the consumer; some people like to eat, and others do not. The consumers and new testers feedback about its taste that the dehydrated version is a little tough and crunchy, recommended with Thai sweet chili sauce.

Armor tail scorpions (Buthidae: Mesobuthus)

Armor tail scorpion is consumed mostly in China, Korea, Japan, and Mongolia. It tastes like shrimp. Due to over-exploitation, it has been red-listed in China (Shi et al. 2007). In this study, *Mesobuthus martensii* (Karsch, 1879), also known as the Manchurian scorpion or the Chinese or Golden Chinese scorpion, was evaluated.

Black scorpion (Scorpionidae: Heterometrus)

As like the armor tail scorpion, black scorpions are common in most parts of Asia. Consumers say they do not look at what it looks like. Its taste is similar to shrimps and lobsters. In this study, *Heterometrus longimanus* (Herbst, 1800) was evaluated.

Flying termites (Isoptera: Termitidae)

There are many species of termites with different morphological forms and all generally termed as termites, flying termites, winged termites, or alates. Also in different parts of Nigeria,



Fig. 1 Experimental samples of studied arthropods (1, female rhino beetles (*Xylotrupes gideon*); 2, male rhino beetles (*Xylotrupes gideon*); 3, armor tail scorpion (*Mesobuthus martensii*); 4, black scorpion (*Heterometrus longimanus*); 5, giant waterbug (*Belostomatidae* sp.); 6, flying termites (*Macrotermes bellicosus*); 7, black ant (*Polyrhachis* sp.); 8, June beetle (*Phyllophaga* sp.); 9, diving beetles (*Dytiscidae* sp.); 10, silkworm pupae (*Bombyx mori*); 11, sago worm (*Rhynchophorus ferrugineus*); 12, bamboo worm (*Omphisa fuscidentalis*))

they are called as aku, chinge, ebu, khiyea, and esusu (Igwe et al. 2011; Ntukuyoh et al. 2012). At least 43 species of four families are consumed in 29 countries around the world (De Figueirêdo et al. 2015). Flying termites are boiled or dried and added to salads or fried by using their fats. Their bodies are naturally rich in oil; thus, consumers do not need oil when they are frying them. Drying makes them remain edible for more than a year, and then they are stored in containers away from moisture. In order to make them dry and last long, the only used additive is salt. Termites can also consumed raw (Igwe et al. 2011; Taru and Chazovachii 2015; Anonymous 2019). They are crunchy, and they have an earthy taste. In this study, *Macrotermes bellicosus* (Smeathman, 1781) was evaluated.

Black ant (Hymenoptera: Formicidae)

Ant species vary in color; most are red, brown, or black; green is rare; and some tropical species are metallic color. The family name came from the Latin word "formica." Formic acid producer ants' taste is sour similar to lemon; many people call it a limey or citrus taste, but not all species are palatable. Formicidae and its species are mainly used as a food and nutritional ingredient in Botswana, Zambia, South Africa, Zimbabwe, Sudan, Mozambique, Namibia, Cameroun, Congo, Botswana, Sri Lanka, Australia, North America, South America, Mexico, Brazil, Ecuador, Venezuela, Guyana, Honduras, Nicaragua, Peru, Thailand, Indonesia, Malaysia, Philippines, Kalimantan, Thailand, Bangladesh, Myanmar, India, and China (Jongema 2017). Weaver ant is called in Thai as "Khai Mot Daeng" (Watanabe and Satrawaha 1984), in Bodos of Assam "Khwjema" (Narzari and Sarmah 2015), and in Lao "Khai mot dieng" (Boulidam 2010). Due to the nutritional value, the State Food and Drug Administration and State Health Ministry of China have used ant in some medical products since 1996 (Shen et al. 2006). In this study, the specimen, indicated on the package, *Polyrhachis* sp. Smith, 1857, was evaluated.

Giant waterbugs (Hemiptera: Belostomatidae)

It is a large insect with very noticeable foreleg pincers, used for hunting, which is reminded of scorpions. It is an aquatic insect that spends part of its life cycle in water. Generally, adults are used as food for humans. The beetle is famous and eaten in Congo, Mexico, Venezuela, Thailand, Vietnam, India, China, Japan, and Singapore (Jongema 2017). The giant waterbug or water scorpion is called in different names, known in the Morigaon district of Assam as "Dagla Bori" (Rahman et al. 2018), in Bodos of Assam "Gangjema" (Narzari and Sarmah 2015), in Thai "Malaeng/Maeng Da Na" (Watanabe and Satrawaha 1984), in India "Naosek, Atsü leplo, Tsuleplo" (Senthilkumar et al. 2008), and in Lao "Meang da" (Boulidam 2010). According to consumers, when they are cooked, they emit a pleasant odor. Scorpion-like appearance does not frighten consumers because the giant waterbugs have an amazing taste and incomparable nutrient values. In this study, *Belostomatidae* sp. Leach, 1815 was evaluated.

Diving beetles (Coleoptera: Dytiscidae)

Diving beetles have a cosmopolitan distribution and can be found on almost all continents. According to Jongema (2017), 41 dytiscid species are consumed worldwide. Like all edible insects, diving beetles are very nutritious and are eaten in throughout East and Southeast Asia. Diving beetle is locally known in Morigaon district of Assam as "Khoi puk," in Bodos of Assam "Chingkhouri" (Narzari and Sarmah 2015), and in Thai "Malaeng Tub Tow" (Watanabe and Satrawaha 1984). In this study, *Dytiscidae* sp. was evaluated.

June Beetles (Coleoptera: Scarabaeidae)

June beetles are called in Thai as "Malaeng Kinoon Daeng." In total, 224 Scarabaeidae species are eaten in Nearctic, Mexico, and Ghana (Jongema 2017). Adults and immature stage can be eaten, and their taste is like buttery walnuts. In this study, the genus *Phyllophaga* sp., which is commonly named June beetles, June bugs, or may beetles, was evaluated.

Rhino Beetle (Coeloptera: Scarabaeidae, Dynastinae)

Rhino beetle males have the characteristic horn, whereas females do not have this feature, and their name was given due to the horns on its head resembling the rhinoceros. They are harmless and do not bite, sting, or hurt people with their horns. Hercules or horned or rhino beetle is called in Thai as "Malaeng Krarm" (Watanabe and Satrawaha 1984), in India "Lessepo" (Senthilkumar et al. 2008), in Southwestern Nigeria "Ipe" (Banjo et al. 2006), and in Lao "Mieng Kham" (Hanboonsong and Durst 2014). The beetle is eaten in Congo, Nigeria, South Africa, DR Congo, Madagascar, Cameroun, Ivory Coast, Benin, Guiné, CAR, and Japan (Jongema 2017). In this study, *Xylotrupes gideon* (Linnaeus 1767) was evaluated.

Silkworms (Lepidoptera: Bombycidae)

Apart from its textile benefits, larval and pupae stages of silkworms are most commonly eaten and are very popular in Asian countries like China, Japan, Thailand, Vietnam, and North and South Korea. Street vendors sell the pupae as street food; it is canned and known commonly as "beondegi." It is known in India as "Mugamesen" (Senthilkumar et al. 2008),

in Lao "Dak dir" (Boulidam 2010), and in Thai "Duck Dae Tua Mai" (Watanabe and Satrawaha 1984). The consumers' opinion about its taste is a bit like mashed potato and a black sea snail. It can be integrated into all kinds of recipes and mostly is eaten with marinated forms in chili and garlic sauce. Mitsuhashi (2010) in his study states that three silkworm pupae are equivalent to one chicken egg. In this study, *Bombyx mori* was evaluated.

Sago worm (Coleoptera: Curculionidae)

Sago worm is a larva of palm weevil that usually feeds on palm, coconut, and sago trees (Hanboonsong and Durst 2014). This insect is eaten mostly by indigenous people in Borneo Island and Southeast Asia countries such as Malesia and Papua New Guinea. It is like natural energy bars, due to its rich fat content. Since it is preferred by people, the Sago Festival, locally known as "Pesta Rumbia," is organized in Kuala Penyu (Sabah), and when a ticket is bought for the festival, different kinds of sago foods can be tried. Consumers can eat it as raw before removing the hard chitinous head, which is quite bland; also, it can be fried, boiled, or grilled (Yew and Kok 2012). It has a creamy taste, and the cooked ones are preferred mostly by consumers. In this study, *Rhynchophorus ferrugineus* (Olivier, 1790) was evaluated.

Bamboo worm (Lepidoptera: Crambidae)

Bamboo worm is also called the bamboo caterpillar and bamboo borer; it inhabits and feeds on bamboo culm, and it is eaten in larval stage. It is consumed mostly in Thailand, Myanmar, Laos, and parts of China (Yhoung-Aree et al. 1997). It is available at almost every street food vendors in these countries. Children generally prefer to eat it because of its taste and ease of chewing (Hanboonsong and Durst 2014). In India, it is known as "Pollo and Michikha" (Senthilkumar et al. 2008), in Lao "Daung-nor-mai" (Boulidam 2010), and in Thai "rot duan" (Yhoung-Aree et al. 1997). In this study, *Omphisa fuscidentalis* (Hampson, 1896) was evaluated.

Results and discussions

The concentration of elements (Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Pb) in the selected species are shown in Table 1. EDXRF was used due to the samples which are not destroyed; its preparation is not time-consuming; and it is a quick, simple, and financially undemanding method. According to EDXRF results, there was considerable variation between the different arthropods for all elements examined. The element concentrations were found notably high in the black scorpion, black ant, flying termites, giant waterbug, June beetle, sago worm and bamboo worm, whereas the elements in the armor tail scorpion, diving beetle, male/female rhino beetle, and silkworm pupae accumulated at lower concentrations. Sixteen elements were measured from these arthropods, and seven of these elements (As, Ti, V, Br, Rb, Sr, and Pb) were thought as hazardous.

Calcium is one of the important minerals and has a large number of vital functions in the body. Ca content of the species ranged between 0,9 ppm dry weight (dw) for diving beetle, male rhino beetle, and silkworm pupae and 1202 ppm dw for giant waterbug. Dietary reference values for adults aged over 19 years are 1000–1300 mg/day. Ca requirement is higher during childhood, adolescence, and during lactation (FAO/WHO 2001; Cormick and Belizán 2019). Giant waterbug package is, therefore, a rich source of Ca.

Toxicity of chromium differs depending on its valence. Chromium has seven oxidation states (0–VI) but trivalent and hexavalent states being the most common. International Agency for Research on Cancer (IARC) is classified hexavalent (Cr(VI)) chromium is known carcinogen and mutagen whereas as a part of chromodulin, pharmacological doses of trivalent chromium (Cr(III)) (0.08 to 1 mg/kg) has a modulating effect on carbohydrate, protein, and fat metabolism (Vincent 2015). According to the Institute of Medicine (2001), the adequate intake for Cr is 35 μg/day for adults. Cr content of the species ranged between 0,3 ppm dw for diving beetle and silkworm pupae and 194 ppm dw for flying termites.

Manganese is necessary for good health. However, excess Mn impairs the nervous system, loss of sex drive, and sperm damage (ATSDR 2012). Adequate intake for adult men and women is 2,3 mg/day and 1,8 mg/day, respectively (IOM 2001). Mn content of the species ranged between 0,2 ppm dw for female rhino beetle, silkworm pupae, and armor tail scorpion (0,26 ppm dw) and 136 ppm dw for giant waterbug.

Iron is one of the most vital but most toxic elements found in the human body. Its excess or deficiency will influence the human health unfavorably. Excess free iron in the body is believed to generate oxidative stress and can lead to several pathological conditions such as hepatotoxicity, heart disease, arthropathy, and neurodegenerative disorders. The average iron intake should be 16–18 mg/day and 12 mg/day for men and women, respectively (IOM 2001). Fe content of the species ranged between 0,2 ppm dw for diving beetle, male/female rhino beetle, silkworm pupae, and armor tail scorpion (0,25 ppm dw) and 136 ppm dw for flying termites.

Cobalt presents the center of the coenzyme cobalamin or vitamin B_{12} (hydroxycobalamin). In addition, it is necessary for DNA synthesis and regulation and influences glucose, protein, and fat metabolism and normal nerve function. The presence of Co in the body stimulates the production of erythropoietin. Thus, cobalt deficiency causes a high accumulation of iron and nickel in the liver. As well as deficiency, an overload of cobalt influences the human body unfavorably.

Table 1 Concentration of the heavy metals/metalloids in the samples in ppm

Heavy metals/ metalloids	Armor tail scorpion	Black scorpion	Black ant	Flying termites	Giant waterbug	June beetle	Diving beetles	Male rhino beetles	Female rhino beetles	Silkworm pupae	Sago worm	Bamboo worm
Ca	1,11	365	389	332	1202	279	0,9	0,9	1,02	0,9	412	569
Ti	0,49	93	92	107	418	103	0,5	0,6	0,6	0,4	116	179
V	0,48	58	59	76	228	53	0,4	0,4	0,4	0,3	70	105
Cr	0,41	36	58	194	141	32	0,3	0,4	0,5	0,3	48	74
Mn	0,26	38	45	48	136	23	0,3	0,3	0,2	0,2	35	57
Fe	0,25	26	18	136	78	14	0,2	0,2	0,2	0,2	21	36
Co	0,33	204	129	125	178	93	0,3	0,3	0,3	0,2	171	51
Ni	0,19	74	68	104	107	62	0,2	0,2	0,3	0,2	104	178
Cu	0,25	57	47	56	62	41	0,1	0,2	0,2	0,1	68	74
Zn	0,16	33	42	53	60	29	0,1	0,1	0,1	0,1	42	56
As	0,25	36	36	43	59	32	0,3	0,3	0,3	0,3	56	97
Se	0,07	9,4	9,7	15	18	8,1	0,08	0,05	0,09	0,06	12	18
Br	0,08	10	7,7	11	13	6,6	0,06	0,06	0,08	0,05	13	19
Rb	0,04	4,7	4,6	5,7	15	4,1	0,05	0,05	0,05	0,041	6,2	12
Sr	0,05	3,9	5,7	4,6	16	4	0,04	0,05	0,04	0,03	5,2	6,5
Pb	0,52	75	75	90	129	67	0,6	0,5	0,6	0,4	116	201

Average B_{12} intake should be 2.4 μg/day, which contains 0.1 μg of cobalt (ATSDR 2004). Co content of the species ranged between 0,2 ppm dw for silkworm pupae and 204 ppm dw for black scorpion.

Nickel may serve as a component of certain metalloenzymes. However, nutritional importance and biochemical function of Ni have not been clearly demonstrated for humans. Thus, there is no adequate daily intake for Ni, but upper intake level for Ni is 1 mg/day (IOM 2001). Nickel ranged from 0,19 to 178 ppm dw and the was highest in the bamboo worm and lowest in the armor tail scorpion.

Copper is a component of a number of metalloenzymes. Recommended daily allowance for Cu is 900 μg/day for adult men and women (IOM 2001). Cu content ranged from 0,1 to 74 ppm dry weight and was highest in the bamboo worm and lowest in the diving beetle and silkworm pupae.

Zinc functions as a component of various enzymes that play a vital role in many biochemical reactions, catalytically, structurally, and regulatory. Recommended daily allowance for Zn are 8 mg/day and 11 mg/day for adult men and women, respectively (IOM 2001). Zn content ranged from 0,1 to 60 ppm dry weight and was highest in giant waterbug and lowest in armor tail scorpion, diving beetle, male/female rhino beetle, and silkworm pupae.

Selenium functions through selenium-containing proteins, known as selenoproteins. Adequate selenium intakes for adults are 70 μg/day for men and 60 μg/day for women (Kipp et al. 2015). Se content ranged from 0,05 to 18 ppm dry weight and was highest in the bamboo worm and giant waterbug and lowest in the male rhino beetle.

Pb concentration was measured at a high level in black scorpion, black ant, flying termites, giant waterbug, june beetle, sago worm, and bamboo worm: 75, 75, 90, 129, 67, 116, and 201 ppm, respectively. Researches stated that 10 μg/dl Pb exposure leads to neurological and cognitive disorders and renal dysfunction (Tong et al. 2000; Patrick 2006). The maximum Pb concentrations in foods allowed by the WHO, the FAO, and the EC (European Community) are 2, 0.5, and 0.2 μg/g, respectively. In this study, Pb concentration exceeds the WHO/FAO/EC limits, in the black scorpion (75 ppm), black ant (75 ppm), flying termites (90 ppm), giant waterbug (129 ppm), June beetle (67 ppm), sago worm (116 ppm), and bamboo worm (201 ppm). Also, depending on the chemical form, the inorganic form of As is the most toxic and bioaccumulative (Spehar et al. 1980). In this study, As levels in the black scorpion, black ant, flying termites, giant waterbug, June beetle, sago worm, and bamboo worm were measured as 36, 36, 43, 59, 32, 56, and 97 ppm dw, respectively. It can be said that these levels are not safe for consumption. Besides, the rest of the non-essential elements (Ti, V, Br, Rb, and Sr) were also higher at the giant waterbug, black scorpion, black ant, flying termites, June beetle, sago worm, and bamboo worm. Thus, these arthropods would be considered a potential threat to human health in terms of Ti, V, Br, Rb, and Sr toxicity.

There is limited information in the literature about the element concentrations of the studied arthropods. Pharmacological and biochemical venom content of *Heterometrus longimanus* (black scorpion) was studied well, however nutritional values, including minerals, are unknown. This study revealed that

Heterometrus longimanus provide a high quality of minerals in terms of Ca, Cr, Mn, Co, Ni, Fe, Cu, Zn, and Se. *Polyrhachis* sp. (black ant) is mainly used for medicine and general consumption. Several studies have been focused on the protein and fat content of *Polyrhachis* sp. but little has been known about the mineral content. The results of this study are similar with Ntukuyoh et al. (2012). Besides, Shen et al. (2006) identified 16 minerals, of which K, Ca, P, Mg, Fe, Mn, and Zn were predominant. According to this study results, the ants are rich in terms of Ca, Cr, Mn, Co, Ni, Fe, Cu, Zn, and Se. The mineral composition of the *Bombyx mori* (silkworm pupae) was given on the package (Ca 102.31 mg, Iron 9.54 mg, Zn 17.75 mg, Mn 2.49 mg, Cu 2.08 mg, Se 0.08 mg), but our results did not match with the package mineral composition. In a study conducted by Verspoor et al. (2020) showed that element concentration (mg/g) of wild-harvested (wh) and commercially bought (cb) *Macrotermes* spp. have different concentration levels of Fe (wh: 10.3 ± 0.3; cb: 9.8 ± 0.5), Zn (wh: 13.8 ± 0.3; cb: 12.0 ± 0.4), Cu (wh: 8.2 ± 0.3; cb: 5.1 ± 0.6), Mn (wh: 292.7 ± 21.4; cb: 481 ± 112). They also found that the accumulation of Mn was higher than the other studied elements and the accumulation was measured at a high level in the abdomen than the head. In this study, the element concentration of *Macrotermes bellicosus* (flying termites) was lower than these results.

Some researchers such as Cain et al. (1992) and Kiffney and Clements (1993) claimed that the body size influences element levels in an organism, for example, smaller-bodied insect's element concentrations are greater than larger-bodied ones. This study result is consistent with the claim. Black ant, flying termites, sago worm, and bamboo worm body sizes are smaller than armor tail scorpion, diving beetles, and male rhino beetles; however, element levels are higher than these. Age, gender, body fat level, and habitat may be also an important factor for variations of heavy metal concentrations in the different arthropod species.

Conclusion

Over two billion edible arthropods consumers, more than a quarter of the world's population, cannot be wrong. They like to eat, and they are highly appreciated especially in Central and South America, Africa, Asia, Oceania, and nowadays in Europe. People's negative opinions on edible arthropods have not deterred entopreneurs in the west. Two hundred fifty-seven edible arthropod companies are selling online, and new ones are adding to those companies. Those "entopreneurs" are launching businesses to feed a growing appetite for crickets, mealworms, and other edible arthropods. Producers are mixing edible arthropods into familiar foods, to change people's minds and palates. It seems that there will be huge demands for online sold edible arthropods in the future.

Food safety begins on the farm; if there are heavy metals or pesticide contamination on the place where the arthropods are rearing, the arthropods would accumulate these metal(loid)s, even they do not use them (like Pb, Cd, As) for their body functions. If the environment is not protected and the environmentally negative situation continues, like the other food sources, edible arthropods become a harmful and unhealthy food source for consumers.

Prior to this study, there is existed no published work that provided element concentration of online sold edible arthropods. Besides, the arthropods' packages do not include nutritional content, including elements. Therefore, to fill in the important gaps in the knowledge, the main target of this study was to determine potentially toxic elements that may exist in the edible arthropod packages. The findings of this study suggested that studied arthropods were rich in terms of elements including the harmful ones. As in other types of food, chemical contamination of the studied arthropods may have happened at the rearing, harvesting, post-harvesting, packaging, storage, transportation, or preparation process. This study needs further documentation of rearing, harvesting, post-harvesting, packaging, storage, transportation, and preparation process in terms of heavy metal contamination level.

In order to protect the consumers from heavy metal(oid)s, to control the toxic elements in an environment, and to make a wise policy about heavy metal(oid)s:

- Safe and quality rearing, harvesting, post-harvesting, packaging, storage, transportation, and consumption processing technologies, in short, production chain, should be monitored in order to make a clean mass production and compete with meat products. It is necessary to know their sources, pathways, and releases to the environment. Water, soil, and weather of the rearing area should be controlled regarding elements.
- Element contents of the edible arthropods should be specified on the package.
- Safety standards or guidelines as well as sanitation procedures should be well defined by legislation.
- Management plans are needed in terms of sustainable collection conditions in a controlled way like arthropod farming.

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Authors' contributions ZA has made contributions to design and acquisition of data, analysis and interpretation of data, wrote the manuscript.

Data availability All data generated or analyzed during this study are included in this article. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The manuscript does not report on or involve the use of any animal or human data or tissue. The manuscript does not contain data from any individual person.

Consent to participate Not applicable.

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