Environ Monit Assess (2023) 195:249
https://doi.org/10.1007/s10661-022-10861-8

Determination of selected elements in two commercially available edible aquatic insects (Coleoptera) and their worldwide updated list

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Received: 28 July 2022 / Accepted: 16 December 2022
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Abstract Many nations and ethnic groups from underdeveloped and developed countries have used insects as human food since ancient times, a practice that has continued into modern times. In many traditionally entomophagous countries, insects are not a "famine food," and demand for edible insects is clearly a "food of choice" rather than a necessity. From a nutritional point of view, depending on the insect species, gender, insect's diet, and seasons, some species of edible insects have significant amounts of fat, protein, carbohydrates, and vitamins, as well as minerals required for human health, thus representing an alternative food source. In addition to their nutritious content, they may also accumulate pesticide residues, microplastics, and heavy metals from their ecosystems. Therefore, this study analyses some mineral (Ca, Fe, Cu, Zn, Se, Co, Cr, As, and Pb) contents of two selected commercialized aquatic edible beetles, *Dytiscus marginalis* and *Cybister tripunctatus* (Dytiscidae), via inductively coupled plasma-mass spectrometry (ICP-MS) and reviews the contemporary list of aquatic edible beetles of the world, summarizing the nutritional characteristics of water beetles with a synthesis of the risks and benefits of edible aquatic beetles in recent literature. The mineral composition of the aquatic beetles is briefly discussed. Antinutritional elements (Pb and As) were detected in aquatic insects, but their contents are below toxic levels for humans. A list of 92 edible aquatic beetle species from Dytiscidae, Gyrinidae, Elmidae, Histeridae, Hydrophilidae, Haliplidae, and Noteridae (Coleoptera) was compiled and updated.

Keywords Anthropoentomophagy · Edible aquatic beetles · Entomophagy · Food security · Malnutrition · Nutrition

Introduction

The majority of all living animal species are invertebrates, and most of these are arthropods. Insects have the highest number of animal groups on earth and are the largest class of Arthropoda, thereby representing enormous diversity and biomass in nature. Insects are an important part of the ecosystem due to fulfilling a number of crucial roles, such as helping with pollination, eating other insects and food for other animals, and recycling organic materials; therefore, insects with different feeding habits occupy different positions in food chains. In short, without insects, the earth would become uninhabitable, and there would be no life. Aside from their ecological benefits, the utilization of insects is very diverse: industry (honey, propolis, pollen, wax, silk, oil, dying, aesthetic, lac, food, and feed), forensic cases, and edible and therapeutic purposes. Concerning food scarcity and malnutrition worldwide in the near future, especially regarding protein sources, edible insects have many advantages

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Published online: 30 December 2022

over several other nutritional sources (Payne et al., 2016). The nutrient profiles of many edible insects are on average compared to those of commonly eaten meat and fish (on a fresh weight basis). Insects are good sources of vital nutrients, such as fatty acids, protein, vitamins, and minerals, and are therefore seen as excellent sources to combat malnutrition and shortages in the world food supply (FAO, 2012). The nutritional composition may vary depending on the insect's species, life stage, body size, gender, feeding habits, geographical location, climate, and preparation and processing before consumption (Melo-Ruíz et al., 2016; Payne et al., 2016).

Insects are internationally accepted as a staple food in many regions of the world. The terms "entomophagy," "insectivory," or "anthropo-entomophagy" refer to the consumption of terrestrial and aquatic insects as food in the human diet. Entomophagy is not a new phenomenon, and archaeological evidence from human coprolites suggests that the consumption of insects by humans dates back to ancestral times (Sutton, 1995). Today, many cultures still conserve ancestral traditions of entomophagy. In addition, eating insect habits in society are affected by religion, tradition, mass media, and trends, in a word by culture. Currently, over 2 billion people, chiefly in the tropics and subtropics, from 130 countries in Asia, Africa, Australia, and Latin America, eat insects at higher concentrations, and the number of identified edible insect species is more than 2100 (Ponce-Reyes & Lessard, 2021). Most commonly consumed insects in the world are dominated by the orders belonging to Coleoptera, Lepidoptera, Orthoptera, Hemiptera, Odonata, Diptera, Hymenoptera, Ephemeroptera, Tricoptera, Megaloptera, and Isoptera (Fig. 1).

Africa is one of the leading continents that consume insects as food to combat hunger and malnutrition, where

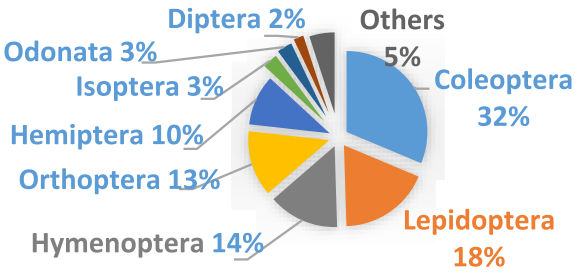


Fig. 1 Percentage of most commonly consumed insects, by order, consumed globally (Jongema, 2017)

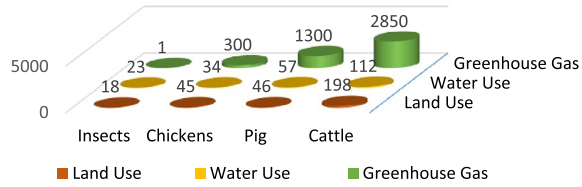


Fig. 2 Comparison of chicken, pig, cattle, insect farming, and their environmental footprint (Van Huis, 2020)

many insects are edible, millions of people traditionally eat insects, and insects are used as feed for their farm animals (FAO, 2012). However, in many parts of traditionally entomophagous countries, they are not a "famine food," as demand for edible insects is appreciated as "food of choice" rather than a necessity. They eat insects due to tradition, taste, nutritious, plentiful, affordable, easy to access, easy to prepare for eating, green product, or just curiosity. Currently, edible insect culture, marketing, online marketing, street vendor sale, and collection from the wild are being made. In addition, insects have been used as insect-based products by Westernized countries due to their low environmental footprint, and high protein, fatty acid, vitamin, and mineral contents. To produce 1 kg of protein, insects need small spaces to farm, less water, and low levels of greenhouse gas emission (Fig. 2).

In recent years, a large number of scientific publications have shown that entomophagy is a primary entomological research interest because of its future prospects for food and feed security (Fig. 3). Therefore, this research area is gaining momentum among nonspecialists, researchers, and environmentalists due to its nutritional, cultural, environmental, and economic advantages. Hence, this study investigates the composition of mineral and toxic metal(oid) contents of two commonly eaten edible aquatic beetles, attempting to summarize the nutritional characterization of the beetles with a synthesis of recent anthropoentomophagic literature,

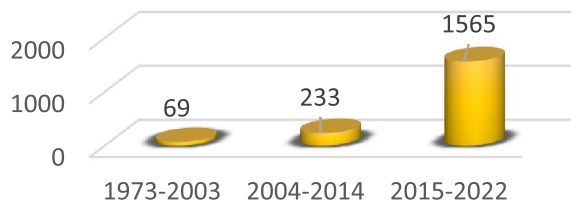


Fig. 3 The number of scientific publications on "edible insect" in the Web of Science

updating the list of edible aquatic beetles, assessing the diversity of commonly eaten aquatic beetles and their taxonomic analysis, and discussing the pitfalls of edible aquatic insects as human food.

Aquatic coleoptera (beetles)

Aquatic insects are abundant in most freshwater habitats, often exhibit high diversity, and are a vital component of any aquatic ecosystem. They serve to decompose leaf litter, indicator the health of living environments, and serve as food items for nearly the full range of vertebrate and invertebrate organisms. Many aquatic insects respond to the quality of the environment where they live, and due to being able to adapt to diverse habitats, they are used in biomonitoring studies (Aydoğan et al., 2016). Aquatic insects consist of several orders, with approximately 76,000 described species belonging to these orders (Koroiva & Pepinelli, 2019). Over 2000 insects have been documented in the literature as edible, and aquatic insects account for 15% of the total number (Zhao et al., 2021). Aquatic insects spend all or part of their life cycle in an aquatic environment and live mainly in shallow water near the shorelines of streams, brooks, marshes, swamps, ponds, puddles, lakes, pools, creeks, springs, fountains, ditches, seepages, wetlands, and dams. Many aquatic insect consumers capture and consume insects from these aquatic environments.

The term "beetle" is a common word for Coleoptera, and Coleoptera means "sheathed wing or trimeran" due to their hard elytra. Based on the number of identified animal diversity, there are more than 13,000 described species of Coleoptera, making them the most abundant animal group existing on Earth (Short, 2018). The majority of the members are terrestrial, while others are aquatics and semiaquatics and are adapted to an aquatic environment. There are 176 families under 4 suborders (Archostemata, Myxophaga, Adephaga, and Polyphaga).

According to the anthropo-entomophagic literature, the taxonomic, geographic, and nutritional analysis of aquatic edible beetles has not been adequately studied. Among the edible insect group (88% are terrestrial, 12% are aquatic), over 250 aquatic insect species have been consumed in 48 countries throughout the world, mostly Coleoptera (79 species), Odonata (58 species), and Hemiptera (55 species) (Macadam & Stockan, 2017). Consumed aquatic insects are mainly larvae and adults, but also some pupae (Table 1). Among the edible aquatic Coleoptera, 7 families, 22 genera, and 79 species have been recorded thus far, mainly belonging to Dytiscidae, Gyrinidae, Elmidae, Histeridae, Hydrophilidae, Haliplidae, and Noteridae (Macadam & Stockan, 2017; Ramos-Elorduy et al., 2009). In total, mostly in the trophic and subtropics, aquatic insect consumption is common, as in Japan, China, India, Vietnam, Myanmar, Thailand, Malaysia, Kenya, the Philippines, Indonesia, Colombia, Chile, Peru, Venezuela, Mexico, Panama, Cameroon, Congo, Cambodia, Laos, Sierra Leone, Gabon, Morocco, Senegal, Madagascar, Venezuela, Australia, and the northern USA (Ramos-Elorduy et al., 2009).

Diversity of edible aquatic beetles worldwide

Needless to say, most insects have great benefits to humanity. Coleoptera is the most commonly consumed order by humans (Jongema, 2017). Table 1 shows a list of world edible aquatic Coleoptera, distribution by species, common English name, local name, consumption stage, the country where it is eaten throughout the world, and references. Observations of the distribution and consumption of edible aquatic insects in the world revealed that the practice of entomophagy is common mostly in the southern USA, China, Japan, India, and Thailand (Table 1). The consumption of aquatic beetles in underdeveloped and developed countries worldwide has been practiced in 28 countries. A list of 92 edible aquatic insect species from Dytiscidae, Gyrinidae, Elmidae, Histeridae, Hydrophilidae, Haliplidae, and Noteridae (Coleoptera) was compiled (see Fig. 4, Table 1). Of these, the majority are Dytiscidae (55.43%), Hydrophilidae (26.09%), Gyrinidae (9.78%), Haliplidae (3.26%), Elmidae (2.17%), Histeridae (2.17%), and Noteridae (1.09%) (see Fig. 4).

There are knowledge gaps in taxonomic investigations, and there are insufficient studies on taxonomy, as some of the names are not found in the literature or some taxonomic names are not correct. For example, *Eretes stiticus* is the correct name, but in some sources, it is misspelled as *Erectes stiticus*; *Hydrophilus acuminatus* is misspelled as *Hydrophilus acminatus*, *Cybister fimbriolatus* (Say 1823) is misspelled as *Cybister frimbiolatus* (Say 1825), *Cybister owas* Laporte 1835 is misspelled as *Cybister hova* (Alluaud, 1900), *Dytiscus circumflexus* is misspelled as *Dytiscus circumflex*, and *Cybister sugillatus* is misspelled as *Cybister singulatus*. Additionally, the taxonomic literature, there are no such names as *Cybister desjardinsii*, *Dytiscus danmcus*, *Hydrophilus aoninatus*, *Cybister sticticus*, *Hydrous* (*Tempnopterus*) *marginatus*, and *Thermonectes bsilaria*.

Table 1 Taxonomy and the list of 92 of global aquatic beetle species (Coleoptera) that have been recorded as being edible

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Family: Hydrophilidae (water scavenger or mud beetles)						
Berosus sp. Leach 1817			Larva		Africa, Mexico	Jongema (2017) Grabowski et al. (2020)
Cymbiodyta marginella (Fabricius 1792) (synonym Hydrophilus marginatus)					Senegal	Jongema (2017)
Hydrobiomorpha spinicollis (Eschscholtz 1822)					Thailand	Hanboonsong (2010) Jongema (2017)
Hydrochara sp. Berthold 1827					Thailand	Mitsuhashi (2016)
Hydrophilus (Dibolocelus) sp. (Regimbart 1901)			Adult		Mexico	Ramos-Elorduy et al. (2009)
Hydrophilus (Hydrous) acuminatus Motschulsky 1853	Dark diving Beetle				China, Japan, India	Williams and Williams (2017) Zhao et al. (2021) Ramos-Elorduy et al. (2009)
Hydrophilus affinis Thunberg 1794		Ko-gamushi, meang ee tao			Japan, Laos	Jongema (2017)
Hydrophilus (Hydrous) bilineatus (Mac Leay 1825)					Thailand, Vietnam, China, Japan	Hanboonsong (2010) Jongema (2017) Ramos-Elorduy et al. (2009)
Hydrophilus bilineatus caschmirensis Redtenbacher 1844					China, Thailand, Vietnam, Laos, Myanmar	Ramos-Elorduy et al. (2009) Jongema (2017)
Hydrophilus caschmirensis Redtenbacher 1844	Large scavenging	Azühpüllau	Adult	Boiling, cooking, or frying	India	Mozhui et al. (2020)
Hydrophilus cavisternum (Bedel 1891)	Water scavenger beetle	Malaeng nian			China, Japan, Vietnam, Thailand, Laos	Williams and Williams (2017) Ramos-Elorduy et al. (2009)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Hydrophilus (Hydrous) hastatus (Herbst 1779)					Vietnam, Laos, Thailand, Cambodia, Myanmar, China, Japan	Williams and Williams (2017) Ramos-Elorduy et al. (2009)
Hydrophilus (Hydrous) indicus Bedel 1892	True water beetle	Tharaokokpi, Chickchribi	Larva Adult		India	Singh and Babu (2021)
Hydrophilus (Hydrous) olivaceus Fabricius 1781	Water beetle	Tharaikokpi, Ankhaouri	Larva Adult	Roasted, fried, or curry forms	India, Thailand, Sri Lanka	Shantibala et al. (2014) Singh and Babu, (2021) Das and Hazarika (2019)
Hydrophilus (Hydrous) pallidipalpis Mac Leay 1825					India, China, Japan	Ramos-Elorduy et al. (2009) Williams and Williams (2017) Jongema (2017)
Hydrophilus picicornis Chevrolat 1863		Obus, Alukap			Philippines	Ramos-Elorduy et al. (2009) Mitsuhashi (2016)
Hydrophilus senegalensis (Percheron 1835)	Water scavenger beetles				Senegal	Ramos-Elorduy et al. (2009) Jongema (2017)
Sternolophus sp. Solier 1834		Tsimangovo, Tsikobo, Tsikoboka, Tsikobono, Mahabo, Maroantsetra	Adult		Madagascar	Randrianandrasana and Berenbaum (2015)
Sternolophus rufipes (Fabricius 1792)			Adult		Thailand	Hanboonsong (2010) Jongema (2017)
Tropisternus sp. Solier 1834	Water beetle	Tharaokokpi, Chickcribi	Larva Adult		Mexico	Ramos-Elorduy et al. (2009) Singh and Babu (2021)
Tropisternus collaris (Fabricius 1775)					Japan	Jongema (2017)
Tropisternus mexicanus (Castelnau 1840)			Larva Adult		Mexico, Panama	Jongema (2017) Williams and Williams (2017)
Tropisternus tinctus Sharp 1882			Larva Pupa Adult		Mexico	Jongema (2017) Williams and Williams (2017)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Tropisternus sublaevis (Leconte 1855)			Larva Adult		Mexico	Jongema (2017) Williams and Williams (2017)
Family: Dytıscıdae (predaceous diving beetles)						
Agabus (*Gaurodytes*) *fulvipennis* Régimbart 1899					China	Mitsuhashi (2016) Williams and Williams (2017)
Acilius sp. (Leach 1817)					China	Ramos-Elorduy et al. (2009)
Copelatus sp. Erichson 1832					Thailand	Hanboonsong (2010)
Cybister sp.		Atopinan or cucarachas de agua		Roasted with salt and in tacos	Mexico	Ramos-Elorduy and Pino (1989)
Cybister binotatus Boheman 1844					Congo	Jongema (2017)
Cybister bengalensis Aubé 1838					China	Ramos-Elorduy et al. (2009) Jongema (2017)
Cybister brevis Aubé 1838					Japan	Jongema (2017)
Cybister confusus Sharp 1882			Larva Adult	Roasted, fried, and curry forms	India	Shantibala et al. (2014) Jongema (2017)
Cybister cinctus Sharp 1882		Voatsingovoka/ vatomandry	Adult		Madagascar	Randrianandrasana and Berenbaum, (2015)
Cybister distinctus Régimbart 1878					Senegal Sierra, Leone, Congo	Jongema (2017)
Cybister ellipticus LeConte 1852					USA	Jongema (2017)
Cybister explanatus LeConte 1852	Predaceous diving beetles		Larva Pupa Adult		North of USA and N. of Mexico	Jongema (2017) Ramos-Elorduy et al. (2009)
Cybister fimbriolatus (Say 1823) (synonim *Cybister flavocinctus* Aubé 1838)	Giant diving beetle		Larva Adult		China, Mexico	Jongema (2017) Ramos-Elorduy et al. (2009)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Cybister guerini Aubé 1838					China, Japan, Indonesia	Jongema (2017) Ramos-Elorduy et al. (2009)
Cybister insignis Sharp 1882					Gabon	Ramos-Elorduy et al. (2009)
Cybister japonicus Sharp 1873					China, Japan	Ramos-Elorduy et al. (2009)
Cybister lewisianus Sharp 1873					China	Jongema (2017) Ramos-Elorduy et al. (2009)
Cybister limbatus (Fabricius 1775)	True water beetle	Maeng-tab-tau Malaeng tub tow Azükhanu	Adult	Boiling, cooking, or frying	China, Laos, Thailand, India	Hanboonsong (2010) Jongema (2017) Ramos-Elorduy et al. (2009) Aydoğan et al. (2018) Mozhui et al. (2020)
Cybister occidentalis Aubé 1838			Larva Adult		Mexico, Cameroon, China	Jongema (2017) Ramos-Elorduy et al. (2009)
Cybister operosus Sharp 1882		Tsikovoka	Adult		Madagascar	Randrianandrasana and Berenbaum (2015)
Cybister owas Laporte 1835					Madagascar	Jongema (2017)
Cybister posticus Aubé 1838					India	Jongema (2017)
Cybister rugosus (W.S. Macleay 1825)					India, Thailand, Laos	Ramos-Elorduy et al. (2009) Hanboonsong (2010) Jongema (2017)
Cybister sugillatus Erichson 1834	Water beetle	Tharaikokpi/chikchribi	Larva Adult		China, Japan, India	Ramos-Elorduy et al. (2009) Jongema (2017) Singh and Babu (2021)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Cybister tripunctatus (Olivier 1795)	Water beetle	Tengbi Tsimangovo Mahabo	Larva Adult		China, Japan, Indonesia, India, Thailand, Madagascar	Jongema (2017) Ramos-Elorduy et al. (2009) Singh and Babu (2021) Randrianandrasana and Berenbaum (2015)
Cybister tripunctatus asiaticus Sharp 1882					Thailand, India	Hanboonsong (2010) Jongema (2017)
Cybister tripunctatus lateralis (Fabricius 1798)		Azükhanu	Adult	Boiling, cooking, or frying	India	Mozhui et al. (2020)
Cybister vulneratus Klug 1834		Tsikobo Tsikoboka Tsikobono Maroantsetra	Adult		Madagascar	Randrianandrasana and Berenbaum (2015)
Eretes sticticus (Linnaeus 1767)	Twinpoes diving beetle	Jujema	Larva	Fried	Myanmar, Malaysia, Kenya, India, Laos, China, Vietnam, Kenya, Sri Lanka	Ramos-Elorduy et al. (2009) Hanboonsong (2010) Jongema (2017) Mitsuhashi (2016) Das and Hazarika (2019)
Dytiscus (*Macrodytes*) *circumflexus* Fabricius 1801					Morocco	Ramos-Elorduy et al. (2009)
Dytiscus dauricus Gebler 1832						Zhao et al. (2021)
Dytiscus habilis Say 1830			Larva Adult		China, Japan, Mexico	Ramos-Elorduy et al. (2009) Jongema (2017) Mitsuhashi (2016)
Dytiscus marginalis Linnaeus 1758	Great diving beetle Diving beetle	Singkhaori	Adult		China, Japan, India	Ramos-Elorduy et al. (2009) Jongema (2017) Mitsuhashi (2016) Choudhury et al. (2020)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Dytiscus (*Dytiscus*) *marginicollis* Le Conte 1844	Giant green water beetle		Larva Adult		Mexico	Ramos-Elorduy et al. (2009) Jongema (2017) Mitsuhashi (2016)
Dytiscus sharpi validus Régimbart 1899		Ko-gengorōmodoki			China, Japan	Ramos-Elorduy et al. (2009) Jongema (2017) Mitsuhashi (2016)
Hydaticus sp. Leach 1817	Water beetle	Tengbi	Larva Adult		India	Singh and Babu (2021)
Hydaticus rhantoides Sharp 1882	Water beetle				Thailand	Hanboonsong (2010)
Laccophilus apicalis Sharp 1873			Larva		Mexico	Ramos-Elorduy et al. (2009)
Laccophilus fasciatus Aubé 1838					Mexico	Ramos-Elorduy et al. (2009)
Laccophilus pulicarius Sharp 1882					Thailand	Hanboonsong (2010) Jongema (2017)
Megadytes giganteus (Laporte 1834)		Haba de agua	Larva Adult		Mexico	Jongema (2017)
Rhantus sp. Dejean 1833	Water beetle	Tengbi	Larva Adult		India, Mexico	Ramos-Elorduy et al. (2009)
Rhantus atricolor (Aubé 1838)			Larva Adult		Mexico	Mitsuhashi (2016)
Rhantus consimilis Motschulky 1859			Larva Adult		Mexico	Mitsuhashi (2016)
Rhantaticus congestus (Klug 1833)					Thailand	Hanboonsong (2010)
Rhantus latus (Fairmaire 1869)					Madagascar	Mitsuhashi (2016)
Rhantus pulverosus (Stephens 1828)						Williams and Williams (2017)
Thermonectes marmoratus (Hope 1832)			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Thermonectes basilaris (Harris 1829)			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)
Platynectes guttula Régimbart 1899 Transfer to *Platambus guttulus*					China	Mitsuhashi (2016)
Sandracottus manipurensis Vazirani 1969		Dzübolo	Adult	Boiling, Cooking or Frying	India	Mozhui et al. (2020)
Family: Gyrınıdae (whirligig beetles)						
Aulonogyrus strigosus (Fabricius 1801)				Roasted	Australia	Jongema (2017)
Gyrinus curtus Motschulsky 1866		Ko-mizusumashi			Japan	Mithsub Williams and Williams (2017)
Gyrinus japonicus Sharp 1873		Hime-mizusumashi			Japan	Mitsuhashi (2016)
Gyrinus (plicatus) obtusus Say 1834			Larva Adult		Mexico	Ramos-Elorduy (2004)
Gyrinus parcus Say 1834	Whirlwind beetle		Larva Adult		Mexico	Mitsuhashi (2016)
Gyrinus plicatus Régimbart M. 1883			Larva Adult		Mexico	Mitsuhashi (2016), jong
Dineutus sp. Macleay 1825		Fandiorano, Vatomandry	Adult		Madagascar	Randrianandrasana and Berenbaum (2015)
Dineutus marginatus Sharp 1873		tao-mizusumashi			Japan	Mitsuhashi (2016)
Dineutus orientalis (Modeer 1776)		ō-mizusumashi			Japan	Mitsuhashi (2016)
Family: Histeridae (clown beetles or hister beetles)						
Hololepta guidonis Marseul 1860			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)
Homolepta sp.	Hister beetles		Larva		Mexico–Oaxaca	(Ramos-Elorduy et al. 1984) Mitsuhashi (2016)

Table 1 (continued)

Specie	Common English name	Local name	Consumption stage	Preparation	Location	Reference
Family: Haliplidae (crawling water beetles)						
Haliplus punctatus Aubé, 1838			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)
Peltodytes mexicanus (Wehncke, 1883)			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)
Peltodytes ovalis Zimmermann, 1924			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)
Family: Elmidae (riffle beetles)						
Elmis chilensis Germain, 1854 (accepted as *Austrelmis chilensis* (Germain 1854))					Chile, Peru	Ramos-Elorduy et al. (2009)
Elmis condimentarius Philippi, 1864 (accepted as *Austrelmis condimentarius*)					Chile, Peru, Colombia, Venezuela	Ramos-Elorduy et al. (2009) Mitsuhashi (2016)
Family: Noteridae (burrowing water beetles)						
Suphisellus sp. Crotch 1873			Larva Adult		Mexico	Ramos-Elorduy et al. (2009)

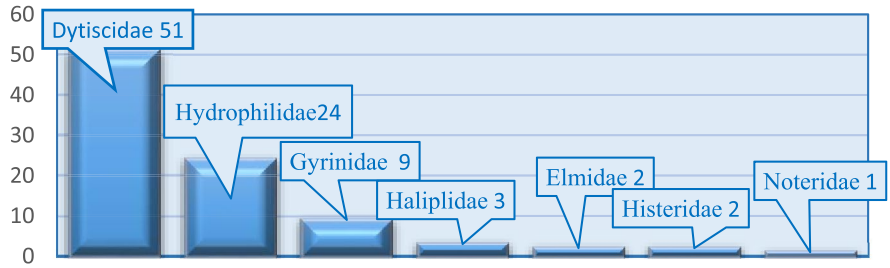


Fig. 4 Recorded number of edible aquatic insect species (Coleoptera) around the world

P. guttula Regimbart was transferred to *Platambus* by Brancucci (1988) (Nilsson, 1998). There is no taxonomic information on *Homolepta* sp. In addition, *Diloboderus* sp. Reiche 1859 is not an aquatic beetle, as it belongs to Scarabaeidae (Coleoptera). Hence, rigorous taxonomic identification is needed.

Currently in Turkey, the consumption of edible insects is culturally inappropriate or even taboo (Karaman, 2019; Yüksel & Canhilal, 2018). According to Mitsuhashi (2016), adults of *Hydrophilus pallidipalpis* and *Hydrophilus piceus*, *Dytiscus marginalis*, *Blaps sulcata*, *Blaps* sp., *Pimelia* sp., *Tenebrio* sp. are consumed in Turkey. However, entomophagy is not a cultural phenomenon in Turkey, and there is no literature on this phenomenon.

Nutrient content

From a nutritional perspective, many edible insects provide balanced nutrients to the human diet. Even in species belonging to the same genus, nutritional values may highly differ. Depending on the insect species, gender, developmental stage, diet, environment, seasons, and processing, some species of edible insects have significant amounts of not only protein but also fat (polyunsaturated and monounsaturated fatty acids), carbohydrates, vitamins (thiamine/B1, riboflavin/B2, pyridoxine/B6, acid pantothenic, biotin, and niacin), minerals (K, Ca, Mg, Zn, P, Fe, Cu, and Se), and some bioactive compounds (tocols, sterols, and carotenoids) required for human health, thus representing an alternative food source to the human diet (FAO, 2012; Rumpold & Schlüter, 2013). It is nutritional ratios relative to plants or meats make them more nutritious.

The literature on the nutrient composition of edible terrestrial insects is quite rich (Fontaneto et al., 2011), whereas for edible aquatic insects much less data are available (Aydoğan et al., 2018; Das, 2019; Yang et al., 2006). Edible aquatic beetles are consumed at different developmental stages, but mostly at the larval and adult stages (Table 1).

Protein

Protein is one of the nutritional needs for people and is mostly obtained from animal and plant-based sources such as meat, fish, legumes, and nowadays insects. Of the 20 proteinogenic amino acids, 9 are classified as essential for humans since they cannot be synthesized in the human body naturally (leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, and histidine). Amino acid composition and digestibility determine the nutritional quality of protein. In general, edible beetles are rich in amino acids such as isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, threonine, tryptophan, valine, arginine, histidine, serine, proline, alanine, glycine, and glutamic acid, as is given in the literature (Rumpold & Schlüter, 2013). However, knowledge about aquatic beetles is quite scarce.

The larval stage dry matter total amino acids (g/100 g) in *Cybister japonicus, Dytiscus dauricus,* and *Hydrophilus acminatus* are 47.89, 48.74, and 47.86, and total essential amino acids are 54.23, 53.10, and 51.25, respectively. Isoleucine, leucine, and lysine contents are higher in aquatic beetles ranging from 4.38 to 14.18 for isoleucine; from 7.59 to 12.16 for leucine, and from 5.14 to 7.08 for lysine (Zhao et al., 2021). Dry tissue (% per 100 g) of *Cybister tripunctatus* contains 26.54 crude proteins (Chutia et al., 2021), and *Dytiscus marginalis* contains 56.37 crude proteins (Choudhury et al., 2020). In another study, *Cybister tripunctatus* contained 22.64 (%) protein (Shantibala et al., 2014). From this point of view, it is evident that aquatic insects serve a good balanced diet because they contain different kinds of amino acids.

Fat

Lipids are important nutrients in the human diet, due to their role in a wide range of metabolic and regulatory processes. In particular, polyunsaturated fatty acids are essential for human health and cannot be synthesized in humans. From 20 to 35% daily intake of fatty acids, especially ω3 (alpha-linolenic/omega 3 fatty acids) (1.6 g/day for men and 1.1 g/day) and ω6 (linoleic acid/omega 6 fatty acid) (17 g/day for men and 12 g/day for women), is recommended (Lichtenstein & Jones, 2012).

According to edible insect nutrient studies, the general proportions of saturated and polyunsaturated fatty acids were similar for both aquatic and terrestrial insects; however, monounsaturated fatty acid levels were significantly higher in aquatic insects (Fontaneto et al., 2011; Yang et al., 2006). Melo-Ruíz et al. (2016) demonstrated that the giant water bug includes sufficient amounts of mono-unsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and ω3 and ω6 fatty acids. The fatty acid content of adult *Cybister japonicus* contains 49.94 MUFA and 22.52 PUFA, respectively. This result is higher in MUFA and similar in PUFA than terrestrial larval Coleopteran species (Zhao et al., 2021). Dry tissue (% per 100 g) of *Cybister tripunctatus* contains 12.35 crude lipids (Chutia et al., 2021). In other studies, *Cybister tripunctatus* contained 21.57 (%) lipids (Shantibala et al., 2014), and *Cybister limbatus* and *Hydrophilus cavisternum* contained 0.373, 0.360, 0.267, and 0.016 and 0.312, 0.343, 0.345, and 0.280 saturated fatty acids, monosaturated fatty acids, polysaturated fatty acids, and eicosapentaenoic acids, respectively (Fontaneto et al., 2011). In addition, dry tissue (% per 100 g) of *Dytiscus marginalis* contains 15.04 fat (Choudhury et al., 2020). Thus, the use of edible insects in daily diets will contribute to human health by providing an adequate source of lipids.

Carbohydrates

Carbohydrates are an important source of energy and mainly exist in insect bodies in two forms: chitin and glycogen. Adult coleopteran beetles have hard elytra made of chitin. It is an aminopolysaccharide (a carbohydrate polymer) derived from the insects' exoskeleton. Chitin is rich in fiber and is a nitrogen-containing carbohydrate (N-acetylglucosamine), which is needed for appropriate food digestive processes. Adequate fiber consumption reduces the risk of colon cancer and lowers cholesterol blood levels, and 20–30 g/day fiber is recommended (Melo-Ruíz et al., 2016). Dry tissue (% per 100 g) of *Cybister tripunctatus* contains 11.00–15.13, *Hydrophilus olivaceus* contains 14.25 and *Dytiscus marginalis* contains 14.28 crude fiber (Choudhury et al., 2020; Chutia et al., 2021; Shantibala et al., 2014). The dry tissue (% per 100 g) of *Cybister tripunctatus* contained 1.67–19.54; whereas that of *Hydrophilus olivaceus* contained 2.39 total carbohydrates, and their energy levels were 554.85 and 584.92 kcal/g, respectively (Chutia et al., 2021; Shantibala et al., 2014).

Vitamins

Vitamins are organic compounds of the human body that are necessary for metabolism. They cannot be synthesized in the human body and thus must be provided constantly via food. Studies on vitamins in edible aquatic beetles are insufficient. Shantibala et al. (2014) reported that *Cybister tripunctatus* and *Hydrophilus olivaceus* contain 268.67 and 202.66 mg/100 g phenol; 301.67 and 528.67 mg/100 g tannin, respectively. However, according to the insect nutrient profile literature, insects contain vitamins and bioactive compounds such as B1, B2, B6, C, D, E, K, folic acid, carotene, thiamine, riboflavin, and ascorbic acid (Ganguly et al., 2018).

Minerals

The natural world is made of elements and their compounds. Minerals are generally required in small amounts for the continuation of biological functions and the maintenance of several physiological processes and thus should be adequately provided in diets. In general, insects have higher contents of Ca, Fe, Zn, and Cu than meat products (Aydoğan et al., 2018; Das, 2019). Mineral content (mg/kg dry matter) of adult *Cybister tripunctatus, Cybister japonicus, Hydrophilus olivaceus, Hydrophilus acuminatus* are 277.000, 3602.820, 243.000,106.700 for Ca; 336.000, 774.520, 990.000, 109.200 for Mg; 6430.000, 6722.650, 3900.000, 1807.700 for K; 3050.000, 2251.760, 8160.000 for Na; 73.000, 148.160, 4610.000, 83.200 for Fe; 51.000, 29.370, 17.000 for Cu; 57.500, 93.990, 118.000, and 29.000 for Zn, respectively. The Mn content was 8.700, the Se content was 0.360, and the P content was 5809.000 in *Cybister japonicus*; the P content was 1905.100 in *Hydrophilus acuminatus*. The results

are lower than those for terrestrial Coleopteran species (Zhao et al., 2021). In another study, *Cybister tripunctatus* had 11.87 mg/100 g Cu, 31.08 mg/100 g Fe, and 8.34 mg/100 g Mn (Chutia et al., 2021).

Uncontrolled use of pesticides and anthropogenic activities leads to an increase in toxic metal(oid)s in the environment, such as aluminum (Al), cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg). These metal(oid)s have no function in the human body and deteriorate multiple human body organs. Al, Hg, and Pb have neurotoxic effects, and Cd is a toxic metal that mainly affects the renal system (Paz et al., 2019). As is a metalloid and has many adverse health effects, such as carcinogenesis, skin, and neurological diseases (Rahaman et al., 2021).

The chemical composition of insects may be affected by environmental factors, body size, feeding habits, and gender. For example, carnivorous insects have higher Hg contents than herbivorous insects, and aquatic insects have higher Hg contents than terrestrial insects (JinDi et al., 2019). It should not be forgotten that aquatic insects have a close relationship with their environment (air, soil, sediment, and water); therefore, they can easily accumulate elements as well as heavy metal(oid)s and pesticides from their environment and can biomagnify through the food chain.

Risks of anthropo-entomophagy

It must be ensured that any nutritious item is safe for consumers. Not all insects are edible. Insects may be a vector for microorganisms and can have a symbiotic or pathogenic relationship (Wielkopolan et al., 2021); therefore, they may lead to zoonotic infections. In addition, depending on the insect species, insects can accumulate contaminants, pesticides, and toxic metals from their feeding environment. Contamination may also be carried out along the insect production system; rearing, harvesting, processing, storing, and transporting may affect food safety. Among the issues that mar the nutrient potential of edible aquatic insects, allergenicity, microbial pathogenicity, pesticides, heavy metal(oid)s, microplastic risks, and hazards related to their environment are worth assessing.

Currently, there are no specific regulations, standards, or guidelines, making industrialized insects potentially toxic metal hazards (Aydoğan et al., 2018; Shantibala et al., 2014). As in other food safety and hygiene standards, the collection and production of insects should receive more attention.

Material and methods

The selected edible aquatic beetles, namely, *Dytiscus marginalis* and *Cybister tripunctatus* (Dytiscidae), were purchased from an online insect market (each at 15 g net weight) in 2019. They were identified using literature and taxonomic keys. Beetles were shipped in sealed plastic bag packages of 15 g weight by an international express courier and stored at an ambient temperature until analyses. The beetles were processed (boiled, dried, and salted) by manufacturers and were ready to be consumed. The beetles originated in Guangdong.

The beetles were all at an adult stage. After identification, the samples were oven dried at 70 °C to reduce the moisture content and then blended into powder forms with a laboratory porcelain mortar. Before use, all laboratory dishes were carefully washed with 10% nitric acid solution for 48 h and rinsed with deionized water. The elemental analysis of the powdered samples was performed using ICP-MS, named at the EAHTARC (Eastern Anatolia High Technology Application and Research Centre) at Atatürk University. The labeled samples with codes were taken to EAHTARC laboratories to determine their mineral content. The elements Ca, Fe, Cu, Zn, Se, Co, Cr, As, and Pb were determined in selected edible beetles using a standard analytical method (Beauchemin, 2008). Fifteen grams of each sample in powdered form was stored in airtight glass containers labeled and then sent to the EAHTARC laboratories.

According to the edible insect literature, due to incorrect use of common and scientific names of insects, an agreement is needed for using the correct taxonomic name. Therefore, in addition to heavy metal analysis, the aim of the present study was to review and compile up-to-date information on edible aquatic insect taxonomy. The information presented here was collected by reviewing the literature on edible aquatic beetles around the world. The keywords included "edible aquatic insects, nutrient, and anti-nutrient status of edible aquatic insects." From the resulting articles, a selection was made of those focusing on edible aquatic beetles, particularly as it relates to their taxonomy, diversity, and mineral and nutrient composition.

Results and discussion

Element content of the selected aquatic beetles

In the present study, the element and toxic metal(oid) concentrations of *D. marginalis* and *C. tripunctatus* online sold packs were evaluated. The results were determined as dry weight. *Cybister* spp. are sought after worldwide, with 25 known as edible aquatic species (Hanboonsong, 2010; Jongema, 2017; Ramos-Elorduy et al., 2009; Randrianandrasana & Berenbaum, 2015; Singh & Babu, 2021). They taste like the meat of a turtle or a crocodile, and prior to eating, the chitinous parts, such as elytra and legs, are removed. Before eating, they are washed with warm water, soaked in salt, and dried (Jäch, 2003). According to Shantibala et al. (2014), they have nutritional value and antioxidant properties. *Dytiscus* spp., with six known species, is currently appreciated as food in China, Japan, Mexico, India, and Morocco (Choudhury et al., 2020; Ramos-Elorduy et al., 2009).

Morphologically, *D. marginalis* (29–33 mm) is larger than *C. tripunctatus* (25–27 mm). *D. marginalis* is a voracious predator, and *C. tripunctatus* is carnivorous and mainly feeds on tadpoles, small fish, and aquatic insects. The obtained results revealed that the highest mineral contents were registered in *C. tripunctatus* compared with *D. marginalis* (Table 2). The most abundant mineral profile in *C. tripunctatus* was Ca (9.257 $mg.kg^{-1}$), followed by Fe, Cu, and Zn. The order of the metal(oid)s in *C. tripunctatus* was Ca > Fe > Cu > Zn > Se > Pb > As > Cr > Co, and in *D. marginalis* it was Ca > Fe > Pb > As > Cr > Co > Cu > Zn > Se. According to the results, it can be hypothesized that the size of the insects, feeding style, dietary preference, feeding habitat, and environmental probability of the element could explain the metal(oid)s differences among these species (Arnold et al., 2021).

For comparison, there is limited information in the literature about the metal(oid)s content of *C. tripunctatus* and *D. marginalis*. According to the literature, Shantibala et al. (2014) measured the concentrations of metals in their study and found that *C. tripunctatus* collected from ponds and paddy fields had significant amounts of Ca (27.7 ± 0.81 mg/100 g), Fe (7.3 ± 0.05 mg/100 g), Zn (5.75 ± 0.32 mg/100 g), and Cu (5.1 ± 0.17 mg/100 g), which were higher than the present study results. In general, the present study results were higher than those of Aydoğan et al. (2020), which were collected from freshwater in the wild. Also, the present study *C. tripunctatus* Cu, Fe, and Mn results were lower than those of Chutia et al. (2021), which were collected from markets and villages; 11.87 mg/100 g Cu, 31.08 mg/100 g Fe, and 8.34 mg/100 g Mn. Guangdong is a densely populated, industrialized, and urbanized area in China. Industrial, agricultural, and domestic wastes may be the reason for the increased load of metal(oid)s in the environment and therefore in the insects. According to the RDA, C. tripunctatus is a good source of Fe and Cu.

However, harmful components of edible insects should also be taken into account. For safe food, toxic elements should also be taken into consideration. In the present study, the Pb concentration was observed 0.761 mg. kg^{-1} in *C. tripunctatus* and 0.638 $mg.kg^{-1}$ in *D. marginalis*. Aydoğan et al. (2020) reported As and Pb levels in adult *C. tripunctatus* from Aydın wetlands of 0.219 and 0.459 ppm, respectively, and *D. marginalis* from Kütahya wetlands of 0.273 and 0.566 ppm, respectively, which are quite similar to those in Table 2. Choudhury et al. (2020) reported Pb and As levels in adult *D. marginalis* 0.044 ppm and 0.014 ppm, respectively. Even lower levels of toxic metal(oid) contents have the ability to bioaccumulate and may transfer through the food chain, thus causing biomagnification in consumers. Pb and As are two of the

Table 2 Mineral profile of studied aquatic beetles (Coleoptera: Dytiscidae) ($mg.kg^{-1}$)

Insect Species	Ca	Fe	Cu	Zn	Se	Co	Cr	As	Pb
Dytiscus marginalis	1.952	1.374	0.156	0.111	0.091	0.209	0.329	0.345	0.638
Cybister tripunctatus	9.257	4.391	3.247	2.323	0.082	0.297	0.318	0.440	0.761
RDA*	1000–1300 mg/day	8–15 mg/day	700–900 µg/day	8.0–11 mg/day	40–55 µg/day	-	20–35 mg/day	-	-

*, Recommended daily allowances for adults (male and female)

main carcinogenic elements and can harm many systems in humans, such as the neurologic, hematologic, cardiovascular, and renal systems (Paz et al., 2019; Rahaman et al., 2021). According to the literature, the health benefits of nutrients provided by edible aquatic beetles have not been properly studied.

Conclusion

Modern life is completely dependent on a large range of elements for all aspects of daily life. Therefore, contamination of food products by toxic metals is becoming an unavoidable problem. The occurrence of toxic metals, such as cadmium, lead, mercury, and arsenic in air, soil, sediment, and water, contributes to their presence in biological organisms and is enriched through the food web. Aquatic insects have the ability to accumulate elements and are used for biomonitoring studies. Exposure to heavy elements may cause blood, skin, teeth, and bone disorders, kidney, or liver damage, causes neurological damage, and decreased mental capacity. Therefore, heavy elements need serious attention.

Insects are a rich source of elements; thus, dieticians recommend eating insects in Africa, where Zn and Fe deficiency is common in women. From a nutritional perspective, these edible insects can be used as nutrient supplements. As there is a potential for insects to bioaccumulate chemical substances, it is, therefore, necessary to control the levels of these toxic elements in food to protect human health. The potential of insects to bioaccumulate chemical substances must be seriously investigated because when insects are used as food or feed, this may pose a risk for people.

According to the aforementioned literature, using insects as food and feed contributes to good health and well-being; reduces hunger and poverty; responsible consumption-production; climate action under the sustainable development goals (SDGs 1, 2, 3, 9, and 12). Aquatic edible beetles could potentially be an alternative nutrient and offer a unique solution for hunger and malnutrition in parts of the world where other viable nutrients are unavailable. The results on element content (Table 2) confirm the claims of other studies that, in general, beetles are good sources of elements. In addition, with the present study, knowledge gaps in aquatic beetle taxonomy were updated, and some misspelled taxonomic names were corrected and given (Table 1). The study recommends that standardized cultivation methods may be safe consumption methods for insects to minimize the presence of heavy metal(oid)s, pesticides, microplastics, etc. In addition, cultivation methods will conserve insect population sustainability.

Author contribution This is a single-author paper. Zeynep Aydoğan performed the element analysis via the EAHTARC, drafted the article, and revised the literature critically. The author confirms the sole responsibility for design, literature collection, interpretation, and manuscript preparation.

Availability of data and materials 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.

Declarations

Ethics approval I hereby affirm that the content of this manuscript is original. Furthermore, it has been neither published elsewhere fully or partially nor, in any language, nor submitted for publication (fully or partially) elsewhere simultaneously. All data generated or analyzed during this study are included in this article. The author has read, understood, and has complied, as applicable, with the statement on "ethical responsibilities of authors" as found in the instructions for authors and is aware that, with minor exceptions, no changes can be made to authorship once the paper is submitted.

Consent to participate The manuscript does not report on or involve the use of any animal or human data or tissue thus, it does not need to "consent to participate."

Consent for publication The manuscript does not contain data from any individual person; therefore, it does not need "consent for publication."

Competing interests The authors declare no competing interests.

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