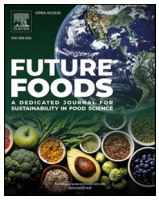
Future Foods 8 (2023) 100267

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo



Future aspects of insects' ingestion in Malaysia and Indonesia for human well-being and religion regulation

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ARTICLE INFO

Keywords:
Ethnoentomology
Edible insect
Medicine
Well-being
Locust

ABSTRACT

Current trends have demonstrated increasing interest in maintaining and improving the state of human well-being. Natural resources, mainly plants, have been constantly used and studied for producing food and pharmaceutical products with beneficial effects on various functions in the body. However, potential food shortages, challenges in maintaining and improving human health and environmental concerns have led to the discovery of alternative and sustainable food sources to accommodate the growing and aging global populations. The consumption of insects in Asia has been mainly reported in China, Japan, the Lao People's Democratic Republic, Thailand, and Vietnam. However, less consumption has been reported in Malaysia and Indonesia due to a lack of traditional knowledge by younger generations and uncertainty in the permissibility of insect consumption from a halal perspective. This review will provide a compilation of the traditional knowledge of insect consumption in Malaysia and Indonesia to provide a better understanding of insect consumption from an Islamic perspective. In addition, we will discuss the potential of locusts, which are permissible and halal for human consumption, for human well-being for Muslim populations.

1. Introduction

Insects, which form part of the arthropod group, are among the largest and most diverse group of animals, with approximately 3.9 million species dominating tropical rainforests (Stork, 2018; Crespo-Pérez et al., 2020). Insects are the only winged invertebrates that undergo metamorphosis to adapt to various climates. Juvenile insects go through nymph and larvae stages and shed skin as they mature. In contrast to complete metamorphosis which turns larvae into pupal stage before reaching adulthood, nymph never enters a pupal stage but undergoes molting process to become an adult insect (Speight et al., 2008). Insects commonly have large populations and are able to reproduce rapidly, thus making them the most sustainable resources for human well-being. Insects are also able to produce silk, dyes, and wax as well as other insect products (including honey, propolis and royal jelly) that have various nutritional and functional values. In addition, insects have efficient feed conversion with a much higher yield than other animals, and they have less land use and a smaller environmental footprint (Dicke, 2018; Moruzzo et al., 2021). Thus, mass production of insects is economically viable and able to accommodate the increasing protein demand and replace conventional livestock while serving as a potential value-added functional compound in the rapidly growing wellness food

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https://doi.org/10.1016/j.fufo.2023.100267
Received 13 July 2023; Received in revised form 15 October 2023; Accepted 2 November 2023
Available online 4 November 2023

and pharmaceutical sector.

Since the nineteenth century, insects have shown a continuous history and connection with humankind according to a series of studies on the nutritional potential and significance of insects to the human diet (Posey, 1986). The study of folk science known as ethnoentomology is defined as the information and practices used by different human societies that are related to insects (Ismail and Mohamed, 2014). Ethnoentomology includes the word "ethno", which indicates knowledge of folk societies or indigenous people, and "entomo", which refers to insects in ancient Greek (ἔντομον); this field focuses on how insects have been or are being utilized in various aspects of human life, including medicine, food, rituals, tools, textile, and folk entertainment. The use of insects and spiders as medicine was reported as far back as the sixteenth century B.C. in The Ebers Papyrus (Weiss, 1946), while Chinese people have used silkworm (*Bombyx mori L.*) as their traditional medicine for at least three thousand years (Zimian et al., 1997). In addition to medicine, the uses of insects in traditional rituals have also long been known and practiced by indigenous tribes. These include the uses of bullet ants *Paraponera clavata* and ant species *Pachycondyla commutata* for rituals for manhood and social status by the Saleter-Mawe people and Ka'apor tribe from Brazil (Costa-Neto, 2005; Haddad Junior et al., 2005). Uniquely, several insects, such as *Eurycantha calcarata* (stick insect), are even used as fishing hooks by native tribes in Papua New Guinea (Balfour, 1915).

Indigenous people are known to possess more traditional knowledge with respect to the utilization of natural resources surrounding them. Traditional knowledge, commonly known as local knowledge, is defined as knowledge, know-how, skill, and practices developed, sustained, and transmitted verbally through generations within a community, often forming part of its cultural or spiritual identity (Anyaoku, Nwafor-Orizy and Eneh, 2015). This knowledge is rarely documented and mostly observed through the knowledge, skill and expertise of the elderly or head of the indigenous tribe. In Malaysia, documentation of insect consumption is still limited, with most of the publication records originating from old reports and past research studies (Gimlette, 1939; Johnson, 2010; Ismail and Mohamed, 2014). Until now, most of the research studies on ethnoentomology in Malaysia were the works of Dr. Arthur Chung and his colleagues from Sabah Forestry Department (Chung et al., 2000, 2001, 2002, 2004, 2005a, 2005b; Chung, 2007, 2008). There are nearly 60 insect species that have been reported by the authors for diverse utilization in East Malaysia (Sabah and Sarawak). This traditional knowledge was collected and documented through a series of in-depth interviews with indigenous communities as well as field observations and references from old reports. In contrast to Malaysia, Indonesia reported diverse utilization of insects, although knowledge gaps do exist in the documentation of this traditional knowledge (Raheem et al., 2019). This gap could be observed in a previous study in which no documentation on ethnoentomological practices was reported in the remote area of Kalimantan despite such practices being very much alive in this area compared to Sabah (Chung et al., 2003).

Malaysia and Indonesia are rich in biodiversity and ethnic diversity. Each ethnic group has demonstrated vast experience and knowledge in the utilization and conservation of biodiversity. Malaysia has reported Malay, Chinese and Indian as the major ethnicities, while *Orang Asli* (Malaysian indigenous people) make up only 1% of the population in Malaysia (Thevakumar et al., 2016). For Indonesia, approximately 370 ethnic cultures have been reported, with four main cultural groups being the Javanese, Sundanese, Madurese, and Balinese (Mangundjaya, 2013; Rintelen et al., 2017). Interestingly, Islam is the most broadly professed religion in both countries; half of their total population is Muslim (Hassan and Omar, 2017). Compared to that of other insect-eating countries, such as Mexico, Zimbabwe, Thailand, China and Japan, the consumption of insects in Malaysia and Indonesia is still rare and viewed as bizarre due to a lack of knowledge and due to doubt from the halal perspective. Less documentation has also been recorded on the association between insects and indigenous peoples from Malaysia and Indonesia, as this insect-eating culture is rarely practiced. Hence, this review will provide an overall compilation of insects consumed for human well-being and therapeutic uses among indigenous peoples from Malaysia and Indonesia and discuss the possibility of these insects being consumed by Muslim communities. This compilation will be beneficial for various industries, especially the pharmaceutical and food industries, to deliver an alternative solution in sustaining the growing global populations.

2. Methodology of the review

We used the Google search engine to collect materials and articles about insect consumption for medicinal uses and human well-being from different countries to compile this review. The findings of these searches are divided into three sections: (1) consumption of insects for human well-being and medicinal uses in Malaysia and Indonesia; (2) opinion on insect consumption from the perspective of halal and Islamic regulations; and (3) potential uses of locust as permissible insects by Muslim communities for human well-being around the world. Keywords that were used to extract articles and information include "ethnoentomology", "entomophagy", "edible insects", "medicinal insects", "human well-being", "physical", "psychological", "Malaysia", "Indonesia", "grasshopper", "locust", "halal", "Shari'ah perspective", and "Islamic regulations". This search is limited to the data description in three languages: English, Indonesian and Malay. From this search, most of the insect consumption in Section (1) was limited to Malaysia and Indonesia with a focus on consumption for human well-being and medicinal uses, while findings in Section (2) were limited to insects that were permissible based on the evidence in the Qur'an and *hadith*. The findings for Section (3) were limited to locusts only, which was reported for human well-being globally. The results were extracted from research findings, conference articles, reviews, books, and dissertations that were carried out up to March 2023. Information on the insects was collected using the Global Biodiversity Information Facility (https://www.gbif.org/) and Malaysia Biodiversity Information System (MyBIS) (https://www.mybis.gov.my/one/). For invasive and pest species, the Invasive Species Compendium database (https://www.cabi.org/isc/) and EPPO Global Database (https://gd.eppo.int/) were used as reference data.

3. Insects as nutrient sources for human well-being

The world population is projected to increase to 9 billion people by 2050, demanding more production from the existing agroecosystems (Alexandratos and Bruinsma, 2012). Entomophagy, also known as insect eating, has been practiced in tropical countries and serves as a potential food to feed the increasing population. The most widely consumed insects are beetles (Coleoptera), which make up 31% of all edible insects, followed by caterpillars (Lepidoptera, 17%) as well as bees, wasps, and ants(Hymenoptera, 15%). In addition, crickets, grasshoppers, and locusts (Orthoptera) account for 13% of the insects consumed, while cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) make up 11% of the insects consumed. Other groups of insects, including termites (Isoptera), dragonflies (Odonata), flies (Diptera), and others, each account for 3% of insects consumed worldwide (Jansson et al., 2019). Compared to Asian communities that have historically included insects as part of their diet (Raheem et al., 2019), Western societies still perceive insects as disgusting and inappropriate for consumption (Woolf et al., 2019; López et al., 2023). However, compared to other Asian countries, Malaysia and Indonesia have shown less documentation on the consumption of edible insects. Table 1 summarizes the list of edible insects reported in Malaysia and Indonesia, with beetles, grasshoppers, crickets, and sago grubs dominating the widely consumed insects. Most of these edible insects were summarized based on the consumption records by indigenous people in Sabah and

Table 1
List of edible insects in Malaysia and Indonesia.

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Preparation method	References
Malaysia	Malaysia (Native)	*Aceraius* spp.	Passalid beetle	Adult beetles are normally toasted, or grilled, and hard parts of the body and legs are removed before eating. For moderately large beetles, the guts are removed because of their bitter taste.	Chung et al., 2002; Chung, 2007, 2008
Malaysia	Malaysia	*Anomala lasiocnemis*	Scarab beetle, *belombog*	Large scarab larvae were toasted to remove the bristles.	Chung et al., 2002; Chung, 2007, 2008
Malaysia	Malaysia	*Anomala concha*		Adult beetle was toasted with guts. The hard and spiny parts are then removed before eating.	Chung et al., 2002; Chung, 2007, 2008
Malaysia	China, Malaysia	*Anomala coxalis*			Chung et al., 2002; Chung, 2007, 2008
Malaysia	Malaysia	*Anomala latefemorata*			Chung et al., 2002; Chung, 2007, 2008
Malaysia	Indonesia, Malaysia, Thailand	*Exopholis hypoleuca*			Chung et al., 2002; Chung, 2007, 2008
Malaysia	Australia, Indonesia, Malaysia (Native), Singapore	*Lepidiota stigma*			Chung, 2007, 2008
Malaysia	Malaysia	*Leucopholis staudingeri*			Chung et al., 2002; Chung, 2007, 2008
Malaysia, Indonesia	Australia, Cambodia, China, Hong Kong, Indonesia, India, Israel, Japan, Laos, Malaysia, Nepal, South Korea, Sri Lanka, Taiwan, Thailand	*Batocera* spp.	Long-horned beetles, *ngatit, buang gavor* (Indonesia)	Adult beetles are normally toasted, or grilled, and hard parts of the body and legs are removed before eating. For moderately large beetles, the guts are removed because of their bitter taste.	Chung et al., 2002, 2003; Chung, 2007, 2008
Malaysia Indonesia	Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam	*Chalcosoma atlas*	Three-horned beetle, *golihot, rangoi, buang unga* (Indonesia)		Chung et al., 2002; Chung, 2007, 2008
Malaysia Indonesia	Malaysia (Native)	*Chalcosoma moellenkampi*			Chung et al., 2002, 2003; Chung, 2007, 2008
Malaysia	Bhutan, Cambodia, China, Japan, Indonesia, Laos, Malaysia, Philippines, Taiwan, Thailand, Vietnam	*Chrysochroa* spp.	Timber beetle, *lingaung*		Chung et al., 2002; Chung, 2007, 2008
Malaysia Indonesia	Australia, Africa, Asia, Europe, North America	*Cybister* sp.	Diving beetle larvae, *tangkub, ulod sek* (Indonesia)		Chung et al., 2002, 2003; Chung, 2007, 2008
Malaysia	Australia, Asia, Europe, North America	*Dorcus* spp.	Stag beetle, *tangkayabang*		Chung et al., 2002; Chung, 2007, 2008
Malaysia	Africa	*Macrotoma* sp.	Long-horned beetles, *ngatit*		Chung et al., 2002; Chung, 2007, 2008
Indonesia	Australia, Indonesia, Malaysia, Singapore	*Lepidiota stigma*	White scarab beetle, *buang mapoh* (Indonesia)		Chung et al., 2003
Malaysia Indonesia	Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Taiwan, Thailand, Vietnam	*Odontolabis* spp.	Stag beetle, *tangkayabang, buang lilot* (Indonesia)		Chung et al., 2002, 2003; Chung, 2007, 2008
Malaysia	Guam, Indonesia, India, Malaysia, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam	*Oryctes rhinoceros*	Asiatic rhinoceros beetle		Chung et al., 2002; Chung, 2007, 2008
Malaysia	Malaysia	*Rhaphipodus suturalis*	Long-horned beetle, *ngatit*		Chung et al., 2002; Chung, 2007, 2008
Malaysia	Australia, Bangladesh, Brunei, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Vietnam	*Xylotrupes gideon*	Elephant beetle, rhinoceros beetles		Chung et al., 2002; Chung, 2007, 2008
Malaysia	Cambodia, China, Indonesia, India, Laos, Malaysia (Native), Philippines Singapore, Thailand	*Ancistroides nigrita*	Chocolate demon	The pupa is eaten raw or boiled until dry. The larvae which often covered with white powdery substance are not preferred as food.	Chung et al., 2002
Malaysia	Bangladesh, Cambodia, China, Germany, Hong King, Indonesia (Native), India, Japan, South Korea, Malaysia (Native), Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam	*Apis cerana*	Honeybees	The wild honeybee larvae and pupae are eaten raw or boiled until dry. Adult bees are boiled to break down the poison (which primarily is a protein) until the stringer softens. Pounding the bees before boiling is also effective.	Chung et al., 2002; Chung, 2007, 2008
Malaysia	Bangladesh, Brunei, Cambodia, China, India, Indonesia (Native), Laos, Malaysia (Native), Nepal,	*Apis dorsata*	Wild honeybee, *petiokan*	The wild honeybee larvae and pupae are eaten raw or boiled until dry.	Chung, 2007

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Table 1 (*continued*)

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Preparation method	References
	Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam				
Malaysia	Malaysia (Native)	*Aplosonyx albicornis*	Leaf beetle, *gandilong*	Boiled or simmered until dry or stir-fried without oil.	Chung et al., 2002
Malaysia Indonesia	Indonesia (Native), Malaysia (Native)	*Camponotus gigas* (Synonym *Dinomyrmex gigas*)	Giant rainforest ant	Used as flavoring by squeezing the fluid (mostly formic acid) onto the plain rice.	Chung et al., 2000; Chung, 2008
Malaysia Indonesia	Brunei, China, Indonesia, India, Malaysia, Philippines, Thailand,	*Dundubia* spp.	Light green cicadas, *tavir, sebeper* (Indonesia)	Wings are removed and then roasted or stir-fried with a pinch of salt and other flavorings without oil.	Chung et al., 2002, 2003; Chung, 2007, 2008; Kemalok et al., 2019
Malaysia	Malaysia (Native)	*Erionota thrax*	Banana leaf-roller pupae, banana skipper, *bingog pisang*	The pupa is eaten raw or boiled until dry. The larvae which are often covered with white powdery substance are not preferred as food.	Chung et al., 2002, Chung, 2008
Malaysia	Australia, Asia, Europe, North and South America	Ephemeroptera	Mayfly, *kelatung*	Mayflies are often stir-fried.	Chung, 2008
Malaysia	Indonesia, Malaysia	*Gryllotalpa hirsuta* (synonym *Gryllotalpa longipennis*)	Mole cricket, *suruk, tongook, sorok-sorok, suuk*	Stir-fry without oil.	Chung et al., 2002; Chung, 2007, 2008; Ismail, 2015
Malaysia	Brunei, Malaysia	*Haaniella echinata*	Prickly Haaniella	The bug is often roasted.	Chung et al., 2002; Chung, 2008
Malaysia	Malaysia	*Haaniella grayii*	Stick insect	Female insect is cut open and egg is removed followed by boiling in water for 30 seconds. Shell of the egg is removed and eaten.	Bragg, 1990; Chung, 2008; Ismail, 2015
Malaysia	Australia, Africa, Bangladesh, Cambodia, Europe, Japan, Indonesia, India, Laos, Malaysia, Myanmar, North and South America, South Korea, Taiwan, Thailand	*Hermetia illucens*	Black soldier fly, maggot, *gizuk*	Maggots are eaten raw with locally brewed beer, known as *tapai*.	Chung et al., 2002
Malaysia	Australia, Africa, Europe India, Nepal, Pakistan, Southeast Asia	*Hippotion celerio*	Sphingid moth, *kalibambang, kelatang*	After removing wings, moth is boiled until dry.	Chung, 2007, 2008
Indonesia	Africa, Bangladesh, Hong Kong, Indonesia, India, Sri Lanka, Taiwan, Thailand, North America	*Hyblaea puera*	Moth cocoon	The cocoon is boiled until dry and stir-fried.	Girsang, 2018; Azis et al., 2021
Malaysia Indonesia	Africa, Asia, Australia, South America, North America	Isoptera	Termites, *tanai*	Eaten raw with wings removed or stir-fried without oil. They are also cooked in porridge or rice. In Indonesia, termites are made into rempeyek by mixing it with flour mixture then is deep-fried.	Chung, 2008; Araya and Susanto, 2019
Malaysia	Asia, Australia, Fiji, Papua New Guinea, Solomon Islands	*Leptocorisa oratorius*	Slender rice bug, rice ear bug, paddy pest, *pesisang, kaber sengagau*	The elderly Kadazandusun mashed the bug with chili and salt. It is then cooked in a hollow bamboo stem and served as a condiment. Occasionally, it is stir-fried and boiled until dry. Lundayeh mashed the paddy pest with boiled tapioca leaves and shoots.	Chung et al., 2002, 2003; 2005a; Chung, 2007, 2008
Malaysia	Australia, Africa, Asia, Europe	*Locusta migratoria*	Locust, *belalang ribu-ribu, hagidan*	After removing wings and legs, they are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Chung et al., 2002
Malaysia Indonesia	Malaysia, Singapore, Indonesia, Thailand, Myanmar, Cambodia, Vietnam, and Philippines	*Macrotermes gilvus*	Reproductive termites, *tanai, kelkatu*	Eaten raw, stir-fried without oil, or cooked in porridge or rice.	Chung et al., 2002; Nandika et al., 2021
Malaysia	Malaysia	*Microcerotermes dubius*	Reproductive termites, *tanai, kelkatu*	Eaten raw, stir-fried without oil, or cooked in porridge or rice.	Chung et al., 2002
Malaysia	Africa, Asia, Europe, Malaysia (Native), North America	*Mantis religiosa*	Praying mantis, *gozen*	Roasted over an open fire.	Chung et al., 2002; Chung, 2008
Malaysia Indonesia	Cambodia, China, Hong Kong, Indonesia, India, Japan, Laos, Malaysia (Native), Nepal, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam	*Mecopoda elongata*	Brown leaf-like grasshopper, *kato buyot*	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Chung et al., 2003; Chung, 2007, 2008
Malaysia Indonesia	Malaysia	*Megapomponia merula*	Cicada, *Riang-riang, pagam, sebeper* (Indonesia)	Stir-fried or deep-fried.	Chung et al., 2003; Chung, 2008

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Table 1 (*continued*)

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Preparation method	References
Malaysia Indonesia	Asia, Africa, Australia, Europe, North and South America	*Nezara viridula*	Green stink bug, *tangkayomot, kaber bilat* (Indonesia)	The bug is eaten raw as snack or made into condiment to be taken with plain rice.	Chung et al., 2003; Chung, 2007, 2008
Malaysia Indonesia	Brunei, Indonesia, Malaysia (Native), Singapore	*Nisitrus vittatus*	Cricket, *gentirik*	Stir-fry without oil.	Chung, 2007, 2008; Ismail, 2015; Girsang, 2018
Malaysia Indonesia	Australia (Native), Bangladesh (Native), Brunei, Cambodia, China, France, Hong Kong, India (Native), Indonesia (Native), Laos (Native), Malaysia (Native), Myanmar, (Native), Nepal, Papua New Guinea, Singapore (Native), Sri Lanka (Native), Philippines (Native), Thailand (Native), Vietnam (Native)	*Oecophylla smaragdina*	Kerengga, *laga, haga, tontoh, tandarapas*, orange gaster, red weaver ants, weaver ants	Adult ants are grounded and mixed with chili and salt and served as a condiment. The ants can also be stir-fried with onions or shallots. Eggs, larvae, and pupae are either eaten raw or cooked in a porridge.	Chung et al., 2002; Chung, 2007, 2008; Ismail, 2015
Malaysia	Indonesia, India, Malaysia, Philippines	*Orientopsaltria* spp.	Brown and green cicadas, *tengir*	Wings are removed and then roasted or stir-fried with a pinch of salt and other flavorings without oil.	Chung et al., 2002; Chung, 2007, 2008
Malaysia Indonesia	Africa, Asia, Australia, Europe	*Orthetrum* spp.	Skimmer dragonflies, *kuyu, siferla* (Indonesia)	Wings is first removed then lightly salted and boiled.	Chung et al., 2002, 2003; Chung, 2008
Malaysia	Australia, Japan, Indonesia, Malaysia, New Zealand, Philippines, Singapore, Taiwan	*Panesthia* sp.	Jungle cockroach, *sarau*	Cockroach is cleaned and boiled until dry.	Chung et al., 2002; Chung, 2008
Malaysia	China, India, Laos, Malaysia, Nepal, Taiwan, Thailand	*Platylomia* spp.	Cicada, *tengir, tais-tais, tavir*	Wings are removed and then roasted or stir-fried with a pinch of salt and other flavorings without oil.	Chung et al., 2002; Chung, 2007
Malaysia Indonesia	Malaysia	*Protocerius* sp.	Giant weevil	Adult weevil is roasted while larvae are stir-fried, boiled, or cooked with rice.	Chung et al., 2003; Chung, 2008
Malaysia Indonesia	China, France, Greece, Indonesia, Israel, Italy, Pakistan, Portugal, Malaysia, Saudi Arabia, Spain, Sri Lanka, Taiwan, Thailand, Turkey, United Arab Emirates, Vietnam	*Rhynchophorus ferrugineus*	Red palm weevil, wild sago grub, *butod, wutod, tobindok, sungut, wot kinangan* (Indonesia), *sungkut* (Indonesia)	Unsavory guts are sometimes cleaned by peeling off the dark brown head capsule. The larvae are either eaten raw or cook in porridge with thin slices of ginger or stir-fry with shallots and soy sauce. Sometimes, the grub is skewed on small sticks then grilled or toasted lightly.	Chung et al., 2002, 2003, 2004, 2005a; 2005b; Chung, 2007, 2008; Ismail, 2015; Nirmala, et al., 2017; Anwari and Tavita, 2018; Girsang, 2018
Indonesia	Indonesia	*Rhynchophorus bilineatus*	Sago grub	Eaten raw or roasted.	Gullan and Cranston, 2010; Ismail, 2015; Girsang, 2018
Indonesia	Australia, Asia, Africa, North America	*Tenodera* sp.	Praying mantis, *kato gadang* (Indonesia)	Roasted over an open fire.	Chung et al., 2003
Indonesia	Cambodia, China, Hong Kong, India, Indonesia, Malaysia, Singapore, Thailand, Vietnam	*Tetracanthagyna* spp.	Dragonfly nymph, *siferla* (Indonesia)	Wings is first removed then lightly salted and boiled.	Chung et al., 2003
Indonesia	Bangladesh, India, Indonesia, Pakistan, Sri Lanka	*Atractomorpha crenulata*	Tobacco grasshopper, *buntak* (Indonesia)	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Anwari and Tavita, 2018
Malaysia Indonesia	Indonesia, Malaysia	*Atractomorpha psittacina*	Pointed-nose grasshopper, *tombuzungus, kato tachong*	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Chung et al., 2002, 2003; Chung, 2007, 2008; Ismail, 2015; Girsang, 2018
Malaysia Indonesia	Australia, Africa, Asia, Europe	*Acrida* spp.			
Malaysia	Africa, Australia, China, Europe, India, Japan, Singapore, Sri Lanka, South Korea, Taiwan, Vietnam	*Aiolopus* sp.	Short-horned grasshoppers, *butoh, kato tulang*	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Chung et al., 2002, 2003; Chung, 2007, 2008; Ismail, 2015
Indonesia	Bangladesh, India, Nepal, Thailand	*Choroedocus* sp.			
Indonesia	Australia, Benin, China, Hong Kong, Indonesia, Japan, Madagascar, South Korea, Thailand	*Gastrimargus sp.*			
Malaysia	Australia, Guam, Hong Kong, Indonesia, Japan, Malaysia, Singapore, South Korea	*Oxya japonica*			
Indonesia	Australia, China, Hong Kong, Laos, Japan, Malaysia, Philippines, Singapore, Sri Lanka, Thailand	*Stenocatantops sp.*			

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Table 1 (*continued*)

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Preparation method	References
Indonesia	Bhutan, Cambodia, China, Hong Kong, India, Indonesia, Japan, Philippines, South Korea, Taiwan, Vietnam	*Patanga sp.*			
Malaysia	China, India, Japan, Malaysia, Singapore, Sri Lanka, Taiwan, Thailand	*Hexacentrus unicolor*	Leaf-like grasshoppers, green bush cricket, *kazap, kato buyot*	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted.	Chung et al., 2002; Chung, 2007, 2008; Ismail, 2015
Malaysia	China, Hong Kong, India, Malaysia, Singapore, Thailand, Vietnam	*Onomarchus* sp.			
Malaysia	Malaysia	*Arachnacris tenuipes* (synonym *Macrolyristes imperator*)			
Malaysia Indonesia	Indonesia, Malaysia, Singapore, Thailand	*Valanga nigricornis*	Javanese bird grasshopper, Valanga grasshoppers, *belalang kunyit, kato mapoh*	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted. In Indonesia, these insects are marinade (using palm sugar and spices prior to frying. They are also served together with *Thiwul* (staple food from cassava).	Chung et al., 2002, 2003; Chung, 2007, 2008; Ismail, 2015; Girsang, 2018; Palupi et al., 2020
Malaysia	Australia, Africa, Asia, Europe, North America	*Zeuzera* sp.	Cossid moth larva, *tataro*	The pupa is eaten raw or boiled until dry. The larvae which often covered with white powdery substance are not preferred as food.	Chung et al., 2002; Chung, 2007, 2008

Sarawak of Malaysia and parts of Indonesia, which are primarily populated by non-Muslims.

Human well-being is commonly associated with the state of physical and mental health with respect to "healthy living", which includes the factors of diet, exercise, and inner harmony (Clark, 2014). The World Health Organization (WHO) defines health in terms of well-being as the state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity (Sartorius, 2006). Insects have demonstrated various health benefits through the presence of bioactive compounds, including bioactive peptides (Hall et al., 2020), chitin and chitosan (Mohan et al., 2020), phenolic compounds (Baigts-Allende et al., 2021; Nino et al., 2021) and fatty acids (da Silva Lucas et al., 2020). Among the bioactivity exhibited by these insect compounds, antioxidants were extensively studied, followed by antihypertensive, anti-inflammatory, antimicrobial and immunomodulatory activities (Aguilar-Toalá et al., 2022). As this section will focus on the utilization of insects for human well-being, the therapeutic effects of edible insects, including antihypertensive and anti-inflammatory effects, will be discussed in the next section.

Among the various insects reported in Table 1, *Rhynchophorus ferrugineus* (palm worm larvae) is a unique species that has been widely consumed among locals in Malaysia and Indonesia. These insects exhibit antioxidant activity, which in general has the capability to protect humans from molecular damage and prevent the incidence of civilization diseases such as diabetes, cancers, cardiovascular or rheumatoid diseases (Ganguly et al., 2018). Palm worm larvae (*R. ferrugineus*) (0.55 ±0.01) were reported to show a higher level of antioxidant activity for water-soluble extract than fresh orange juice (0.40±0.01), while fat-soluble extracts (0.017±0.0010) ranked at the bottom of the ranking compared to olive oil (0.063±0.010) (Di Mattia et al., 2019). The antioxidant capability of *R. ferrugineus* was further confirmed with an enzymatic study by Mohamed and colleagues, who reported high activity of superoxide dismutase (SOD) and glutathione S-transferase (GST) in the fat body, whereas the hemolymph and whole gut demonstrated significant activity of polyphenol oxidase (PPO) and peroxidase (PO). However, glutathione reductase (GR) and glutathione peroxidase (GPO) exhibited low enzymatic activity in the vital organs of *R. ferrugineus*, signifying that the examined organs, preferably the fat body, hemolymph, and whole gut, defend significantly against the ROS generated (Mohamed et al., 2022). Interestingly, defatted flour produced from these palm worm larvae also showed high antioxidant values for DPPH, ABTS and ferric-reducing antioxidant powder (FRAP) assays when compared to house crickets, mealworms and superworms (Botella-Martínez et al., 2021). These studies further confirmed the possibility of *R. ferrugineus* as a source of ingredients for the development of functional food.

Honeybee (*Apis* spp.) is one of the most extensively studied insects in terms of antioxidant activity. However, studies on the antioxidant benefit of these honeybees are mainly focused on their products, particularly honey (Alvarez-Suarez et al., 2010; Philip and Fadzelly, 2015; Cornara et al., 2017; Kek et al., 2017; Zhao et al., 2017), with only a few studies reporting the presence of gene-encoded proteins that are associated with antioxidant activity, such as cytochrome P450, glutaredoxins (Grxs), glutathione S-transferase (GSTs), methionine sulfoxide reductase B (MsrBs), microsomal glutathione-S-transferase (MGST), protein disulfide isomerases (PDI) and thioredoxins (Trxs) (Yao et al., 2013; Yao et al., 2014; Liu et al., 2015; Zhu et al., 2016; Meng et al., 2021; Zhao et al., 2021). In Malaysia and Indonesia, *A. cerana* and *A. dorsata* were among the honeybees that were uniquely consumed for their larvae and pupae instead of their known byproducts to secure the antioxidant benefits (Chung et al., 2002; Chung, 2007, 2008). In addition to honeybees, native ant species in Malaysia and Indonesia known as *Camponotus gigas* (giant rainforest ant) also show strong scavenging activities against free radicals (Pratiwi et al., 2019). This antioxidant activity may be attributed to the presence of flavonoids (2,3-dihydro-3, 5-dihydroxy-6-methyl-4(H)-pyran-4-one (DDMP-4-one), phenolic compounds, fatty acids and butylated hydroxytoluene (BHT) in the ethanolic extract of *C. gigas* (Velayutham and Karthi, 2015). Although various insects have emerged as potential antioxidants, most of the studies cover the bioactivity of notable mealworms (*Tenebrio molitor*) and silkworms

(*Bombyx mori*), signifying that more efforts are needed to cover the potential of edible insects, especially those consumed in Malaysia and Indonesia, as value-added ingredients for antioxidant products in the future (da Silva Lucas et al., 2020; Aguilar-Toalá et al., 2022).

In addition to antioxidants, the unique representatives of reproductive termites (*Macrotermes gilvus*) and giant rainforest ants (*C. gigas*), which are mainly consumed in Malaysia and Indonesia, also demonstrated significant antimicrobial activity (Pratiwi et al., 2019; Aguilar-Toalá et al., 2022; Witasari et al., 2022). Malaysia and Indonesia serve as a home to various beetle species, including Asiatic coconut palm beetles, and *Oryctes rhinoceros* is among the many that has received central attention in antimicrobial peptide (AMP) research (Azmiera et al., 2022). Insects are a notable reservoir of AMPs, namely, defensins, cecropins, attacins, gloverins, moricins, lebocins and other proline-rich peptides (de Castro et al., 2018; Azmiera et al., 2022). AMPs vary significantly according to the species and modes of action, which includes the production of reactive oxygen species, rupture or change in the electrochemical membrane gradient and inhibition of protein synthesis and permeabilization (de Castro et al., 2018). Antimicrobial activity exhibited by chitosan has been widely approved as a food preservative and natural antioxidant in Europe, Japan, Korea, and the United States (Abd El-Hack et al., 2020). As such, the antimicrobial compounds discovered in edible insects may then contribute to the development of new and natural preservatives in the food industry.

Interestingly, edible insects produce several components, such as short-chain fatty acids (SCFAs) and chitin, that could contribute to a healthy gut ecosystem, either due to their prebiotic effect or antimicrobial activity toward pathogens (Nowakowski et al., 2022). Cricket, which is mostly prepared by stir-frying by locals in Malaysia and Indonesia, has not been preprocessed into powder until recently. An experiment with a healthy adult supplemented with 25 grams/day roasted cricket powder for 14 days exhibited an increase in the abundance of the probiotic bacterium *Bifidobacterium animalis* and a decrease in plasma tumor necrosis factor (TNF)-α. These outcomes suggested the potential of edible insects to be used as prebiotic supplements in the future, as they improve gut health and exert protective effects against proinflammatory cytokines associated with inflammatory bowel disease (Stull et al., 2018). The presence of chitin in edible insects has served as a potential source of dietary fiber that provides various health benefits, such as lowering triglycerides and cholesterol levels, as exhibited by *Hermetia illucens* (Acosta-Estrada et al., 2021; Nowakowski et al., 2022). Normally, larvae of *H. illucens* were dried and baked before consumption, but in Sabah, these maggots were consumed raw with their notable brewed beer, known as *tapai*, as local delicacies (Chung et al., 2002). As the production of SCFAs could lead to the secretion of hormones associated with satiety and an increase in energy, these insects could benefit humans in the long term by promoting gastrointestinal health (Nowakowski et al., 2022).

Although insects are generally consumed as a whole through various preparation methods, including stir-frying, roasting, and boiling, by Malaysians and Indonesians, the benefits of these insects could be further exploited through the extraction only of unique compounds and not necessarily by consumption. These techniques would be superior for broader applications in the pharmaceutical and food industries, as the formulation of unique compounds could conceal the appearance of the insects, thus allowing humans to benefit from the salutary effect of edible insects in a manner that is similar to when insects are consumed directly.

4. Insects for medicinal purposes in Southeast Asia

The therapeutic use of insects and their products is known as entomotherapy. Insects can be utilized as adult insects or larvae, eggs, eggshells, exuvium, cocoons or insect bodies that have been infected with fungi for medicinal purposes (Feng et al., 2009). Moreover, venom or toxins secreted from insects could also serve as a potential source of novel therapeutic compounds. Table 2 shows the medicinal uses of edible insects that were consumed to alleviate illness in Malaysia and Indonesia, as well as their method of preparation/consumption, which appears unique compared to other parts of the world. Asthma is one of the prevalent diseases that is cured through the consumption of edible insects in Malaysia and Indonesia. One of these edible insects was the Javanese bird grasshopper (*Valanga nigricornis*), which was reported to treat asthma and heart diseases as well as be used a supplement to boost stamina (Zayadi et al., 2016). These grasshoppers were commonly fried after light seasoning with salt, but locals in Indonesia demonstrated unique preparation methods that included marinating with palm sugar and spices or serving together with *Thiwul*, a staple food prepared from cassava (Palupi et al., 2020). Moreover, native insects of Malaysia, including *Haaniella grayii* (stick insect) and *Megapomponia merula* (*riang-riang*), also demonstrated the ability to treat asthma by drinking the mixture of boiled water of these insects and local herbs (Chung et al., 2001; Kemalok et al., 2019).

Palembus dermestoides, which is uniquely distributed in Brunei, Indonesia and Malaysia, has reported promising therapeutic effects on asthma as well as rheumatic arthritis and diabetes. A previous study exhibited high antioxidant activity of the methanolic beetle extract containing n-pentadecannol and 4-ethyl resorcinol as the main components contributing to their uses in traditional medicine (Meza et al., 2013). Although *P. dermestoides* has demonstrated various metabolites with vital biological activity, terpene groups consisting of limonene, fucosterol and dehydroabietic acid were reported to present the greatest variety of biological activities, such as gastroprotective, hepatoprotective, antihyperlipidemic and antidiabetic activities, justifying its versatility in medicinal uses (Cázares-Samaniego et al., 2021). In Sabah, these beetles are taken regularly as an aphrodisiac by eating them alive with banana or honey to cover the pungent smell; alternatively, the beetles are dipped in hot water before being eaten (Chung et al., 2001). In addition, dung beetles (*Catharsius* sp.), also provide therapeutic effects against asthma, diarrhea, and convulsions, improving blood stasis, relaxing bowels, and counteracting toxins (Seabrooks and Hu, 2017). The Kadazandusun people have used the crushed internal organs of these beetles as a natural remedy to remove spines or thorns that were trapped under the skin by inducing the formation of pus (Chung et al., 2001). The anti-inflammatory properties exhibited by *N*-acetyldopamine dimer (termed molossusamide A-C) compounds isolated from the dung beetle have led to the discovery of their potential to be used against pathogens and wound infection in the future of the health care and pharmaceutical industries (Verheyen et al., 2021).

Diabetes is a metabolic disease that is characterized by abnormalities in insulin secretion, function, or both. *Myrmeleontidae* is an edible insect that is reported to be effective in treating diabetes, as its body contains sulfonylureas that can stimulate insulin secretion in pancreatic beta cells (Puspito et al., 2021). A previous study in Indonesia demonstrated that the juice of *undur-undur* (antlion) significantly lowers the level of blood glucose in aloxan-induced hyperglycemic rats after 14 days of treatment (Kurniasih et al., 2006). Numerous alkaloid isoindolines, including 4-hydroxy isoindoline-1-one and 2-(2-hydroxietile)-4hydroxy isoindoline-1-one, have been reported to exhibit antidiabetic activity in addition to alleviating diseases mediated by TNF-α (Rahma et al., 2007). Locals in Indonesia have recorded unique consumption of *undur-undur*, in which whole insects can be eaten with lady finger banana (*pisang mas*) to exploit the therapeutic effects of the insect against diabetes, jaundice, and liver diseases (Zayadi et al., 2016; Nukraheni et al., 2019). In addition, *Myrmeleontidae* also exhibits interesting capabilities in preventing hypertension among locals (Rahmawati and Bajorek, 2018; Apriyanto, 2020). Low blood pressure is possible with the inhibition of angiotensin converting enzymes (ACEs) by specific peptides defined as ACE inhibitors or antihypertensive peptides (Iwaniak et al., 2014). Asian weaver ant, *Oecophylla smaradina*, has identified two potential ACE peptides, namely, sequences of FFGT and LSRVP, with ACE inhibition

Table 2
List of insects for medicinal uses.

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Medicinal uses	Treatment method	References
Indonesia	Australia, Africa, Asia, Europe, North and South America	*Apis melifera*	Honeybee, *tawon*	Treatment for rheumatic pain	Patient is directly stung by the bee.	Zayadi et al., 2016
Indonesia	Africa, Asia, Australia, Europe, New Zealand, North and South America	*Blatella* sp.	*Keoca tanah*, german cockroach	Treatment for tooth pain	The head is first removed then the body is rubbed on the cheek near to the tooth pain.	Lusma, 2015; Nukraheni et al., 2019
Malaysia	Cambodia, Chinese Taipei, Hong Kong, Indonesia, India, Myanmar, Sri Lanka, Thailand, Vietnam	*Catharsius molossus*	Molossus dung beetle, *kuzung* or *serung* (Sabah)	Asthma	Roasted over an open fire, grounded into powder, and added to warm water.	Chung et al., 2001, 2004, 2005a; Ismail, 2015
				Remove spines or thorns trapped under the skin	Internal organs of the crushed beetle are placed onto the injured skin for few days.	Chung et al., 2001, 2005a
Malaysia	Malaysia (Native)	*Erionota thrax*	*Tataro* (larvae)	Treat pimples	White powdery substance on the larvae is applied to pimples.	Chung, 2008; Chung et al., 2005b; Ismail, 2015
Malaysia	Africa, China, Chinese Taipei, Europe, Indonesia, Japan, North America, South Korea	*Gerris* sp.	Water strider, pond skater, skimmer, *tampukau-kau*	Colds and fever	Bug is squashed on a spoon using thumb, mixed with warm water and drunk. Lundayeh culture treat cold and fever by rubbing crushed bug onto the stomach or forehead.	Chung et al., 2001
				Back pain	Crushed bug is rubbed onto the back of the body.	Chung et al., 2001
				Ward off fear among children	Crushed bug is added to water and used for bath.	Chung et al., 2001
Indonesia	Australia, Asia, Africa, Europe, North and South America	*Gerridae*	*Anggang-anggang*, pond skater	Treatment for centipede bite	The whole insects are crushed until fine and applied to the centipede bite.	Afriyansyah et al., 2016
Malaysia	Malaysia	*Haaniella grayii*	Stick insect	Asthma, abdominal pain, and muscle pain	Insects are first dried then boiled and mixed with herbs and drunk.	Boyle, 1992; Kemalok et al., 2019
Malaysia	Africa, Asia, Australia, South America, North America	Isoptera	Termites, *tanai*	Aphrodisiac	Drink with liquor or dip in alcohol before swallowing.	Chung, 2008; Ismail, 2015
Indonesia	Africa	*Macrotoma* sp.	*Serangga kura-kura gunung, kumbang*, beetle	Treatment for wounds, bites, skin itchiness, muscle soreness, stomach upset, headache and other external uses.	Whole beetle is roasted and mixed with coconut oil. The oil is then used as ointment.	Priyansah et al., 2021
Malaysia	Malaysia	*Megapomponia merula*	*Riang-Riang, Pagam*	Asthma	Mix with other herbs and boiled with water.	Chung et al., 2001; Ismail, 2015
Indonesia	Australia, Bhutan, China, Japan, India, Malaysia, South Korea, Sri Lanka, Russia, Taiwan, Thailand, Europe, Africa, North and South America	*Myrmeleontidae*	*Undur-undur*, antlion, *kekipu*	Indigestion	The whole insect is eaten raw.	Afriyansyah et al., 2016; Amelia, 2022
				Hernia	The whole insect is eaten raw.	
				Jaundice	Whole insect is eaten raw, fried, or eaten with lady finger banana (*pisang mas*).	Zayadi et al., 2016; Nukraheni et al., 2019
				Hypertension	Whole insect is eaten raw.	Rahmawati and Bajorek, 2018; Apriyanto, 2020
				Treatment for liver diseases	Whole insect is eaten raw, fried, or eaten with lady finger banana (*pisang mas*).	Zayadi et al., 2016; Apriyanto, 2020
				Diabetes	Whole insect is eaten raw, fried, or eaten with lady finger banana (*pisang mas*).	Zayadi et al., 2016; Paisal et al., 2018 Prastikawati and Husain, 2019
				Treatment for typhoid fever	Whole insect is eaten raw.	Amin et al., 2020
Indonesia	Australia, Africa, Brunei, Cambodia, China, Hong Kong, Indonesia, India, Malaysia, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand, Vietnam	*Oecophylla* sp.	*Kerengge, semut rang-rang*, weaver ant	Hypertension	Whole insect is eaten.	Nukraheni et al., 2019

(*continued on next page*)

Table 2 (*continued*)

Source of traditional knowledge	Distribution (Continent/ Country)	Scientific Name	Common Name	Medicinal uses	Treatment method	References
Malaysia	Brunei, Indonesia, Malaysia	*Palembus dermestoides* (synonym *Ulomoides dermestoides*)	*Bubuk* (Sabah), *buong darah* (Lundayehs) *and kumbang sukarno* (Indonesia), *semut jepang* (Indonesia), Chinese beetle, Chinese weevil, peanut beetle, cancer beetle, or asthma beetle	Aphrodisiac, stomach upset, rheumatism, diabetes, and arthritis	Eaten alive with banana or honey, or dip in a hot water before eating.	Chung et al., 2001; Flores et al., 2020; Cázares-Samaniego et al., 2021; Grimm and Schawaller, 2021
Indonesia				Diabetes	Whole insect is eaten raw.	Prastikawati and Husain, 2019; Apriyanto, 2020
Malaysia	Africa, North America, Middle East	*Periplaneta americana*	Cockroach	Fever	Cockroach is crushed and mixed with oil and applied in a small quantity onto the child's tongue.	Chung et al., 2001, 2005a; Ismail, 2015
				Stomach upset	The guts and head are removed from cockroach and boiled with shallot. The cockroach is then crushed and filtered. The filtered water is mixed with Chinese herb and drunk while warm.	Chung et al., 2001, 2005a
				Asthma	Cooked cockroach is ground and mixed with boiled water. The water is sifted and drunk.	Costa-Neto et al., 2000; Chung et al., 2001, 2005a
Indonesia	Australia, Africa, Asia, Europe, North and South America	*Phasmatidae*	*Ajong jepang, belalang*	Stomach upset	Feces of the insects are mixed with cold water and drank.	Afriyansyah et al., 2016
Indonesia	Africa, Asia, Australia, Europe, North and South America	*Pediculus humanus*	*Kutu kepala, kutu rambut*, fleas	Jaundice and treatment for liver diseases.	Whole insect is eaten raw, eaten with lady finger banana (*pisang mas*), or added with *Curcuma zanthorrhiza* (*temulawak*).	Zayadi et al., 2016; Prastikawati and Husain, 2019; Nukraheni et al., 2019
Malaysia	China, France, Greece, Israel, Italy, Pakistan, Portugal, Malaysia, Saudi Arabia, Spain, Sri Lanka, Taiwan, Thailand, Turkey, United Arab Emirates, Vietnam	*Rhynchophorus ferrugineus*	Red palm weevil, sago grub, *butod, wutod, tobindok, sungut*	Diarrhea	Larvae is boiled, stir-fried, or cooked in porridge (avoid overcooking).	Chung et al., 2001; Raheem et al., 2019; Ismail, 2015
				Mild tuberculosis	Larvae is eaten raw.	Chung et al., 2001; Ismail, 2015
Indonesia	Indonesia, Malaysia, Thailand	*Setora nitens*	Nettle caterpillar, *ulod daling*	Treatment for rashes caused by the caterpillar itself.	Guts are applied onto the skin.	Chung et al., 2003
Indonesia	Indonesia, Malaysia, Singapore, Thailand	*Valanga nigricornis*	Javanese bird grasshopper, Valanga grasshoppers, belalang *kunyit, kato mapoh*	Asthma, treatment for heart and supplement to boost stamina.	After removing legs and wings, grasshoppers are lightly salted, boiled with little water, and simmered until dry. Occasionally, they are stir-fried while the big ones are deep-fried until crispy. The insect can also be roasted. In Indonesia, these insects are marinade (using palm sugar and spices prior to frying. They are also served together with *Thiwul* (staple food from cassava).	Zayadi et al., 2016; Palupi et al., 2020
Malaysia	Africa, Asia, Europe, North America, South America	*Xylocopa* sp.	Carpenter bees	Sore throat	Bees are boiled with herbs and drunk.	Gimlette, 1939; Chung et al., 2001
Indonesia	Australia, Africa, Asia, Europe, North America	*Zeuzera* sp.	Cossid moth larva, *kalatang* (Indonesia)	Treatment for asthma, cancer, and excessive bleeding after giving birth.	The larvae are cooked and eaten.	Chung et al., 2003
				Treatment for insect and snake bites as well as wound.	Guts are removed by peeling off its head then kept in a large quantity in a bottle. It is then applied as ointment for bites and injuries.	

values of 19.5±1.7 and 52.7±4.0 μmol L^{-1}, respectively (Pattarayingsakul et al., 2017). In addition to antihypertensive activity, these ants have been processed into various tonics with notable defense and recovery of the immune system in mice (Sun-Waterhouse et al., 2016). Likewise, *R. ferrugineus* and sago grub (*R. bilineatus*), one of the local delicacies consumed in Papua Province in Indonesia, also demonstrated antihypertensive activities contributed by tocotrienol compounds along with other properties, including anticancer and neuroprotective properties (Köhler et al., 2020; Pan et al., 2022).

The notable American cockroach, *Periplaneta americana*, is a promising insect with various therapeutic effects, affecting asthma, earache, intestinal colic, diarrhea, sepsis, and cancer (Seabrooks et al., 2017; Verheyen et al., 2021). Although cockroaches are widely distributed around the world, the use of cockroaches in Malaysia has been recorded in the Dictionary of Malayan Medicine since 1939 (Gimlette, 1939). Interestingly, locals had previously discovered the potential of cockroaches to be used as medicine, particularly in alleviating an upset stomach by drinking water mixed with the ashes of cockroaches as well as relieving toothache by applying mashed cockroaches to the face (Gimlette, 1939). The therapeutic effects of insects are not only limited to alleviating internal diseases but also to curing skin problems. Locals in Indonesia have reported the application of guts of *Setora nitens* (nettle caterpillar) for the treatment of rashes caused by the caterpillar itself (Chung et al., 2003), while an insect native to Malaysia, *Erionota thrax* (*tataro*), demonstrated promising capabilities as a remedy for pimples through the utilization of white powdery substances on the *tataro's* larvae (Chung, 2008).

Although the consumption of insects for physiological well-being is still limited in Malaysia and Indonesia, the various ways in which insects have been utilized as medicines in different cultures should be discussed, as these serve as valuable leads for pharmacognosy and drug discovery in the future. Moreover, more research needs to be conducted to discover the metabolites and bioactive compounds that are involved in the therapeutic action exhibited by insects. Despite limitations for eating insects for Muslims, locusts have been deemed permissible for consumption by Islamic law. In the next section, we will discuss the possibility of using locusts to cure various ailments for the Muslim community.

5. Overview of insect consumption from the Halal perspective

Currently, there has been broad interest in insect consumption around the world as a sustainable replacement for livestock and staple foods (Jansson et al., 2019). However, knowledge of eating insects in Muslim countries is still scarce due to the possible religious connotations of eating insects. The term 'halal' is derived from an Arabic word that is defined as permissible, lawful, allowed, authorized, approved, sanctioned, legal, valid, or trustworthy (Khattak et al., 2011). Halal food is a food that is permissible according to Islamic Shari' ah law as revealed in the Quran by Allah, in the Hadith by Prophet Muhammad and in doctrines by scholars. Halal dietary laws generally consider the permitted and prohibited animals as well as slaughtering methods. Compared to halal animals, haram animals, which are defined as prohibited and impermissible, are clearly mentioned by the Prophet Muhammad and doctrines (Benzertiha et al., 2018). Among Islamic schools, only the Maliki sect allows the consumption of nonhazardous and nonpoisonous arthropods other than locusts, while only locusts are viewed as permissible by the Hanafi, Shafi'i, and Hanbali sects (Bakharudin and Yahaya, 2018; Rahim, 2018). The Hanafi schools consider all types of hasharaat, which refers to insects, rodents and reptiles, as haram, and insect-based food is prohibited (Bakharudin and Yahaya, 2018; Rahim, 2018; Tajudeen, 2020). This is further supported by a verse in the Al-Quran (Surah A'raf verse 158) that prohibits the consumption of khabeeth (malice, malignant and filthy things). In contrast, the Maliki school adjudicates that all types of hasharaat are permitted (halal), except those that are harmful and disgusted by people based on the verse of Al-Quran in Surah Al-Ma'idah (verse 93), which allows the consumption of all on earth except those that are prohibited by Shariah or harmful to humans (Bakharudin and Yahaya, 2018; Rahim, 2018; Tajudeen, 2020). The rule of carcasses is originally mentioned as impure as the word of Allah SWT, which means: "it is forbidden for you (to eat) carcasses (animals that die without being slaughtered)," as mentioned in verse 5:3 in Surah al-Mai'dah. Regarding the Shafi'i and Hanbali schools, both regard all insects, except locusts, as khabeeth (filthy); hence, they are regarded as not halal (Bakharudin and Yahaya, 2018; Rahim, 2018; Tajudeen, 2020).

Locusts are halal to be eaten regardless of scholars' differences of views or whether the locusts dies of natural causes, is killed by a Muslim or a magus, or dies with or without its head is cut of; this is the consensus view of the Shafi'i, Hanafi and Hanbali schools and of the majority of adherents of these schools (Nawawi, 2009). Locusts are frequently mentioned in numerous hadiths, with 14 hadiths describing the ethics or permissibility of eating locusts (Baharuddin et al., 2021). The ruling on locust consumption is further mentioned in Sahih Bukhari (Volume 7, Book 67, Number 403) as follows: "*I asked 'Abdullah bin Abu Awfa about killing locusts and he said: I went on six or seven military campaigns with the Messenger of Allah, and we ate locusts.*" (Tajudeen, 2020). In addition, locusts are also mentioned in Sunan Ibn Majah (Hadith No. 3219 and 3222) narrated by Abu Hurairah RA, who shares a story of Prophet Muhammad traveling together with his companions to perform hajj and umrah when they encounter a swarm of locusts and kill the locusts. The Prophet Muhammad said, *"Most of the forces of God, I do not eat them, and I do not forbid them"* (i.e., locusts) (Sunan Ibn Majah, Hadith No. 3219) and "*Eat them for they are the game of sea*" (Sunan Ibn Majah, Hadith No. 3222). Based on the scriptures that indicate their permissibility, locusts are halal to be eaten without the need to slaughter them because their carcasses are considered sacred, similar to the carcasses of aquatic animals. This is further supported by the sayings of Prophet Muhammad as follows: "*Two kinds of dead meat have been permitted to us: fish and locusts*" (Sunan Ibn Majah, Hadith No., 3218). This contrasts with the Maliki school, which justifies that edible insects should not be consumed alive but must be killed by plucking off the head, roasting or other permissible means and invoking the name Allah (Bismillah) on it while killing it (Tajudeen, 2020). In summary, most insects except locusts are stated to be haram for consumption, although no clear status is established about insects in Islam (Tajudeen, 2020).

In addition to locusts, insects such as crickets and cochineal have also been utilized as ingredients in the cosmetics and food industries. According to a previous study by Bakharudin and Yahaya, the use of hasharaat animals in cosmetic products is permissible if it is used for wound treatment, which can cause shame and deformity on the face or body (Bakharudin and Yahaya, 2019). Moreover, the permissibility for cochineal coloring in food products also differs among countries; Malaysia and Indonesia permit the use of carmine dye (E120) as halal, while Brunei, Iran, Pakistan, the United Arab Emirates and the Gulf states do not (Bakharudin and Yahaya, 2019; Salleh et al., 2020). The Malaysian National Fatwa Committee has agreed that cochineal is a type of insect (female beetle) that is not harmful and that the corpse of an insect whose blood does not flow, which includes the carcasses of cochineal insects, is sacred. Based on the ruling, Muzakarah agreed that the use of cochineal dyes obtained from dead cochineal insects in food, drinks and consumer goods is needed, and the permitted rate of use according to the ruling of the Ministry of Health is that it must not exceed 0.003% (it may be up to 0.006% if approved by the National Fatwa Council) (JAKIM, 2015; Manaf, 2017). Different opinions on the uses of cochineal dyes among these countries include understanding of the uncleanliness status of insect carcasses, the use of different fatwa elicitation methods between countries and consideration between the good and harmful benefit for consumers (Salleh et al., 2020). As such, permissibility of insects bred for human consumption should be discussed carefully among Islamic scholars to establish opinions that can render the consumption of insects as an alternative source of protein,

similar to the uses of cochineal color, if the required conditions are fulfilled. Moreover, nutritional quality and risk analysis of each insect are essential to allow insect-based food products to be certified as halal for global consumption in the future (Tajudeen, 2020).

6. Locusts as a delightful source for edible foods and compounds of human well-being for Muslim communities

Locusts have been confused with grasshoppers due to their similarity in physical appearance, but these two insects differ in their behavior (Symmons and Cressman, 2001). Locusts are short-horned grasshoppers that can exist in two behavioral states, which are solitary and gregarious at higher population densities, whereas grasshoppers are always solitary (Simpson and Sword, 2008). Both insects belong to the order Orthoptera and Acrididae family, with exception that all locusts belong to this family but not all species are considered as locust (Symmons and Cressman, 2001). As the permissibility of locust consumption is clearly mentioned in the hadith and agreed upon by all four Sunni madhab, namely, Hanafi, Maliki, Shafi'I and Hanbali, this section will discuss the compounds in locusts and their potential uses for human well-being globally.

Among the 12,000 grasshopper species described, 21 are regarded as locusts (Cullen et al., 2017). Table 3 summarizes the potential uses and bioactive compounds of locusts for human well-being, with desert locust (*Schistocerca gregaria*) and migratory locust (*Locusta migratoria*) as the most studied species, while other species are mostly studied for ecological characteristics and preventive control of locust outbreaks (Latchininsky, 2013).. In addition, these insects have demonstrated their effectiveness in curing anemia, with consuming a mixture of powdered locust and honey three times a day before meals being the most effective method. Interestingly, locusts are also used for fumigation against anuresis in women, as well as treatment for scorpion stings when dried and consumed with wine (Costa-Neto, 2005).

The locust is an insect containing various nutritional elements that can benefit human health. Most locusts contain high amounts of protein and fat, especially high amounts of omega-3, creating a desirable low omega-3/omega 6 ratio and providing protection against heart diseases (Egonyu et al., 2021). Desert locust (*S. gregaria*), which is rich in phytosterols, has the ability to lower cholesterol levels in the body and serve as an antihypertensive agent by inhibiting ACE (Vercruysse et al., 2005; Cheseto et al., 2015; Zielińska et al., 2015; Sun-Waterhouse et al., 2016; Kinyuru, 2021). In a previous study, *S. gregaria* was reported to be one of the most profitable insects to consume due to its high nutritional values compared to those of *Gryllus bimaculatus* and *L. migratoria* (Fombong et al., 2021). This is due to the notorious and devastating behavior of the insect, which prevents the use of insecticides when harvested, hence improving the livelihood and income of the affected areas. Nevertheless, locust species such as *L. migratoria* and *Nomadacris septemfasciata* also serve as potential sources of dietary fiber, boosting overall metabolic health (Turck et al., 2021; Mac Donald et al., 2022). A previous study reported the development of edible chitosan and oil as ingredients in the food, pharmaceutical and cosmetics industries (Baiano, 2020; Castro-López et al., 2020). Moreover, this chitosan could be shaped into various forms, including fibers, hydrogels, beads, sponges, and membranes, which could be applied in various fields, including agriculture, food packaging, or in the biomedical and pharmaceutical industries as drug delivery systems and formulations (Marei et al., 2016). Interestingly, bioactive compounds from insects such as retinol as well as collagenase and elastase inhibitors from *L. migratoria* and *P. succincta* demonstrated their potential as antiaging and anti-wrinkles agents and were also reported to be efficient in improving aging skin (Oonincx et al., 2011; Zielińska et al., 2015; Yeerong et al., 2021). The discovery of these compounds could contribute to the emergence of new, natural and halal locust-based products, adding value to the existing formulations in the cosmetics and skincare industries.

Compounds from insects have also been reported for their contribution in providing unique flavors for food products. Submerged fermentation of *L. migratoria* using *Aspergillus oryzae* as a starter culture and the insect powder demonstrated high levels of glutamate and aspartate, which are responsible for the savory and umami flavor characteristics (Mouritsen et al., 2017; Althwab et al., 2021). Glutamate also serves to improve appetite in older individuals, reduce sodium uptake, regulate food digestive processes, and release neurotransmitters (Jinap and Hajeb, 2010; Niaz et al., 2018). The uptake of aspartate as a supplement together with glutamate, tyrosine, serine, and alanine was reported to lower the symptoms of depression and other mental health problems among office workers. In addition, aspartate was also reported to increase the activity of oxidative metabolism in energy production, delay exhaustion during physical activity and serve as a neurotransmitter, although extensive consumption is associated with the occurrence of diabetes (Li et al., 2018; Zhao et al., 2019; Vangipurapu et al., 2019; Umeda et al., 2022). In addition to their unique contribution to food flavoring, *L. migratoria* also demonstrated a favorable polyunsaturated fatty acid (PUFA) percentage and n-6/n-3 ratio with a value of 1.3 along with a lower cholesterol content of 78.9 mg/100 g dry weight. The polyunsaturated fats extracted from *L. migratoria* showed interesting value-added ingredients for biomedical and nutritional products as well as fortified foods and health supplements (Ramos--Bueno et al., 2016; Clarkson et al., 2018).

In addition to crickets, cockroaches, beetles and butterfly larvae, protein hydrolysates and peptides from *S. gregaria* and *L. migratoria* have been reported to exhibit antioxidant activities (Castro-López et al., 2020; Jakubczyk et al., 2020). A previous study in which milk powder was substituted with 30% migratory locust powder (MLP) successfully demonstrated the highest radical scavenging ability against DPPH, indicating antioxidant capability and iron chelating activity. In addition, peanut-based ready-to-use therapeutic foods with MLP also showed high amino acid, thiamine and niacin levels, demonstrating the capability of MLP to be used as a cheap substitute for milk powder in producing ready-to-use therapeutic foods for the treatment of malnutrition (Akande et al., 2022). Interestingly, protein hydrolysates/peptides from edible insects have shown relatively high antioxidant activity compared to protein hydrolysates from fish, jujube red dates and canola, thus serving as a sustainable food ingredient for human well-being (Nongonierma et al., 2017).

Various studies have been conducted to improve organoleptic knowledge about the edible locust, such as by incorporating locusts into muffins, bread, cake, extruded rice, egg pasta, cookies, brood, and fermented sauce (Perez-Santaescolastica et al., 2022). A study by Cheseto and colleagues reported cookies prepared with insect oils as substitutes for traditional butter, which are compositionally richer in omega-3 fatty acids, flavonoids, and vitamin E than plant oils (Cheseto et al., 2020). However, cookies prepared with *S. gregaria* oil were negatively perceived with 50% dislikes due to their aroma and taste. Bread with *S. gregaria* powder also received a negative trend due to its smell, although no significant difference was observed for color and taste parameters, and a positive trend was reported for its texture (Haber et al., 2019). In addition, sensory evaluation for egg pasta and muffin derived from *L. migratoria* flour also reported low ratings for smell and color attributes despite improvement in the nutritional content, especially in the protein value (Çabuk and Yilmaz 2020; Çabuk, 2021). To improve the taste of edible insect flour-fortified food products, the addition of herbs or spices has been suggested to modify the smell of insect flour and encourage acceptability among consumers in the future (Çabuk and Yilmaz 2020).

7. Conclusion and recommendations

There is no doubt that insects have served as a potential source of unique compounds that can benefit humans. Compounds including bioactive peptides have prevalently been reported in various studies to exhibit prominent efficiency in protecting body cells and supporting

Table 3
List of locusts used globally for human well-being and their bioactive compounds/products.

Distribution (Continent/ Country)	Scientific Name	Common Name	Compounds/Products	Uses	References
Afghanistan, Africa, Europe, India, Middle East, Nepal, Pakistan	*Schistocerca gregaria*	Desert locust	Amino acids	Build and repair body tissue, source of energy, production of hormones and enzymes, and regulate immune system response.	Gibreil and Idris, 1997; Adeyemo et al., 2008; Zielińska et al., 2015; Wahed et al., 2019; Fombong et al., 2021
			Bioactive peptides	Antioxidant activity.	Zielińska et al., 2017a; Zielińska et al., 2018
				Anti-inflammatory.	Zielińska et al., 2017a; Zielińska et al., 2018
				Inhibition of angiotensin-converting enzyme (ACE), pancreatic lipase, and α-glucosidase activity.	Vercruysse et al., 2005; Nongonierma et al., 2017; Zielińska et al., 2020
			Chitin	Source of dietary fiber, reduce cholesterol absorption and prevent cancer.	Badanaro et al., 2014; Haber et al., 2019; Kietzka et al., 2021
			Chitosan	Prebiotics, improve gastrointestinal health and immune system, produce beneficial short-chain fatty acids, modulate gut microbiota, reduce pathogenic microorganisms, and support weight management.	Marei et al., 2016; Mohd Zaini et al., 2023
			Fatty acids (oleic acid, palmitic acid, omega-3 and omega-6)	Serves as energy source, supplier of essential fatty acids, prevention of heart disease, and increase palatability of foods by adding flavor.	Zielińska et al., 2015; Fombong et al., 2021; Kinyuru, 2021, Kietzka et al., 2022
			Flavonoids	Anticancer, anti-inflammatory, and antiviral properties.	Cheseto et al., 2020
			Micronutrients (copper, magnesium, iron, potassium, and zinc)	Human growth and maintenance of physiological functions.	Zielińska et al., 2015; Wahed et al., 2019; Fombong et al., 2021
			Phytosterols (β-sitosterol, campesterol and stigmasterol	Reduce cholesterol level, modulation of endothelial function, antioxidant, anti-inflammatory, anticancer and immune regulatory effects.	Cheseto, et al., 2015; Sun-Waterhouse et al., 2016; Kietzka et al., 2021
			Protein hydrolysates	Stimulate proliferation of human skin fibroblasts.	Zielińska et al., 2015; Nongonierma et al., 2017
			Vitamin B12	DNA synthesis, regenerating methionine for protein synthesis and methylation, and preventing homocysteine accumulation.	Fombong et al., 2021
			Vitamin E	Antioxidant properties and strengthen the immune system.	Cheseto et al., 2020
Australia, Asia, Africa, Europe	*Locusta migratoria*	Migratory locust	Amino acid, thiamine, and niacin	Treat malnutrition.	Mohamed, 2015a; Bernard and Womeni, 2017; Çabuk and Yilmaz 2020; Althwab et al., 2021; Çabuk, 2021; Fombong et al., 2021; Akande et al., 2022
			B-carotene	Precursors of vitamin A, anticancer, antioxidants, improve vision, enhance immune system, and lower the risk of heart disease.	Oonincx et al., 2011
			Chitin	Dietary fiber.	Althwab et al., 2021; Turck et al., 2021
			Fatty acids (palmitic acid, stearic acid, oleic acid, linolenic acid, omega-3, and omega-6)	Serves as energy source, supplier of essential fatty acids, prevention against cardiovascular diseases and increase palatability of foods by adding flavor.	Mohamed, 2015a, 2015b; Ramos-Bueno et al., 2016; Brogan, 2018; Clarkson et al., 2018; Althwab et al., 2021; Çabuk, 2021; Fombong et al., 2021
			Micronutrients (potassium, phosphorus, and sodium)	Human growth and maintenance of physiological functions.	Fombong et al., 2021
			Non-essential amino acids (aspartate)	Provide umami and savory flavor characteristic, increase the contribution of oxidative metabolism in energy production, delay exhaustion during exercise, serve as neurotransmitter, lower the symptom of depression and other mental illness when consumed with other amino acids.	Mouritsen et al., 2017; Li et al., 2018; Zhao et al., 2019; Althwab et al., 2021; Umeda et al., 2022
			Non-essential amino acids (glutamate)	Provide umami and savory flavor characteristic, increase appetite in older individuals, reduce sodium uptake, regulate food digestive process, serve as neurotransmitter, lower the symptom of depression and other mental illness when consumed with other amino acids.	Jinap and Hajeb, 2010; Mouritsen et al., 2017; Niaz et al., 2018; Zhao et al., 2019; Althwab et al., 2021; Umeda et al., 2022
			Protein hydrolysates/ peptides	Antioxidant activity.	Nongonierma et al., 2017; Zielińska et al., 2017b; de Castro et al., 2018

(*continued on next page*)

Table 3 (*continued*)

Distribution (Continent/ Country)	Scientific Name	Common Name	Compounds/Products	Uses	References
			Retinol	Improve aging skin and vision.	Oonincx et al., 2011
			Vitamin B12	DNA synthesis, regenerating methionine for protein synthesis and methylation, and preventing homocysteine accumulation.	Fombong et al., 2021
Bhutan, Cambodia, China, Hong Kong, Japan, Nepal, Philippines, Taipei, Vietnam	*Patanga succincta*	Bombay locust	Amino acids (histidine, lysine, methionine)	Antioxidant activity.	Chatsuwan et al., 2018; Indriani et al., 2020; Kingwascharapong et al., 2021; Yeerong et al., 2021
			Collagenase and elastase inhibitor	Protection against wrinkles and sagging skin.	Yeerong et al., 2021
			Fatty acids	Serves as energy source, supplier of essential fatty acids and increase palatability of foods by adding flavor.	Yhoung-aree, 2010
			Micronutrients (iron and zinc).	Human growth and maintenance of physiological functions.	Köhler et al., 2019
			Non-essential amino acids (glutamic acid, aspartic acid, alanine, glycine)	Provide umami and savory flavor characteristic.	Chatsuwan et al., 2018; Kingwascharapong et al., 2021
Africa	*Nomadacris septemfasciata*	Red locust	Amino acids	Build and repair body tissue, source of energy, production of hormones and enzymes, and regulate immune system response.	Mac Donald et al., 2022
			Chitin	Dietary fiber.	Mac Donald et al., 2022
			Micronutrient (iron)	Essential element for blood production.	Mac Donald et al., 2022
Africa	*Anacridium melanorhodon*	Tree locust	Amino acids	Build and repair body tissue, source of energy, production of hormones and enzymes, and regulate immune system response.	El Hassan et al., 2008; Bernard and Womeni, 2017; Meena and Meena, 2021
			Fatty acids	Increase palatability of foods by absorbing and retaining their flavors and help in the transport of nutritionally essential fat-soluble vitamins.	El Hassan et al., 2008; Meena and Meena, 2021
			Micronutrient (potassium and iron)	Human growth and maintenance of physiological functions.	El Hassan et al., 2008; Meena and Meena, 2021

disease prevention. Chitin from the insect exoskeleton also serves as a source of dietary fibers, while its derivative, chitosan, functions as a prebiotic that promotes a healthy gastrointestinal system. Instead of plants and nuts, which have been the main sources of phytosterols, these compounds can also be extracted from members of the locust family. These compounds were reported to be valuable as blood cholesterol level regulators, antioxidants, anticancer agents, and anti-inflammatory agents. Various evidence of insect compounds as remedies for illness and human health has been progressively documented from the region of Southeast Asia. Despite various capabilities exhibited by edible insects reported in this review paper, there is still a lack of research performed to study the bioactivities and therapeutic compounds that could be value-added ingredients in the pharmaceutical, food, cosmetics, and medical industries in the future. Moreover, a comprehensive study is needed to look at the gaps in existing knowledge to provide space for scholars and scientists to discuss the needs of entomophagy and refine the law for the benefit of Muslims in particular. Scientific exploration and updating of this traditional knowledge are vital to ensure continuous research efforts to discover more unique compounds for maintaining and improving the state of human wellbeing. The future of insect nutrition has opened a great research window in the Muslim halal food industry. Therefore, industry players and researchers in the halal food sector need to play a comprehensive role by carrying out research according to Islamic ethics meeting the demand of the entomophagy market globally. This would also provide an opportunity for halal certification bodies to be more proactive in establishing and controlling legislation related to insect-based food and its safety to ensure that universal human health is preserved. It is time for researchers in Southeast Asia to seize this opportunity and cultivate the utilities and benefits of these insect compounds.

Ethical Statement - Studies in humans and animals

There are no human or animal subjects in this article and informed consent is not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

This research was carried out with financial support from Delightex Pte. Ltd. and facilitation from Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia (Kuala Lumpur, Malaysia).

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