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REVIEW ARTICLE

Edible dragonflies and damselflies (order Odonata) as human food – A comprehensive review

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Abstract

The rapid growth of the human population leads to a big concern about the food y and demand worldwide. However, due to the reduction in global arable land area, humans need to find alternative food sources to fulfil their needs. Consequently, edible insects have been identified as a promising solution to ameliorate food security and increase global nutrition. Among more than 2,100 identified edible insect species, dragonflies and damselflies (order Odonata) are considered as one of nutritious food resources. Nevertheless, detailed information on the frequency and distribution of consumption of odonatans around the world is scattered and poorly documented. Based on this review, at least 61 out of 1,964 species of odonatans were reported consumed by people worldwide. The most consumed dragonflies (suborder Epiprocta; infraorder Anisoptera) are from the family of Libellulidae, followed by Aeshnidae and Gomphidae, whereas the most consumed edible damselflies (suborder Zygoptera) are from the Coenagrionidae family. Many nutrients, including proteins, lipids, energy, fibre, vitamins, and minerals are abundant in edible odonatans. Moreover, studies reported that humans employed these insects as therapeutic agents to remedy various ailments. Challenges associated with the consumption of edible odonatans include safety concerns, legal frameworks, and limited information on their bioecology which become barrier for their successful mass-rearing. However, because entomophagy is gradually gaining recognition, new and more improved methods of rearing are now being developed including for edible odonatans, encouraging sustainable insect farming. As the

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world strives to achieve the sustainable development goals, insect farming will pave a way for resources to be utilised for sustainable economic development.

Keywords

edible insect – Anisoptera – Zygoptera – mass-rearing – entomophagy – sustainable

1 Introduction

The world population is predicted to reach more than 8 billion people at the end of 2022 (United Nations, 2022a). This number is estimated to grow and reach a peak of around 10.4 billion people in 2080 and expected to remain at that level until 2100 (United Nation, 2022b). The rapid growth of human population then leads to a major concern on the food supply and demand worldwide. However, in order to fulfil the human needs, many agricultural lands were transformed into human settlement, industrial area and recreational park. As a consequence, it has reduced the yield of agricultural production; thus, may increase the rates of food insecurity and malnutrition around the world. This is proven in a report issued by the Food and Agriculture Organization of the United Nations (FAO) as it is estimated between 702 and 828 million people in the world faced hunger in 2021 alone (FAO, 2022).

As the fertile land is scarce, humans need to boost the agriculture methods and practices to improve the crop and animal husbandry yield. In addition to that, humans also need to find the alternative food source in order to fulfil their needs. Traditionally, humans are mainly depended on crop, meat, as well as poultry and animal products such as eggs and milk as a main food source. However, the consumption of protein from animal husbandry considered as not environmentally friendly and bad for natural environment as it may contribute to climate change, such as global warming (Wanapat *et al.*, 2015). Livestock farming can produce greenhouse gases such as methane, carbon dioxide, and nitrous oxide through the destruction of forest ecosystems and farming activities (Gaitán *et al.*, 2016). Deforestation will release enormous amounts of carbon dioxide into the atmosphere (Baccini *et al.*, 2012), while animal farming creates large amounts of methane as they digest food (Abbasi *et al.*, 2012). Insect farming, on the other hand, presents a promising solution to address these issues. Insects require significantly less space, water, and feed compared to conventional livestock (Henchion *et al.*, 2017). Moreover, insect farming has a considerably lower carbon footprint compared to conventional livestock farming (Vauterin *et al.*, 2021). Furthermore, insect farming presents a potential resolution to the ethical issues associated with intensive livestock farming. The controversial treatment and confined environments of animals in conventional livestock farming have sparked significant ethical discussions (Leroy and Praet, 2017). Conversely, insect farming employs vertical farming methods that afford insects abundant room to live and mitigate stress and anguish. This approach, which prioritizes the well-being of insects, aligns with the increasing consumer interest in ethically produced and environmentally friendly food.

In this modern era, the usage of insects as the alternative food source for protein has become a new trend in food science (da Silva Lucas *et al.*, 2020). Even though insects have been part of the human diet since prehistoric era, the practice of eating insect or entomophagy has just recently gotten some spotlight among modern people. In line with the current food trend, insects are promoted as clean meat, nutritious as similar as the traditional animal meat and more importantly the method used for insect farming is proven more environmentally friendly compared to the traditional animal farming (Gamborg *et al.*, 2018; Lee *et al.*, 2020; Stull *et al.*, 2018). In addition to that, awareness about the effect of environmental issues such as deforestation, environmental pollution, water crisis and global warming on the human health also influence people to choose insect as alternative food as it can be produced sustainably, with less hazard to the environment.

The taste of insects is considered as delicious by those accustomed to eating them (Tan *et al.*, 2015). Those people stated that insects taste a lot like shellfish due to its external skeletons, while some others described insects are taste like meaty vegetable and a bit nutty, especially when roasted. Even though entomophagy was popular among Asian and African food cultures (Batat and Peter, 2020), most Westerners find entomophagy disgusting and reject the idea of adopting insects as part of food for human (Jensen and Lieberoth, 2019). However, it is estimated at least 2 billion people in 113 countries

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around the world consume insects as part of their traditional diets and nearly 2,100 species of insects have been documented as edible (Van Huis *et al.*, 2013; Van Huis, 2021). Raheem *et al.* (2019) reported that the most commonly eaten insects around the world are beetles, caterpillars, bees, ants, crickets, and grasshoppers. Ancient people believed that insects are not only important as nutritious food, but also have medicinal value. (Meyer-Rochow and Chakravorty, 2013). Nowadays, insects and products derived from them are commercialized and marketed for their nutritional value. As an example, insect protein is being used as an ingredient in a wide range of products including protein bars, snacks, baking mixes, and even beverages (Lamsal *et al.*, 2019; Melgar-Lalanne *et al.*, 2019). Among all, insect-based snacks have become quite popular. Companies such as Ento operating in Malaysia have developed products such as roasted crickets with flavors like Korean Kimchi, Texas BBQ and Singaporean Salted Egg Yolk (Today Online, 2019).

Scientific research shows that edible insects are rich in nutritional value with protein, fat, carbohydrate, vitamins and minerals at levels that meet human nutritional requirements (Kouřimská and Adámková, 2016; Zielińska *et al.*, 2015). Among those, dragonflies and damselflies (Odonata) are considered as one of the best and nutritious edible insect resources (Jiang *et al.*, 2017). As an example, the nymph of dragonfly *Pantala* sp. (Figure 1a) is not only rich in protein, fat, carbohydrate and ash, but it is also excellent in phosphorus, iron, copper, calcium and contains all essential amino acids for human consumption (Maneechan and Prommi, 2021). Similar to that, the nymph of damselfly *Lestes praemorsus* was also found to have good amount of protein and rich with different kinds of essential acid amino (Zhao, 2021). According to Macadam and Stockan (2017), there are about 58 edible species of Odonata recorded worldwide. From that number, at least 14 species of dragonflies are reported consumed by the people of India. In China, the commonly eaten dragonflies and damselflies are *Anax parthennope* (Feng *et al.*, 2018) (Figure 1b), *Crocothemis servilia* (Figure 1c), *Gomphus cuneatus* and *Lestes praemorsa* (Macadam and Stockan, 2017). These insects were eaten raw or cooked depending on local costumes. Edible odonatans were commonly harvested from wild using various techniques such as handpicking or installing simple traps (Chakravorty *et al.*, 2019). In Bali, adult dragonflies were caught using the sticky sap from jackfruit or frangipani trees; while in Laos, dragonflies were captured using a candle suspended over a dish of water. As there are difficulties to get the sustainable supplies of edible dragonflies, trials have been done to rear this insect at industrial scale, but yields have yet to be financially viable (Locklin *et al.*, 2012).

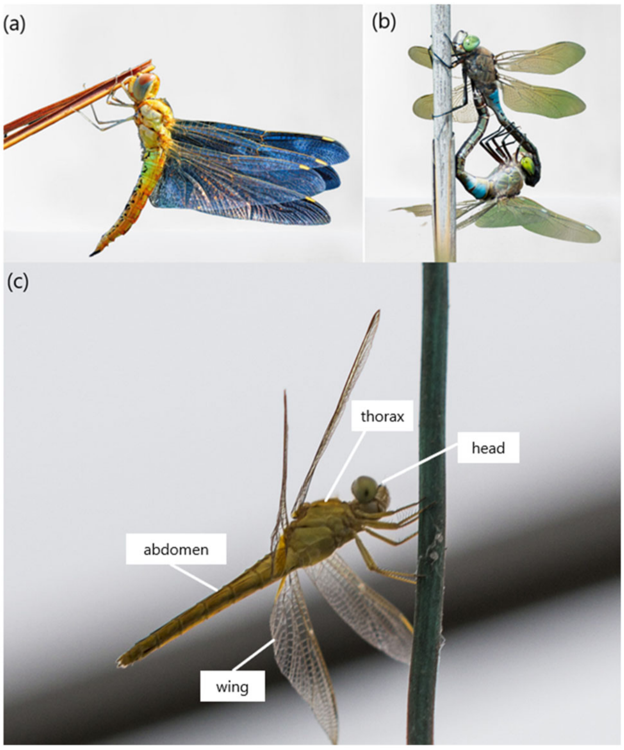

FIGURE 1 Edible dragonflies' adult (a) *Pantala* sp, (b) *Anax parthenope* and (c) *Crocothemis servilia*. Source: https://www.inaturalist.org/.

Until November 2022, there were 1,964 species of insects belonging to order Odonata which were recorded worldwide (ITIS, 2022). From that number, 8 families (1,033 species) are categorized under suborder Epiprocta; infraorder Anisoptera (dragonflies) while another 12 families (931 species) categorized under suborder Zygoptera (damselflies). Both dragonflies and damselflies (Figure 2) can be differentiated through the characteristics and morphology of their eyes, body, wing structure and their behaviour during resting activity (Bastos *et al.*, 2021). Generally, the body size of dragonflies is much larger and bulkier compared to the damselflies. However, the easiest way to differentiate both species are by observing their eyes; dragonfly eyes generally meet at the top of their head while damselflies eyes are always separated. The position of their wings while not in flight further helps tell them apart; a dragonfly's wings stick straight out while damselflies hold their wings close along the length of their abdomen.

Taking into account the limited information about the potential of both dragonflies and damselflies as alternative food for human, we have done a comprehensive review to gather all the details about this mir-

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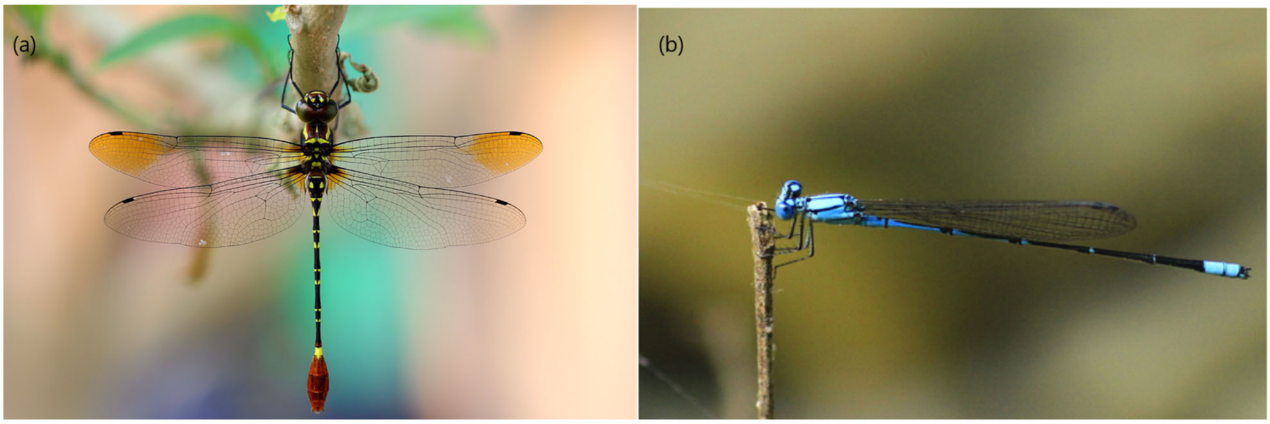

FIGURE 2 Resting position of dragonfly and damselfly. (a) *Phyllomacromia trifasciata* is a dragonfly in the family Macromiidae; (b) *Pseudagrion calosomum* is a damselfly in the family Coenagrionidae. Source: https://www.inaturalist.org/.

acle insect for the benefits of science. This review paper begins with the info's on the distribution of dragonflies and damselflies consumed worldwide. We then discussed about the nutritional composition and benefits of both insect species on human health especially in terms of medicinal uses. The legal status on the consumption of these insects around the world was also discussed. The barriers and challenges associated with the consumption of these odonatan insects were also reviewed in this paper. At the end of the paper, we have discussed the potential of dragonflies and damselflies farming activity and gathered the information of odonatan insect cooking methods in different countries around the world. We believe all this information will benefit society and guarantee food security.

2 Distribution of dragonflies and damselflies consumed worldwide

To date, detailed information on the frequency and distribution of the consumption of odonatans around the world is poorly documented. Most of the research related to dragonflies and damselflies only focussed on the taxonomy and biology of these insect species with some research done on the importance of these insects for environmental assessment. The research on the entomophagy of odonatans is also scarce. Most of the reports are from Asian and African countries as both continents are well known to practice entomophagy. However, we managed to dig out some information regarding the distribution of edible dragonflies and damselflies consumed worldwide through the citizen science observation as reported in the iNaturalist website. iNaturalist is an online social network of people sharing biodiversity information to help each other learn about nature. It is also a crowdsourced species identification system and an organism occurrence recording tool. Since its launching in 2008, this website was used by many researchers around the word for their scientific study on the distribution of many types of organisms such as plants and insects (Mesaglio and Callaghan, 2021; Unger *et al.*, 2021; Wilson *et al.*, 2020).

In our comprehensive literature review search, only 61 out of 1,964 species of odonatans were reported consumed by people worldwide (Supplementary Table S1). The most consumed dragonflies are from the family of Libellulidae with 33 species followed by Aeshnidae (9 species) and Gomphidae (7 species). In addition to that, the most edible damselflies are from Coenagrionidae family (5 species). In the suborder Anisoptera (dragonflies), there is no report on the edible odonatan species from the Austropetaliidae, Cordulegastridae, Neopetaliidae and Petaluridae family. These 4 odonatan families have a low number of identified species, thus may influence the findings. In addition, only 8 species of odonatan insects from the suborder Zygoptera (damselflies) were reported edible. These 8 species were represented by 4 families which are Calopterygidae (1 species), Coenagrionidae (5 species) Megapodagrionidae (1 species) and Lestidae (1 species). As mentioned before, the body size of damselflies is smaller compared to the dragonflies; thus, may influence the human preference towards which insect species will be chosen for consumption.

Our comprehensive data collection from the iNaturalist website shows that 43 out of 61 species of edible dragonflies were observed in Asia continent (Supplementary Table S2). Nine species of odonatans which are *Aeschna* sp., *Argia* sp., *Ceriagrion* sp., *Crocothemis servilia*, *Diplacodes trivialis*, *Enallagma* sp., *Ischnura* sp.,

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Leucorrhina sp., *Libellula pulchella*, *Pachydiplax* sp., *Pantala flavescens* and *Sympetrum striolatum* were observed more than 10,000 times by the citizen science since the year of 2008. From all 61 species of edible dragonflies identified, only the *Ischnura* sp. (Zygoptera: Coenagrionidae) were found distributed in all continents in the world.

The information on the distribution and biodiversity of these edible odonatans has given the first insight on the link between location, species richness and human cultural factors that may influence the entomophagy around the world. This information may explain some of the demographic factors that influence people around the world to practice entomophagy. It then will give some idea to understand the research related to the entomophagy among people at different locations especially when investigating the factors that may influence the acceptance and perception of humans towards the future of insects as alternative food for human survival.

3 Nutritional composition of dragonflies and damselflies

Nutritional problems are accepted on a global scale as the leading cause of death (de Carvalho *et al.*, 2020). According to studies, insects might, in the near future, provide a solution to the needs that are now being met because they are a rich source of protein, fibre, and fatty acids (de Castro *et al.*, 2018). The nutritional content of many insects has been researched globally as they are a fantastic source of nutrition for both humans and animals (Ordoñez-Araque *et al.*, 2022). The importance of insects as a source of macro and micronutrients, including protein, lipids, amino acids, fatty acids, minerals, and vitamins, is well established and the nutrients are enough to meet human nutritional needs (Feng *et al.*, 2018). Each species' nutritional levels may differ depending on several variables, including its stage of development, environment, feeding practices, and method of processing (Ordoñez-Araque *et al.*, 2022). In addition to being a significant source of nutrition, edible insects have some environmental benefits over consuming meat, i.e. (i) less damage to the environment as a result of decreased greenhouse gas emissions, (ii) less need for land during production, (iii) an alternate and effective biological control strategy for the production of agricultural crops, and (iv) environmental sustenance while preserving the diversity of habitats for various living types. Hence, intake of edible insects along with their preservation can improve health and the environment as a whole and promote long-term usage of this valuable bioresource (Mozhui *et al.*, 2020). Eating edible insects is healthier, tastier, sustainable, and ecologically friendly when compared to eating other types of food (Zhou *et al.*, 2022).

The orders of insects that are most often consumed globally include Blattodea (cockroaches and termites), Coleoptera (beetles), Diptera (flies), Odonata (dragonflies and damselflies), Orthoptera (grasshoppers, crickets and locusts), Hemiptera (true bugs), Hymenoptera (bees, ants, and wasps), Lepidoptera (butterflies, caterpillars and moths), and Mantodea (mantis) (Ordoñez-Araque *et al.*, 2022; Zhou *et al.*, 2022). According to studies, dragonflies and damselflies are consumed worldwide in northern Italy (Fontaneto *et al.*, 2011), India (Mozhui *et al.*, 2020), China (Feng *et al.*, 2018), Thailand (Maneechan and Prommi, 2021), Indonesia, Venezuela, Japan, Ecuador, Mexico, Madagascar, Myanmar, Vietnam, USA and South Korea (Fontaneto *et al.*, 2011). Dragonfly nymphs from six to seven different species can be eaten, from which *Anax parthenope* (Maneechan and Prommi, 2021), *Lestes praemorsa*, *Gomphus cuneatus*, and *Crocothemis servilia* are the prevalent species (Chen *et al.* 2009). Although dragonflies are consumed in both their adult and nymphal stages, nymphs are preferred. Many nutrients, including proteins, lipids, energy, fibre, vitamins, and minerals are abundant in dragonflies and damselflies.

Proximate composition

Table 1 shows the proximate composition of different species of dragonflies and damselflies. Protein is a necessary component of human health that gives the body energy when it is required (Zhou *et al.*, 2022). One factor that makes edible insects a viable substitute for traditional animal-based sources is their high protein content. Insects such as dragonflies and damselflies are used as food and play a significant part in the diets of the many ethnic communities worldwide (Mozhui *et al.*, 2020). In general, dragonflies are great sources of protein (45% to 76%) (Ordoñez-Araque *et al.*, 2022), which is more than that of traditional meat from animals (Zhao *et al.*, 2021). Data on the protein content (Table 1) showed that *Sympetrum* species contains the highest amount of protein (76.75%) (Narzari and Sarmah, 2017), whereas *Pantala sp.* contains the lowest (45.14%) (Maneechan and Prommi, 2021).

Lipids are the most representative macronutrient after proteins. The body receives a lot of energy and necessary fatty acids from insects' lipids. Insects can have up to 50% of fat to their dry weight (Ordoñez-

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TABLE 1 Proximate composition of some edible odonatans

Species	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Moisture %	Total carbohydrate %	Total energy (Kcal/ 100 g)	Reference
Anisoptera (Dragonlfy)								
Aeschna multicolor	54.24	16.72	12.85	9.96		6.23		Rumpold and Schlüter, 2013
Anax parthenope	65.76	22.93	4.21	13.62		3.02	431.33	Rumpold and Schlüter, 2013
Crocothemes servillia	70.48		1.34	9.62	13.46	1.18	496.78	Devi *et al.*, 2023; Shantibala *et al.*, 2014
Epophthalmia elegans	65.23							Zhao *et al.*, 2021
Gomphus cuneatus	64.64							Zhao *et al.*, 2021
Ictinogomphus rapax	62.37							Zhao *et al.*, 2021
Orthetrum pruinosum	71.53							Zhao *et al.*, 2021
Pantala sp.	45.14	4.93	5.24		35.11	9.60	263.25	Maneechan and Prommi, 2021
Sinictinogomphus clavatus	63.34							Zhao *et al.*, 2021
Sympetrum sp.	76.75	4.53	5.11		1.61	12.00	395.77	Narzari and Sarmah, 2017
Zygoptera (Damselfly)								
Lestes praemorsus	46.37							Zhao *et al.*, 2021

Araque *et al.*, 2022; Zhou *et al.*, 2022). Insect lipids contain mostly cholesterol and phospholipids, with around 80% of their total lipid content made up of fatty acids (Ordoñez-Araque *et al.*, 2022). Arachidonic and eicosapentaenoic acid concentrations of the dragonfly *Gomphus vulgatissimus* eaten in Italy range from 0.3 to 0.6 mg/g of dry insect (Fontaneto *et al.*, 2011).

In a study done by Maneechan and Prommi (2021) and Maneechan *et al.* (2022), they used the whole dragonfly insect (*Pantala sp.*) in their final instar nymphal stage for analysis of the nutritional composition. It has been found that the carbohydrate content of odonatans (1.8 to 9.6%) is low in comparison to the primary sources of energy for people and other animals (Maneechan *et al.*, 2022; Shantibala *et al.*, 2014) as demand for human is of about 260 g/day (Maneechan and Prommi, 2021). According to Rumpold and Schlüter (2013), dragonflies and damselflies in their nymphal stage contain only 4.63% NFE (nitrogen-free extract), a frequently used measurement of carbohydrates other than fibre. However, fibre is present in significant proportions, serves as a measure for the carbohydrate content (Illa and Yuguero, 2022). Chitin, mainly found in their exoskeleton, is the most widely distributed fibre. Chitin is related to improvement of the immune system, a decrease in allergic reactions in humans, and strong resistance against parasite diseases (Mohan *et al.*, 2020; Zainol *et al.*, 2020). The dragonfly *Anax imperator* is reported to contain on an average 11.00%-12.00% chitin and 67.00% of chitosan in their larval stage (Kaya *et al.*, 2014). An excellent source of energy is provided by insects, which have 400-500 kcal per 100 g of dry matter (Maneechan and Prommi, 2021). Two species of dragonfly *Pantala* sp. and *Crocothemes servillia* are found to contain total energy of 263.25 Kcal/100 g and 496.78 Kcal/100 g, respectively, in their nymphal stage of the whole insect (Maneechan and Prommi, 2021; Shantibala *et al.*, 2014). These edible insects' macronutrient content reflects their gross energy value, which is also impacted by other parameters including nutrition and sex. As

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TABLE 2 Fatty acid composition of some edible odonatans

Species	Lipid (%)	Fatty acid composition (% of total fatty acids)			References
		SFA	MUFA	PUFA	
Anisoptera (Dragonlfy)					
Anax parthenope	11.06	34.68	27.85	27.85	Jiang *et al.*, 2017
Crocothemis servilia	4.93	–	–	–	Shantibala *et al.*, 2014
Epophthalmia elegans	9.14	33.73	32.84	21.05	Jiang *et al.*, 2017
Ictinogomphus rapax	10.59	30.11	35.75	20.33	Jiang *et al.*, 2017
Inictinogomphus clavatus	11.9	34.43	42.28	17.75	Jiang *et al.*, 2017
Orthetrum pruinosum	11.9	34.97	31.53	26.70	Jiang *et al.*, 2017
Pantala flavescens	10.4	32.3	33.07	27.51	Jiang *et al.*, 2017
Sympetrum sp.	–	50.62%	–	49.36%	Narzari and Sarmah, 2017

SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids.

compared to adults, nymphs are often higher in energy (Kouřimská and Adámková, 2016).

Fatty acid composition

The fatty acid composition of different species of dragonflies and damselflies containing saturated fatty acid (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) are listed in Table 2. The fat content of dragonflies varies from 4.93% to 11.9% which are again higher than that of pork (2.2%), beef (8.7%), chicken (2.6%), and fish (salmon) (4.7%) (Liceaga, 2022). Odonatan larvae are a rich source of SFAs, MUFAs, and PUFAs as that of common meat of pork, beef, chicken, fish or milk. The content of unsaturated fatty acids (UFA), palmitic acid, and oleic acid in the oil of their nymphs is high. The oil includes 1.23%-7.05% odd carbon fatty acids (OCFA), which resemble ordinary insect oil in their properties (Zhao *et al.*, 2021). 18 to 29 different types of fatty acids, such as long-chain PUFAs, Eicosapentaenoic acid (EPA), and docosahexaenoic acids (DHA), are present in the oil of dragonflies (Jiang *et al.*, 2017). In dragonfly *Pantala* sp., total SFA concentration is highest, followed by MUFA and PUFA. SFA concentrations varied from 10 mg/100 g to 1,300.00 mg/100 g (Maneechan and Prommi, 2021), whereas for the pork, beef, chicken, egg and milk it is 2.7, 1.7, 0.76, 3.1, 2 g/100 gm, respectively (Illa and Yuguero, 2022). The UFA made up 61.50% to 65.22% of all fatty acids, PUFA made up 29.57% to 50% of all UFA. Hexadecanoic acid had the highest concentrations, ranging from 17.57% to 24.61%. The ratios of n-6 to n-3 PUFA is 0.68 to 1.30, which are comparable to freshwater fish oils (Jiang *et al.*, 2017). Maneechan and Prommi (2021) found that the most prevalent fatty acid in *Pantala sp.* is palmitic acid, which is followed in abundance by stearic acid, cis-9-oleic acid, and linolenic acid. The odonatan species in rice fields had an EPA greater than the five terrestrial insects consumed in South Korea when compared to those reported by Ghosh *et al.* (2017). Jiang *et al.* (2017) in their study found the oil contents of six different kinds of dragonfly naiads were 5.72%-11.90% with *Sinictinogomphus clavatus* containing highest oil content, whereas *Orthetrum pruinosum neglectum* containing the lowest. The total PUFA concentration of *Pantala* sp. is higher than that of some edible insects like beetles (516.73 mg/100 g), termites (465.06 mg/100 g), and crickets (771.63 mg/100 g) and to raw meats like mutton (673 mg/100 g) and beef (448 mg/100 g). Hence, direct ingestion of edible Odonata may considerably reduce the need for good fat in humans (Maneechan and Prommi, 2021).

Amino acid composition

The different species of odonata are found to contain excellent protein content in the range of 45.14% (*Pantala sp*) to 76.75% (*Sympetrum* sp.) which is higher when compared to that of beef (22.5%), pork (21.0%), chicken (22.2%), fish (22.2%) (Liceaga, 2022), eggs (12.5%), and milk (3.3%) (Illa and Yuguero, 2022; Maneechan and Prommi, 2021). Hence the protein from dragonflies can replace the other regularly eaten meat species as it can fulfil the daily requirement of protein for adult which is 50 g/day. Protein is made up of 20 amino acids, however eight of them cannot be produced by the body and must be ingested from outside sources in order to fulfil nutritional needs. It is interesting to note that proteins from dragonflies have all the necessary amino acids. Moreover, studies revealed that the proteins from dragonflies

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not only include the necessary amino acids but also contain a good balance of various amino acids (Zhou *et al.*, 2022). Zhao *et al.* (2021) studied the content of the necessary amino acids in dragonfly nymphs from various geographic locations and discovered that there is minimal variation, even between distinct species. Dragonflies contain essential amino acids (EAAs) as well as non-essential amino acids (Supplementary Table S3). The essential amino acids include methionine, threonine, lysine, tryptophan, leucine, isoleucine, valine, phenylalanine and histidine. Valine is the most prevalent amino acid among the EAAs. Arginine and Glutamic acid are the most prevalent amino acid among non-essential amino acids. Compared to traditional animal sources, dragonfly species have much higher concentration of essential amino acids (Maneechan *et al.*, 2022). In different species of dragonflies, the concentration of essential amino acids, lysine (up to 8.37%), histidine (up to 6.93%), and methionine (up to 4.07%) are found higher compared to those found in regularly eaten meat species including beef (1.94 g/100 g of lysine, 0.82 g/100 g of histidine and 0.61 g/100 g of methionine), pork (1.80 g/100 g of lysine, 0.82 g/100 g of histidine and 0.59 g/100 g of methionine), and chicken (1.79 g/100 g of lysine, 0.69 g/100 g of histidine and 0.62 g/100 g of methionine) (Amadi and Kiin-Kabari, 2016). According to the investigations by Maneechan and Prommi, (2021) *Pantala* sp. has higher lysine and histidine concentrations which are greater than those found in regularly eaten meat species like chicken, beef, pork, etc.

Amino acids play a critical role in the metabolism of man and their presence in dragonflies makes the insect a good source of protein. For example, *Gomphus cuneatus* is a good source of isoleucine which the body can use during exercise. The amino acids found in the different odonatans include valine, leucine, isoleucine and others. They are predominantly used in repair or worn or damaged tissues and in enzymatic functions (Table 3).

Vitamins and minerals

The vitamins and minerals found in insects are an additional crucial element of their nutrition. Minerals and vitamins are necessary for both human and animal metabolism (Kinyuru *et al.*, 2015), and their deficiency may lead to various diseases like anaemia, iodine deficiency goitre, growth retardation, inflammatory bowel disease, etc. (Fritz *et al.*, 2019; Rempel *et al.*, 2021; Zhou *et al.*, 2022). Dragonflies and damselflies contain vitamin C, thiamin, riboflavin, pantothenic acid, niacin, pyridoxine and vitamin B12. In general, dragonflies are a good source of B vitamins (Ordoñez-Araque *et al.*, 2022). Dragonflies are found to contain up to 30 mg/kg of vitamin C, 34.1 mg/kg of vitamin B2, 38.4 mg/kg of B3 and 23 mg/kg B5 and 54 ug/Kg of vitamin B12 (Ordoñez-Araque *et al.*, 2022).

Dragonflies are also a good source of minerals, such as iron, calcium, phosphorus, potassium, zinc, copper, magnesium, and manganese (Table 4). As compared to the composition of meat, dragonflies contain higher levels of these minerals, regardless of species (Ordoñez-Araque *et al.*, 2022). The iron content of *Pantala* sp. is 788.8 mg/kg which is higher than the content found in other species like *Anax parthenope*, *Epophthalmia elegans*, *Crocothemes servillia*. Moreover, *Pantala* sp. has a calcium content of 206.03 mg/100 g, which is higher than the calcium content of all edible insects reported by Shantibala *et al.* (2014), Narzari and Sarmah (2017) and Rumpold and Schlüter (2013). In the human body, calcium is the most prevalent mineral, making about 1.5%-2% of the total weight in the form of bones and teeth. Those who do not get enough calcium may develop osteoporosis. Eating dragonflies like *Pantala* sp. might be a source of calcium to supplement the diet in cases of calcium deficiency (Maneechan and Prommi, 2021). In China, dragonflies are frequently eaten as a delicacy because of their high selenium concentration. The selenium content in two dragonfly species *A. parthenope* and *E. elegans* are reported to contain 0.193 mg/kg and 0.223 mg/kg of dry weight, respectively (Jiang *et al.*, 2017; Zhao *et al.*, 2021). Table 5 shows the different minerals and which dragonfly species they can be found in. Table 5 also shows the importance of several minerals in humans and these include cognitive functions, cell functions, metabolism and repair of tissues.

The nutritional composition of different insects, even in the same species, are different due to some internal factors i.e. diet, sex, species, developmental and physiological state for sample analysis as well as external factors i.e. season, environmental temperature, geographic location, migratory flight, techniques employed, etc. (Illa and Yuguero, 2022; Zhao *et al.*, 2021). Highly unsaturated fatty acid (HUFA) concentration in aquatic insects (odonatan larvae) is greater than in terrestrial insects, particularly the EPA level, since they eat diatoms and freshwater algae, which are particularly abundant in HUFA and EPA (Zhao *et al.*, 2021).

4 Medicinal uses of dragonflies and damselflies

From ancient times, numerous cultures throughout the world have employed insects and items produced from

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TABLE 3 Amino acids found in some edible odonatans and their functions in human health (Solano, 2020)

Species	Amino acid found in dragonfly/damselfly	Function of amino acid
Ictinogomphus rapax	Valine	It is an energy source during intense exercise
Gomphus cuneatus	Isoleucine	It increases proteins and serves as an alternate source of energy during exercise
Crocothemis servilia	Leucine	It provides energy during intense exercise
Crocothemis servilia	Lysine	It is an essential amino acid used for the formation of collagen
Ictinogomphus rapax	Tyrosine	It is used in the production of useful amines
Crocothemis servilia	Threonine	It is used in the formation of enzyme active sites
Ictinogomphus rapax	Phenylalanine	It is used in the synthesis of useful amines
Crocothemis servilia	Tryptophan	It is used in the production of useful amines
Gomphus cuneatus	Histidine	It is an essential amino acid for the production of histamine and other amines
Gomphus cuneatus	Methionine and Cysteine	It is used in the production of useful amines but cysteine may be deficient in infants
Pantala flavescens	Arginine	It maintains normal functions of blood vessels and other organs
Gomphus cuneatus	Serine	It regulates appetite and is used in the production of phospholipids and glyceric acid
Gomphus cuneatus	Glutamine	It efficiently provides energy and regulates appetite and cell signalling
Gomphus cuneatus	Glycine	It is used in the synthesis of glutathione and porphyrin, which is part of haemoglobin
Crocothemis servilia	Alanine	It serves as an energy source for the liver and regulates appetite
Anax parthenope	Proline	It is used in the synthesis of collagen and other tissues; used as energy source

TABLE 4 Mineral content [mg/kg, DM] of some edible odonatans

Species	Ca	Mg	K	Na	Fe	P	Mn	Cu	Zn	Se	References
Anisoptera (Dragonfly)											
Anax parthenope	124.96	116.9	1591.9	1339.76	158.210	–	6.790	4.180	74.77	0.193	Zhao *et al.*, 2021
Crocothemes servillia	865.0	370.0	2680.0	14,100.0	113.0	–	–	19.0	93.0	–	Zhao *et al.*, 2021
Epophthalmia elegans	90.11	101.8	1350.79	1372.49	22.640	–	12.050	2.460	40.410	0.223	Zhao *et al.*, 2021
Pantala sp.	2060.3	731.3	6252.6	5572.4	788.8	5003.0	–	13.4	50.1	–	Maneechan and Prommi, 2021
Sympetrum sp.	20.50	22.0	1690.05	240.80	13.50	626.78	–	2.00	0.50	–	Narzari and Sarmah, 2017

Mineral compositions (mg/kg) of Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, Fe = iron, P = phosphorus, Mn = manganese, Cu = copper, Zn = zinc, and Se = selenium, DM = Dry matter.

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TABLE 5 Some minerals found in some edible odonatans and their effect on human health (Maathuis, 2009)

Mineral	Odonatan containing mineral	Effect on human health	References
Potassium	*Pantala* sp.	It helps maintain normal levels of fluids inside the cell	Maathuis, 2009; Weyh, 2022
Sodium	*Crocothemis servilia*	It helps maintain normal levels of fluids outside the cell	Maathuis, 2009; Weyh, 2022
Phosphorus	*Sympetrum* sp.	It is needed for growth, maintenance and repair of damaged cells	Maathuis, 2009
Calcium	*Gomphus cuneatus*	It builds bones and teeth, helps in blood clotting/muscle contraction, regualtes heart rhythms	Maathuis, 2009; Nasirian and Irvine, 2017
Magnesium	*Pantala* sp.	It is involved in enzymatic reactions, energy metabolism, protein synthesis	Maathuis, 2009; Weyh, 2022
Iron	*Lestes praemorsa*	It is used in the formation of haemoglobin	Maathuis, 2009
Zinc	*Sympetrum* sp.	Creation of DNA, building proteins, healing damaged tissue, boosting immune system	Maathuis, 2009; Nasirian and Irvine, 2017
Copper	*Pantala* sp.	Works with iron in formation of red blood cells	Maathuis, 2009

them as therapeutic agents (Siddiqui *et al.*, 2023). Earlier, people have used insects as medicine, and now researchers are looking into them and attempting to find new uses for their natural components (Bairagi, 2019). With the enormous diversity of the insect species, it can be a treated as a promising field for drug discovery (Ouango *et al.*, 2022). In many regions of the world, including India, China, Korea, Brazil, South America and Africa, traditional medicine is still used along with proper documented information on medicinal insects (Verheyen *et al.*, 2021). Insects are and will continue to be a valuable source for the development of novel medications (Feng *et al.*, 2009). But, to do so effectively, one must have a thorough understanding of the medicinal insects, their chemical constitution, and their prospective uses (Ouango *et al.*, 2022). In general, insects may be considered a source to produce medications with antibacterial, immunological, analgesic, anaesthetic, diuretic, anti-rheumatic qualities (Chakravorty *et al.*, 2013), for the treatment of nocturnal emissions, burning and gastroenteritis, fevers (Dev *et al.*, 2020), coughs and colds, stomach disorders, malaria, skin allergies, scabies, boils, blood pressure anomalies (in case of humans) and mouth and foot disease of bovids and cattle (Chakravorty *et al.*, 2011). Different body parts of insect are used as traditional medicine like the whole body, insects' secretions, eggs, and egg shells, etc. (Feng *et al.*, 2009). Extracts obtained from insects act as one of the important medicinal agents.

From ancient times, edible aquatic insects such as dragonflies, damselflies, water striders, and whirligig beetles have been used in medicine or to treat human ailments (Chakravorty *et al.*, 2011; Meyer-Rochow, 2017). According to traditional Chinese medicine, aquatic insect provides benefits for the kidney, replenish the essence, moisten the lungs, and soothe coughs. The dried adult dragonfly body can be used to treat impotence, nocturnal emission, sore throat, and whooping cough. They can be used alone or in conjunction with other substances for medicinal uses (Zhao *et al.*, 2021). Mozhui *et al.* (2021) investigated the traditional use of medicinal insects among the ethnic communities of Nagaland, a state in North-Eastern India. In the survey they found that, in terms of fidelity level (FL) value, dragonfly nymphs were the top insects for both ophthalmological issues like conjunctivitis (FL = 51.5%) and skeleton-muscular disorders like body pains (FL = 60.9%). Dragonfly nymphs are used for wound healing as well as the treatment of body pains, colds, and ophthalmological issues. For instance, the Meitei community of Manipur, a state in North-Eastern India with a large Naga population, has also reported using cooked dragonfly nymphs for wound healing (Mozhui *et al.*, 2021). A study conducted by Kemprai *et al.* (2022) in Dima Hasao District of Assam in India

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found that the dragonfly species *Diplacodes trivialis*, *Crocothemis servilia*, *Neurothemis fulvia*, *Orthetrum pruinosum neglectum*, *Orthetrum sabina*, *Orthetrum triangulare*, *Pantala flavescens*, and *Potamarcha congener* are used in the treatment of respiratory and gastrointestinal issues by several tribes of that area. They also employ dragonfly nymphs to cure body aches, colds, ophthalmological issues, and wounds (Kemprai *et al.*, 2022). The Ao-Naga people of North-East India employ two species of dragonfly nymphs viz. *Acisoma panorpoides* and *Aeshna petalura* to produce tonics that are used for anaemia treatments and as blood purifiers. The use of dragonflies as a cure for asthma and urinary issues is also common in traditional medicine (Meyer-Rochow, 2017). However, dragonflies are feared among the Hausa and Ngambaye in Africa since it is believed that they might cause seizures and disorientation (Meyer-Rochow, 2017). Other medicinal uses of dragonflies and damselflies are listed in Supplementary Table S4.

It has been demonstrated in the literature that the consumption of PUFA has various health advantages, such as increased cognitive development and the reduction in glucose tolerance, hence reducing the risk of diabetes, lowering blood pressure, and avoiding insulin resistance (Ayensu *et al.*, 2019). Dragonfly and damselfly fats have been shown to be rich in PUFA such as linoleic and α-linolenic acids; and chitin and chitosan (Bernard and Womeni, 2017; Womeni *et al.*, 2009), which may beneficially influence these conditions. Diets containing a high level of PUFA may be utilised to reduce cardiovascular problems that are related to diabetes. Dragonflies possess a considerable amount of this fatty acid which potentially implies that inclusion of dragonfly species in diets may have possibilities for the therapy of certain coronary heart problems (Womeni *et al.*, 2009).

Linoleic acid (LA) is shown to be present in *Pantala* sp. with a quantity of 363.33 mg/100 g. Because LA is the precursor of arachidonic acid, which is the precursor of prostaglandin E2 and is involved in the control of gene expression, LA is crucial for humans. Furthermore, serving as a structural element of cell membranes, LA is crucial for cell signalling (Maneechan and Prommi 2021).

Homeopathy is an alternative style of treatment that makes use of extremely diluted compounds that are thought to make healthy persons have symptoms that are comparable to those shown by patients (Ernst, 2002). The homeopathic dragonfly *Anax imperator* medicine is intended to treat attention deficit hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), headache, sinusitis, and influenza. In addition, it produced hyperactivity and weight loss in naive mice and had antidepressant, anxiolytic, and analgesic effects (Mutlu *et al.*, 2015). Using the Morris water maze (MWM) test, Mutlu *et al.* (2016) investigated the effects of *A. imperator* remedy on learning and memory. In the MWM test, the results revealed that a homoeopathic dragonfly boosted learning immediately but interfered with memory and learning when used chronically and cell damage was improved as compared to control group. Findings revealed that dragonfly had positive effects on abnormal cell morphology and can hinder learning acquisition and reference memory (Mutlu *et al.*, 2016). In a related study, Mutlu *et al.* (2015) shown that *A. imperator* affected the expression of the NPY1 receptor in naive mice during the forced swim test (FST), hot plate (HP) test, elevated plus-maze (EPM) test, and open field test. The findings showed enhanced time spent in open arms during the EPM test, decreased immobility time during the FST test, reduced time of licking the hind feet by mice in the HP test, and increased the time and speed of moving by mice as compared to the control group in the open-field test. Results also showed the significant weight loss in mice, decreased NPY1 and NPY2 receptor expression (Mutlu *et al.*, 2015).

5 Legal situation on edible insects being eaten as food in different countries

In many societies throughout the world, insects are a common category of traditional foods, and they have had a significant impact on global human nutritional needs. At least 113 nations are thought to use insects as food, and more than 2,100 insect species have been identified as edible. Presently, 11 European nations, 14 Oceanian nations, 23 American nations, 29 Asian nations, and 35 African nations consume insects. The top consuming nations and those with the most species are Mexico, China, Thailand, and India (Baiano, 2020). In markets, supermarkets, festivals, private parties, and occasionally even online, insects are offered for sale as food. The availability of edible insects has increased significantly in recent years compared to a few years ago. Many businesses and research initiatives are investigating the most effective approach to include insects in the diet (Belluco *et al.*, 2017). Despite their widespread intake and the advantages associated with it, promoters of edible insects must struggle with two significant obstacles (Lotta, 2019). Firstly,

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a large portion of the population believes that finding novel ways to include insects in the human diet has been a top concern and topic of discussion. Secondly, a lack of clear regulations for this new cuisine might discourage companies from raising and marketing insects as food, because it may increase the cost and time (Belluco *et al*., 2017). According to the Insect Food Business Operators (iFBOs), the market for edible insects would grow to 260,000 tonnes by 2030 from its current 500 tonnes. In terms of consumption globally, beetles (Coleoptera) are the most often consumed species, followed by caterpillars (Lepidoptera) (18%), honey bees, wasps, and ants (Hymenoptera) (14%), and grasshoppers, locusts, and crickets (Orthoptera) (13%). Hemiptera, Isoptera, Odonata, and Diptera are the remaining species (Carcea, 2020). In order to contribute to food safety and quality on a global scale, the Codex Alimentarius offers a set of guidelines, benchmarks, and rules of conduct. Although the Codex has a significant impact on food law, it is not legally enforceable (Mariod, 2020). Laws greatly vary from one country to another (Supplementary Table S5), and most of the western nations do not even officially address insects. The largest challenge for the edible insect industry is this inconsistent legal position throughout the world since it prevents or inhibits the growth of a worldwide edible insect market (Baiano, 2020).

European countries

In the European Union (EU), the new Regulation 2283/2015 on 'novel foods' and its implementing Regulations 2468/2017 and 2469/2017 simplified and standardised the previously undefined laws regarding edible insects. Edible insects are clearly regarded as 'novel foods' in modern society. In fact, according to Regulation 2283/2015, both whole insects and their parts fall under the definition of novel foods. Starting from January 1, 2018, approval is required before insects and insect-based goods may be sold, and the process typically takes at least 17 months (Baiano, 2020; Marberg *et al*., 2017; Stull and Patz, 2020).

The European Food Safety Authority (EFSA) is the main regulatory body for food safety in Europe. It is an independent organisation which conducts risk analyses for the security of food. Under the EC General Food Regulation 178/2002, it was created in 2002. EFSA closely collaborates with Member States to monitor European food safety and provide advice on current and emerging concerns (Belluco *et al*., 2017; Stull and Patz, 2020). The legal implications of introducing edible insects have received very little consideration in EU. The EU's stance on encouraging the breeding of edible insects is currently undetermined and appears to address many issues: Firstly, the environmental advantages of producing edible insects and secondly, the food safety (Mlcek *et al*., 2014). The European Parliament revised the Commission's first proposal to rewrite the Novel Food Regulation. This change is the result of both harmonisation regarding the selling of edible insects across all European member states and the rising popularity in edible insects as a viable source of protein. The legal categorization of edible insects as novel foods was unclear prior to the implementation of the new law (Lotta, 2019). Almost a hundred pages of amendments to the original document were accepted by the members of the European Parliament. The first set of changes related to the new innovative food regulation's goals. Only the highest degree of protection for consumer interests and for human health were added by the European Commission. Also, the European Parliament Environment Committee included the precautionary principle, animal welfare, and environmental considerations to the objectives sought by the new regulatory framework (Grmelova and Sedmidubsky, 2017). Nevertheless, these modifications also brought about a large amount of uncertainty, particularly for British businesses following the United Kingdom's withdrawal from the European Union. The future of the UK's Food Standards Agency's compliance with EFSA rules is now unknown. This may lead to more legislative independence, which would help the industry, but it might also prevent the UK edible insect industry from benefiting from future changes to EU food law (Yang and Cooke, 2021). The sale of the whole insects was not subject to the old food law in various European nations including Belgium, the UK, and the Netherlands, however, several other member states have considered both whole insects and their parts to be novel foods and as such, subject to the legislative risk assessment procedure (Lotta, 2019).

Some European nations, including Italy and Sweden, approached the subject very differently. The Italian Ministry of Health produced an explanation note in 2013 that made it clear that edible insects belong under the new food regulation since they are animal-derived products without a history of safe eating in the European Union prior to 1997. Hence, if the food company operator cannot prove that there has been a significant history of consumption, pre-marketing permission must be obtained before they may be put on the market (Lotta, 2019).

Regulation (EU) No 2017/893 brought about one of the most significant modifications in 2017 regarding

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insects used as animal feed, with the amendment of Regulations (EC) No. 999/2001 and (EU) No. 142/2011. According to the law, feeding seven different insect species to farm animals is permitted viz. common housefly (*Musca domestica*), black soldier fly (*Hermetia illucens*), lesser mealworm (*Alphitobius diaperinus*), yellow mealworm (*Tenebrio molitor*), banded cricket (*Gryllodes sigillatus*), house cricket (*Acheta domesticus*) and field cricket (*Gryllus assimilis*). These species do not spread illnesses that are specific to plants, animals or humans; they are non-invasive and they do not negatively impact crops (EFSA Scientific Committee, 2015). Regulation (EU) No 2019/1981 established a list of third countries which were permitted to export insect goods in accordance with the aforementioned Regulation (EU) No 2017/893 (Lähteenmäki-Uutela *et al.*, 2021). In November 2020, the application to recognise mealworm larvae as a new food was authorised by the European Food Safety Authority (EFSA-Q-2018-00262). The published opinion states that mealworm larvae can be used whole, dried as snacks, and pulverised, powdered in a variety of different culinary products, including baked products, protein bars, and pastas (ON-6343) (Skotnicka *et al.*, 2021)

American countries

Latin America is the second-largest market for edible insects in the world and has a long history of entomophagy. When compared to Europe and North America, the number of companies generating edible insects is still incredibly low. Due to their ecological and ethnic variety, Mexico, Brazil, Colombia, Venezuela, Ecuador, and Peru stand out as the major countries in Latin America that have the practise of eating insects. The edible insect value chain may differ significantly between nations where entomophagy is practiced and those where it is not. The key causes for this observed phenomenon may be: (i) many Latin Americans are ashamed of their cultural tradition of eating insects rather than embracing it, (ii) the supply chain-related market flaws, (iii) lack of food safety, production and commercialization regulations, and (iv) lack of governmental initiatives to advance the edible insect business for economic growth. Despite various obstacles, South America has a lot of potential for developing an insect-based business. To do this, unique items and solutions for the market should be developed using the traditional expertise associated with consuming insects (Bermúdez-Serrano, 2020).

In Northern America, good manufacturing practises (cGMP, 21CFR110) must be followed while breeding insects for human use. Until it has been granted by Generally Recognised as Safe (GRAS) certification, insect protein is considered as food additive (Lähteenmäki-Uutela *et al.*, 2018). Whereas FAP (food additive petition) is run by the government, GRAS is essentially a self-approval mechanism. There is no requirement to submit a GRAS notification for FDA assessment. The guidelines of the Association of American Feed Control Officers (AAFCO) serve as the foundation for many states' feed laws. Prior to being marketed in Canada, innovative foods must undergo safety and nutritional adequacy testing (Canada Gazette Part II, Division 28: Novel Foods, October 27, 1999) (Lähteenmäki-Uutela *et al.*, 2021). To oversee Mexico's food safety regulations, it is the duty of two government secretaries, SSA (Health Secretary) and SAGARPA (Agriculture, Cattle, Rural Development, Fishing and Feeding Secretary). The later concentrates on primary farming, and the former mostly targets processed food. Insects are not yet permitted as animal feed under Brazilian feed regulation. Allegretti *et al.* (2018) claim that Brazil frequently adheres to Codex Alimentarius criteria. In Argentina, the government has informed the emerging business that the national Food Code does not yet include insect food. The National Food Commission must receive a request to include insects in the Food Code. The National Administration of Pharmaceuticals, Food, and Medical Technologies must also approve all packaged foods (Lähteenmäki-Uutela *et al.*, 2021).

Oceanian countries

There are no separate laws or government restrictions regarding insect farming in Australia or New Zealand. For the benefit of its members, the Insect Protein Association of Australia (IPAA) has created guidelines. Typically, a novel food cannot be marketed as food or utilised as an ingredient in food until it is listed in the Standard. If it is not on the list, a request can be sent to Food Standards Australia New Zealand (FSANZ), who will conduct a pre-market safety assessment and add the new product to the list. Both Australia and New Zealand's feed production are subject to two regulations and standards i.e. The FeedSafe Standard and the New Zealand Feed Ingredients and Additive Suppliers Code of Practice (FIAAA Code of Practice). Dragonflies are permitted to be consumed in Australia but cannot be sold. (Lähteenmäki-Uutela *et al.*, 2021).

Asian countries

Usually, there is no particular law governing the production or sale of edible insects in Asian nations. The

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habit of raising and eating insects is widespread. Yet, during the 17th FAO/WHO Codex Alimentarius Coordinating Committee for Asia (CCASIA) in November 2010, one of the first project examples addressing insects as food control was presented. A Codex food standard for crickets fit for human consumption was suggested by the Lao People's Democratic Republic (Lao PDR) delegation. This proposal for the Codex Committee was developed in cooperation with the Food and Agricultural Organization (FAO) and the Ministry of Health of Laos (MoH). The plan was supported by a number of nations, including Malaysia, Thailand, and Cambodia. In order to promote the growth of the entomoculture sector in South-East Asia, AFFIA (The Asian Food and Feed Insect Association) was established in 2016 (Preteseille *et al.*, 2018). In China, huge number of edible insects which are common as food for consumption are recorded in the China Food and Drug Administration (Feng *et al.*, 2018).

Thailand is one of the world's most rapidly expanding markets for edible insects and insect protein with a 12% market share. Similar to traditional Thai cuisine, edible insect-based Thai cuisine is well-known in many other nations and offers a variety of alternatives and nutritional benefits (Jintapitak *et al.*, 2019). In an effort to promote Thai food products on the domestic market, enhance food quality and safety, and broaden access to international food markets, the Thai government introduced the voluntary Q-GAP certification programme for agricultural output in 2004 (Preteseille *et al.*, 2018). The primary regulatory organisation now enforcing Thailand's laws governing the production and eating of insects is the Ministry of Public Health. Items produced from insects that are sold locally or internationally must first have legal approval from the Food and Drug Administration (FDA). Because there are no special requirements for eating insects in Thailand, they are handled similarly to other food products under the Food Act of B.E. 2522 (1979) (Halloran *et al.* 2015).

African countries

Due to several difficulties, food safety rules regarding edible insects are not effectively implemented throughout Africa. These issues include the following: limited adherence to international agreements on food safety and quality standards; limited enforcement of local, regional, and international standards and global best practises; limited funding to promote scientific risk analysis; lack of established hazard and critical point checklists/systems; limited data and information on health burden, particularly food-borne diseases. In Kenya, there are no special regulations for the usage of insects as food and insects are viewed as impurities in food that need to be removed. Rules governing the use of insects as food and feed are now supported, and discussions are now being held with the Kenya Bureau of Standards (KEBS) and other pertinent organisations in order to form a technical committee and create the standards that would control their usage as food. These standards would likely include provisions for traceability of insect material throughout the food supply chain (Halloran *et al.*, 2015). The Kenyan government has made sure that safe food trading procedures adhere to WTO/SPS regulations and other global norms. The Ministries of Public Health and Sanitation, Industrialization, Trade and Business Development, Agriculture, Livestock and Fisheries, and Environment and Forestry in Kenya have agencies that carry out food regulations (Niassy *et al.*, 2022).

Zimbabwe's Ministry of Environment and Tourism has extensive environmental legislation pertaining to environmental concerns, including the 1949 Forest Act and the 1941 Forest Resources Act to control the gathering of wild edible insects. In the states of Nigeria, the local government authorities in conjunction with the state ministries of health are in charge of monitoring food quality and safety, general public health surveillance, and complaints. Regulation of edible insects is also crucially influenced by other Ministries, such as the Federal Ministry of Industry, Trade and Investment, the Federal Ministry of Environment, and the Federal Ministry of Science, Technology, and Innovation. This includes traceability measures for insect material (Niassy *et al.*, 2022). Standards for the sustainable use of edible insects in Nigeria are being developed by the National Agency for Food and Drugs Administration and Control (NAFDAC) and the Standard Organization of Nigeria (SON). When it comes to the packaging, marking or labelling, and industrial preservation of edible insects, the role of SON is essential for the best performance of services and related activities (Usman and Yusuf, 2021). Under Section 6 of the 1992 Food and Drugs Act, the Food and Drugs Authority in Ghana has enacted laws that control the manufacturing of novel food items. On the other hand, Ghana's environmental protection agency is lacking in controls over and regulations for insect farming (Niassy *et al.*, 2022).

It is important to note that the level of regulation and implementation may vary among African countries. However, the recognition of the significance of traceability in ensuring food safety and quality standards is evident through the ongoing discussions and efforts

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to establish appropriate regulations and standards for the usage of insects as food and feed. Regulations (EC) 853/2004 and 1169/2011 shall be followed on the traceability of food ingredients. The product should be evaluated at this point to see if it complies with food safety regulations. Transporting goods should follow the regulations outlined in Regulations (EC) 852/2004 and 183/2005. Live insects should be transported in accordance with laws governing the welfare of animals, with a minimal amount of time spent in transit, under temperature control, and using a vehicle with a ventilation system. Insects are shipped live and processed either directly to customers and animal breeders or to manufacturers of food and feed (Żuk-Gołaszewska *et al.*, 2022).

6 Barriers/challenges associated with the consumption of dragonflies and damselflies

The production of edible insects is still relatively new and the practice is gradually gaining popularity around the world (Moruzzo *et al.*, 2021). The practice of rearing edible insects such as dragonflies and damselflies is more popular in Africa than in the Western world where very few insects are allowed to be incorporated into the diets of animals such as poultry (Moruzzo *et al.*, 2021). In the tropics and subtropics, about 2,100 insects have been documented as edible insects but these organisms are from different sources (van Huis, 2021). In certain parts of the world or country and in cultures where certain insects are eaten, new insects such as dragonflies may not be the preferred option (Tanga *et al.*, 2021). In Kenya, Tanzania and Uganda, it is usually the coleopterans and lepidopterans which are farmed for food according to their culture (Tanga *et al.*, 2021). Therefore, introducing odonatans as food may pose a threat to the consumers of the product.

One of the major barriers to odonatan and other edible insect rearing is the lack of information (Niyonsaba *et al.*, 2021) (Figure 3). The European insect sector is not yet fully developed. In other parts of the world, small scale farms have been established as opposed to the large scale livestock farms (Niyonsaba *et al.*, 2021). Information of poultry and fish farming is readily available however information on insect rearing, more specifically dragonfly farming is difficult to acquire. When information about insect farming is available, it usually focuses on the technical aspects of insect production, nutritional content of insects and environmental benefits (Niyonsaba *et al.*, 2021). This research though useful, does not provide all the information needed to successfully rear insects, more specifically dragonflies. It is important that more research is carried out on rearing edible insects of every order especially Odonata.

Another important barrier to the consumption of dragonflies is the presence of heavy metals (Table 6) which are toxic and affect the ecosystem negatively. Heavy metals enter the environment in numerous ways especially by the process of mining (Wegenast and Beck, 2020). They are contaminants and they do not have any odor, colour or taste (Blanco *et al.*, 2020) Mining processes require the use of hazardous substances including heavy metals and cyanide (Wegenast and Beck, 2020). These substances enter the agricultural environment as well as the ecosystem where they accumulate in the food chain (Blanco *et al.*, 2020). Once in the ecosystem they may accumulate in insects such as dragonflies. Gold and copper extraction are known to be associated with the release of metals such as arsenic, cyanide or mercury (Wegenast and Beck, 2020). In order to limit the accumulation of heavy metals in the environment, the health and safety standards of mining need to be evaluated and pollution reduction is very important.

One of the main challenges and barriers in the Western world is the issue of food safety (Moruzzo *et al.*, 2021). It has been reported that some edible insects cause allergic reactions after being consumed, inhaled or touched (De Marchi *et al.*, 2021). The allergic reactions occur as a result of cross reactivity with other taxonomically related food allergens like crustaceans and inhalant allergens like house dust mites. Tropomyosin (TM), arginine kinase (AK), and glyceraldehyde 3-phosphate dehydrogenase (GAPDH) are examples of allergens found in invertebrates (De Marchi, Wangorsch and Zoccatelli, 2021). Food safety is part of a larger issue which is the legalities of producing, marketing and selling food (Moruzzo *et al.*, 2021). According to the FAO, some of the important food safety issues which need to be considered include biological agents such as bacterial viral and fungal organisms and chemical contaminants (FAO, 2021). If insects are to be produced commercially, detection of microorganisms and chemical contaminants is vital (FAO, 2021). It has been reported that toxic metals which are deposited into water bodies can also accumulate within the bodies of aquatic animals and these include dragonflies (Nasirian and Irvine, 2021). The heavy metals have disastrous consequences on the health and well-being of mankind therefore it is important that food sources which contain these pollutants are avoided. Table 7 shows the adverse effects of the toxic metals and they include tissue and organ

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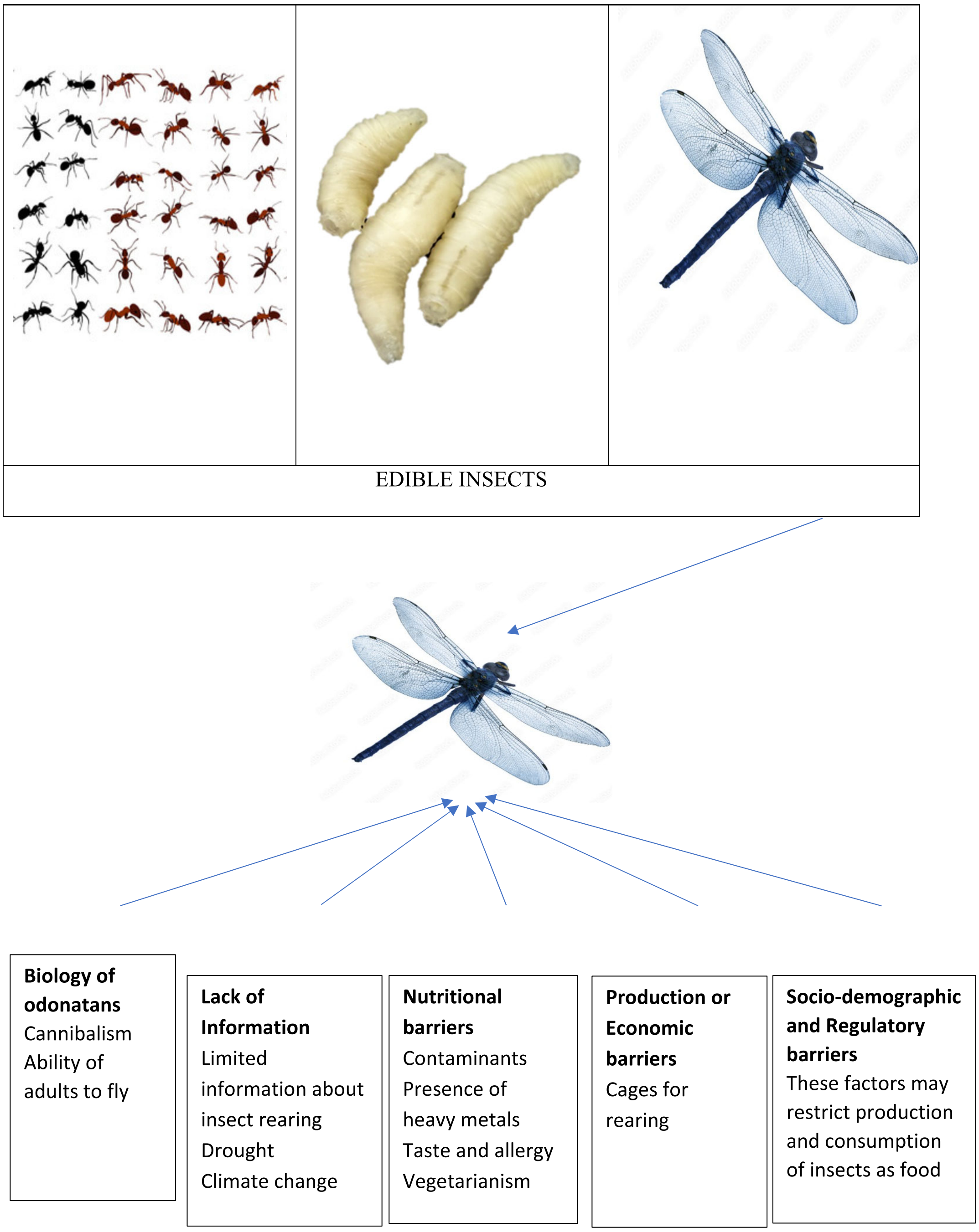

FIGURE 3 Barriers to the use of edible dragonflies and damselflies as food.

TABLE 6 Approximate levels of heavy metals (dry weight $\mu g\ g^{-1}$) in five species of odonatan nymphs in Shadegan wetland of Iran. Source: Nasirian and Irvine, 2017

Species	Mercury levels	Lead levels	Chromium levels	Copper levels
Ischnura ramburii	0.13	0.55	69.14	358.65
Libellula semifasciata	241.05	0.55	91.8	675.14
Argia fumipennis	0.13	0.55	66.43	250.81
Argia sedula	0.13	0.55	0.67	0.61

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TABLE 7 Heavy metals found in some edible odonatans and their effects on human health. Source: Mitra *et al.*, 2022

Heavy metal	Species	Symptoms and effects of heavy metal	References
Mercury	*Ischnura ramburii*	Side effects include eye irritation, difficulty in breathing, chest pain, exhaustion, weight loss	Mitra *et al.*, 2022; Nasirian and Irvine, 2017
Cadmium	*Zonophora* sp.	Cadmium is a cancer causing agent. It can cause kidney disease and fragile bones.	Kiran *et al.*, 2022
Nickel	*Libellula semifasciata*	Side effects include allergy, cardiovascular and kidney diseases, nasal and lung cancer	Kiran *et al.*, 2022
Chromium	*Castoraeschna castor*	Asthma, eye and respiratory irritation, pulmonary congestion, pain in upper abdomen, skin irritation	Mitra *et al.*, 2022
Arsenic	*Ischnura ramburii*	Overexposure to large quantities causes cancer and skin lesions. Early exposure in babies affects cognitive development	Kiran *et al.*, 2022; Nasirian and Irvine, 2017
Lead	*Neurothermis tullia*	Kidney and brain damage, anaemia and weakness	Kiran *et al.*, 2022
Copper	*Argia fumipennis*	High quantities can cause vomiting nausea, abdominal pain and diarrhoea. Severe illness include kidney and liver damage	Mitra *et al.*, 2022
Tin	*Argia sedula*	Large quantities cause, stomach upsets, anaemia, kidney and liver problems	Mitra *et al.*, 2022
Manganese	*Gomphoides selys*	Large quantities leads to neurological condition called 'manganism' which includes trembling	Mitra *et al.*, 2022

damage as well as eye irritation. Other effects are the interruption of proper metabolic pathways in the body and in severe cases death may occur. In Figure 4, the effect of pollution of waterbodies containing dragonfly nymphs is shown. The toxic metals remain in the bodies of nymphs and even when they mature into adult dragonflies. When humans consume the adult dragonflies, the toxic metals are deposited into humans and the adverse effects described become evident.

Edible insect like larvae of palm weevils *Rhynchophorus* spp. have been cooked and eaten in many parts of Africa and Asia (Fernando *et al.*, 2023). They are consumed in foods as raw, boiled, fried or smoked forms (Adepoju and Ayenitaju, 2021). Likewise, dragonflies mostly are eaten as food by cooking them first using the same processes of smoking, frying or boiling. Unlike palm weevil larvae, the physical appearance of edible odonatans may cause fear, therefore removing the legs and intestines or converting them into powdery additives is more advisable. Because the nutritional value of insects has been compared to meat, it is possible to convert insects into additives which can then be added to foods (Adepoju and Ayenitaju, 2021). Thus, edible odonatans can also be converted into additives to be added to foods or processed into snacks.

The laws regulating insect farming in the world have limited the production of many species of insects, more specifically dragonflies. In some countries the production of insects using human excreta as feed is allowed however in the European Union (EU), this practice is not allowed (Niyonsaba *et al.*, 2021). In addition, very few insects have been chosen which can be used in fish meal (Niyonsaba *et al.*, 2021). Several different species of insects are reared throughout the world however edible insects in one part of the world may not necessarily be consumed in other parts of the world.

The culture and psychological state of the people of Gelao in China, the Mazahua of Mexico and the Kiriwinians in Papua New Guinea has made it possible for these people to consume insects (Zhao *et al.*, 2021). Various surveys in Europe have shown that very few people are ready to replace the consumption of meat with insects (Hartmann, 2017). In a Dutch survey only 4% chose a snack containing insects (Hartmann, 2017). Europe in general react negatively to insects as food when compared to Asia and more specifically, China.

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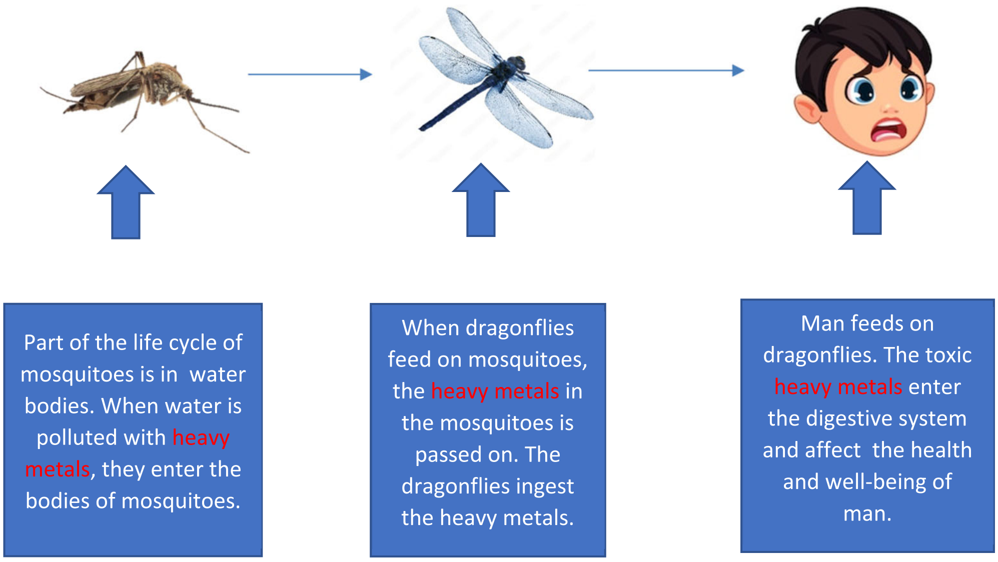

FIGURE 4 Transfer of toxic heavy metals from insects in aquatic environment to mankind.

This is evidence to support the claim that the cultural sphere in which an individual grows up affects the decision to consume insects as food. Insects such as fried silkworms were found to be more acceptable as food in China than in Germany (Hartmann, 2017). In Western cultures insects are associated with contaminated food not healthy food (Hartmann, 2017). Hartmann *et al.* (2015) carried out a cross cultural comparison in China and Germany on consumers' willingness to eat different insect-based processed foods such as cookies based on cricket flour and unprocessed insect food (e.g. crickets). It was found that the Chinese rated all insect based foods more positively in regards to taste, nutritional value, familiarity and social acceptance compared to Germans (Hartmann, 2015). In addition, there was no difference in the ratings of processed and unprocessed insect food by the Chinese whilst the Germans were more willing to eat the processed insect food compared to the unprocessed insect food (Hartmann, 2015). Furthermore, it has been reported that gender influences the acceptance of insects as food and more men seem to react more positively to insects as food than women (Hartmann, 2017). Where insects are not consumed, they may not be produced unless production is for export. It is important to work on the production, import and export laws of insects in order to have uniform international regulations to govern this upcoming venture (Moruzzo *et al.*, 2021). Dragonflies and damselflies have not yet been officially added to the list of insects which can be incorporated into livestock feed.

The biology of the odonatan is an important factor which poses a challenge to the use of the insect as food or feed. Dragonflies and damselflies are relatively large insects and they have excellent flying capabilities (Okude, 2017). Their ability to fly over long distances may be a challenging factor when rearing. Some insects such as adult dragonflies and damselflies are very mobile therefore little is known about which organisms they feed on and how their diets can be monitored (Chari *et al.*, 2018). This is another challenge which has been highlighted in insect farming. Insects which are taken from the wild cannot be classified in certain food groups since the nutrition of the insect in the wild cannot be monitored (van Huis, 2021). The choice of a rearing chamber would need to factor in the flying potential whilst in the adult stage. Also, it has been reported that cannibalism is an attribute of dragonflies and this can cause a decline of populations within a rearing chamber (Okude, 2017). Multi-well plastic containers have been strategically used to reduce the possibility of cannibalism during rearing (Okude, 2017).

Another important factor to be considered is the economic costs of producing dragonflies. Insect production is highly specialised depending on the insect being reared. For example, dragonflies complete part of their life cycle in water and this makes water a requirement in dragonfly farming (Krull, 1929). Edible insect farming is not expensive however a basic capital is required (Niyonsaba *et al.*, 2021). In developed countries, crowd funding has enabled several edible insect businesses to start up. In developing countries, access to funds for such start-ups may not be available therefore economic costs are a limiting factor.

In conclusion, rearing dragonflies for food or feed is quite rare. Even though some of the species are edible, production of dragonflies in the laboratory is usually

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done for scientific experimentation, not for food. Several challenges have not been officially documented in dragonfly rearing however, it can be deduced that climate change will be a critical factor which would affect dragonfly rearing since the insect requires water during part of the rearing phase.

7 Rearing and preparation of edible dragonflies and damselflies

Because entomophagy is gradually gaining recognition, new and more improved methods of rearing insects are now being developed (Janra *et al.*, 2020). Scientists have the challenge of building and developing new and improved rearing cages to suit the different insects in the different orders of insect classification (Janra *et al.*, 2020). Furthermore, insects have several diets and as some feed on plant and vegetable matter, other insects such as dragonflies and damselflies feed on other insects and serve as the natural enemies of those insects (Janra *et al.*, 2020). It has been reported that rearing dragonflies and damselflies in the laboratory has several advantages including uniformity of ages of the offspring (Janra *et al.*, 2020). However, the major challenge of rearing and consuming dragonflies and damselflies is being able to produce enough insects within a limited time.

In warm regions insects are available throughout the year (Kouřimská and Adámková 2016); weather could therefore be a barrier to the supply of insects. In Africa, the tropical weather and the existence of rural settlements where there are sufficient resources for rearing insects makes it relatively easy to do so. However, in Europe, where warm weather may last for less than half of the year, the process of rearing as well as the production costs may be high (Williams *et al.*, 2021)

Several methods of rearing insects in the order Odonata have been described and implemented but these methods require a lot of resources and time in order to be effective (Locklin *et al.*, 2012). Several apparatus are also used in the collection and rearing process (Tennessen, 2019). A species of dragonfly, *Sympetrum obtrusum* has been successfully reared under laboratory conditions by starting with the egg stage (Krull, 1929). Mated female dragonflies are made to lay eggs in vials (Krull, 1929). It is reported that eggs are easily obtained by keeping the abdomen of the female dragonfly out of water (Krull, 1929). It was previously stated that eggs had to be deposited in dirty water however, it was discovered that hatchability of eggs was highest when eggs were placed in clean water. In addition, newly hatched nymphs were easily seen (Krull, 1929). In order to reduce fungal growth is dishes containing water, it was recommended that the water is changed frequently (Krull 1929). In addition, salt was added to the water on several occasions (Krull, 1929). Not only did the salt reduce fungal growth but also hatchability was not affected (Krull, 1929). Previously published research has suggested that algal growth in water has to be inhibited to successfully rear dragonflies (Locklin *et al.*, 2012). It has also been stated that multiple food sources as well as daily water changes are required to rear odonatans effectively however, advancements in research have resulted in improved rearing protocols (Locklin *et al.*, 2012). For example, nymphal mortality has been reduced by the immediate isolation of nymphs as soon as hatching has taken place. Diverse food sources were previously used in rearing protocols; such food sources included paramecium and tubificid worms (Krull, 1929). Improvements in rearing dragonflies have resulted in the use of few or limited food products in rearing (Locklin *et al.*, 2012). There is a general ban in the European Union on the use of waste to feed insects to reduce contaminants such as heavy metals and to improve health and safety (Schrögel and Wätjen, 2019). Cadmium and arsenic have been recorded as contaminants in black soldier fly and yellow mealworm (Schrögel and Wätjen, 2019). An approach used to reduce the transfer of contaminants by consumption is to starve the insects before harvesting them as most of the contaminants are found in the gut of the insect (Schrögel and Wätjen, 2019). An experimental method to produce a large quantity of *Ischnura ramburii* by rearing in the laboratory has been reported (Locklin *et al.*, 2012), however the data was only gathered from the first generation of dragonflies. Consequently another successful protocol was produced which enables three generations of *Ischnura elegans* to be produced in a single year with hundreds of insects in each generation (Piersanti *et al.*, 2015). In order to reduce heavy metal contamination of dragonflies, the practice of starving insects before harvesting should be investigated in odonatans. Consumption of edible odonatans should be associated with environmental sustainability in order for humans to understand the benefits of insect production and consumption to the environment. Where there is doubt, the insect can firstly be used to feed livestock to prepare humans psychologically for direct consumption of the odonatans.

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8 Future perspectives and conclusions

Biochemical and ecological studies of dragonflies can provide information on the food chain and the nutrients which are passed on in the food chain. Studies have shown that carotenoids such as lutein and zeaxanthin which were found in dragonflies originated from insects such as mosquitoes, flies, butterflies, planthoppers and moths which the odonatans feed on (Maoka *et al*., 2020). The specificity of odonatan to aquatic habitats means that they can be exploited technologically to monitor the health of aquatic ecosystems. In addition, even though dragonfly nymphs are edible, they are also used as biosentinels for the detection of mercury in freshwater food webs.

When more information on insects is made available, consumers would appreciate the science and nutrition of insect farming. The nutritional composition of 236 edible insects have been published (FAO, 2021). When insects such as dragonflies become recognised as food, more studies would be conducted on them. In some parts of the world, very few studies have been conducted on dragonflies and the total number of species found in certain countries is unknown. However, information on the nutritional content of dragonflies is readily available and all the different micronutrients including the amino acids found in the species have been documented. It is therefore important to increase and improve dragonfly rearing protocols. Patents need to be granted for food processing of insects as food and feed.

Technological innovations of science improve quantity and quality. There is an increased risk of contamination when insects are collected and consumed directly from the wild. This can be avoided by farming insects in a controlled environment where the inputs of the farm are controlled and monitored in order not to have adverse conditions on mankind as they enter the food web. In future, more scientific studies into nutrition, biochemistry and entomology will be needed in order to diversify the substrates used for rearing insects. In East Africa, more specifically Kenya and Uganda, where insect consumption is on the increase, organisations and stakeholders are drawing up legal standards to regulate how insects are farmed and handled before they reach the consumer (Tanga *et al*., 2021). The two African countries are more flexible in regards to legislation on insects and they farm any insect and use all available substrates to feed the insects. On the other hand, in Europe, only seven insects are farmed and the use of certain substrates to feed the insects are prohibited (Tanga *et al*., 2021). International legislations are needed in order for insects to be farmed and exported from one country to another.

As the world's population increases, insects will not only provide nutrients to mankind but also work will be available to sustain the economies of countries where insect farming is essential. The livelihood of rural communities is being diversified by rearing and selling insects. Several enterprises have also been developed to produce insects in various countries. As the world strives to achieve the sustainable development goals, insect farming will pave a way for resources to be utilised for sustainable economic development.

Supplementary material

Supplementary material is available online at:
https://doi.org/10.6084/m9.figshare.24969909

Authors' contribution

S.A.S.: conceptualization, methodology, validation, formal analysis, data curation, writing – original draft, writing – review and editing, visualization, supervision, resources, project administration; K.A.: writing – original draft; N.N.: writing – original draft; Y.R.S.: writing – original draft; Y.S.W.: validation; M.L.: writing – original draft; O.F.A.: methodology; I.F.: writing – original draft, writing – review and editing; S.N.P.: validation; R.C-M.: validation.

Conflict of interest

The authors declare no conflict of interest.

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