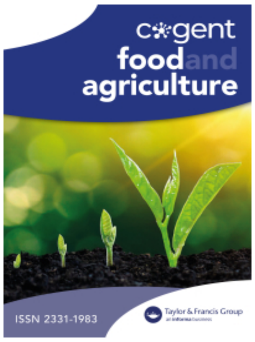

Taylor & Francis
Taylor & Francis Group

Cogent Food & Agriculture

ISSN: 2331-1932 (Online) Journal homepage: www.tandfonline.com/journals/oafa20

Edible ants (Hymenoptera: Formicidae) as human foods: a comprehensive review

Ito Fernando, Bara Yudhistira, Krishnamanikumar Premachandran, Shubhra Singh, Faiz Nashiruddin Muhammad, Natalya Pavlovna Oboturova , Andrey Ashotovich Nagdalian , M. Bayu Mario, Luqman Qurata Aini & Widya Satya Nugraha

To cite this article: Ito Fernando, Bara Yudhistira, Krishnamanikumar Premachandran, Shubhra Singh, Faiz Nashiruddin Muhammad, Natalya Pavlovna Oboturova , Andrey Ashotovich Nagdalian , M. Bayu Mario, Luqman Qurata Aini & Widya Satya Nugraha (2025) Edible ants (Hymenoptera: Formicidae) as human foods: a comprehensive review, Cogent Food & Agriculture, 11:1, 2568196, DOI: 10.1080/23311932.2025.2568196

To link to this article: https://doi.org/10.1080/23311932.2025.2568196

Published online: 08 Oct 2025.

COGENT FOOD & AGRICULTURE
2025, VOL. 11, NO. 1, 2568196
https://doi.org/10.1080/23311932.2025.2568196

ENTOMOLOGY | REVIEW ARTICLE

OPEN ACCESS

Check for updates

Edible ants (Hymenoptera: Formicidae) as human foods: a comprehensive review

Ito Fernando[a], Bara Yudhistira[b], Krishnamanikumar Premachandran[c], Shubhra Singh[d], Faiz Nashiruddin Muhammad[a,e], Natalya Pavlovna Oboturova[f], Andrey Ashotovich Nagdalian[f], M. Bayu Mario[g], Luqman Qurata Aini[a] and Widya Satya Nugraha[h,i]

[a]Department of Plant Pest and Diseases, Faculty of Agriculture, Universitas Brawijaya, Malang, East Java, Indonesia; [b]Department of Food Science and Technology, Sebelas Maret University, Surakarta, Indonesia; [c]Centre for Climate Change Studies, International Research Centre, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India; [d]Department of Tropical Agriculture and international Cooperation, National Pingtung University of Science and Technology, Pingtung, Taiwan; [e]Species Obscura, Depok, Jawa Barat, Indonesia; [f]North Caucasus Federal University, Stavropol, Russia; [g]Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Hasanuddin, Makassar, Indonesia; [h]Department of Agricultural Socio-Economics, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia; [i]Doctoral School of Food Science, Hungarian University of Agriculture and Life Sciences, Budapest, Hungary

ABSTRACT

The consumption of insects by humans has been around since the dawn of mankind, with many people around the world incorporating edible insects into their diets today. This practice is increasingly recognized as a potential solution to food insecurity issues. It is worth noting that ants (Hymenoptera: Formicidae) occupy a significant position within entomophagy since they are one of the most noticeable and plentiful groups of insects in forests, agricultural ecosystems, and urban habitats. As much as 59 species of ants are recognized as edible and are consumed during their egg, larva, pupa, or adult stage. However, available scientific information shows that their consumption must be accompanied by standardized and sustainable production. In this review, the use of ants as food will be discussed, with special reference to different ant species, the regional and country-specific meanings, differences in entomophagy related to ants, the bioecology, nutritional characteristics, and pharmaceutical benefits, and the rearing and processing processes. Additionally, consumer acceptance towards the consumption of edible ants will be overviewed. This review aims to provide a foundation for further research on the use of ants as food, while serving as a valuable source of information in response to growing interest in this field.

ARTICLE HISTORY
Received 31 January 2024
Revised 21 August 2025
Accepted 24 September 2025

KEYWORDS
Edible insects; food insecurity; entomophagy; nutritional characteristics; consumer acceptance

SUBJECTS
Entomology; Food Additives & Ingredients; Food Chemistry; Nutrition

1. Introduction

The various global developments today are leading to changes in the way humans live. Progressive climate change is one of the greatest challenges facing humanity and is associated with far-reaching effects on human life and health, as well as on life on Earth in general (El Bilali et al., 2020). Mitigating the effects of climate change and combating this process will require changes in all aspects of life, including the production and provision of food for humans (Lake et al., 2012). In addition, the continued growth of the world's population—projected to reach 9.7 billion in 2050 and potentially peak at nearly 10.4 billion in the 2080s—will lead to increased demand and a greater need for food, which is expected to rise by 60% by 2050 (Lee et al., 2021; Payne & Van Itterbeeck, 2017; Szmigiera, 2022). Furthermore, 795 million people suffer from hunger today; in Africa, for example, 30% of children under the age of five suffered from chronic malnutrition and another 7% from acute malnutrition in 2017 (Casas Reátegui

CONTACT Ito Fernando i_fernando@ub.ac.id Department of Plant Pest and Diseases, Faculty of Agriculture, Universitas Brawijaya, Malang, East Java, Indonesia; Widya Satya Nugraha widya.satya.nugraha@ugm.ac.id Department of Agricultural Socio-Economics, Faculty of Agriculture, Universitas Gadjah Mada, 55281, Yogyakarta, Indonesia.

et al., 2018; Mariod, 2020). To address these developments without creating food insecurity or increasing greenhouse gas emissions in the food sector, innovative approaches are needed (Chen et al., 2009). Consumption of alternative foods has also increased in recent years for various reasons, such as ethnic preferences or environmental concerns (Batat & Peter, 2020).

One such innovation in the food supply is the consumption of edible insects. The consumption of insects by humans, known as entomophagy, can be traced back to the dawn of humankind and even to primate relatives. Evidence of this practice exists in antiquity, such as 3,000-year-old records from China (Chen et al., 2009; Meyer-Rochow et al., 2021). The history of entomophagy extends into modern times and has resulted in insects being part of the diets of 2 billion people in over 113 countries today (Batat & Peter, 2020; Chakravorty et al., 2013). Consumption is especially common in Africa, Asia, and South America, whereas it is uncommon in Western countries and often evokes disgust (FAO, 2013). Despite this food neophobia, entomophagy is becoming more popular in Western countries, with increasing public interest in the topic, and eating insects is slowly gaining importance (Batat & Peter, 2020).

Approximately 500 insect species are used for human consumption in Africa alone, and over 2,100 species are consumed worldwide, most of which are native to tropical regions (Batat & Peter, 2020; Casas Reátegui et al., 2018; Mariod, 2020; Mitsuhashi, 2016; Van Itterbeeck & Pelozuelo, 2022). Among these, locusts, crickets, beetles, caterpillars, bees, and ants are the most widely consumed (FAO, 2013). Insects are a sustainable, nutritious, and protein-rich alternative to other foods, and they are relatively easy to maintain and rear. They provide proteins, amino acids, fats, carbohydrates, vitamins, and trace elements through their beneficial composition (Chen et al., 2009). In addition, compared with animals raised in factory farms, insects require less land and emit fewer greenhouse gases (Lee et al., 2021).

Recent work highlights that ants are widely recognized as edible insects, consumed not only directly as food but also as flavoring agents and ingredients in diverse culinary preparations across Africa, Latin America, Europe, and Asia (van Huis, 2025). In this review, the use of ants (Hymenoptera: Formicidae) as food for humans is considered and discussed. The review provides a checklist of known edible ant species along with their regional consumption and importance. Furthermore, it discusses the bioecology and nutritional properties, as well as the pharmaceutical benefits, of the most commonly consumed ant species. Finally, the rearing, harvesting, and processing of ants are addressed. In view of the changing public perception of entomophagy and the expected increase in its importance, this review summarizes the literature to date on the consumption of ants and provides a basis for future research on this specific form of entomophagy.

2. List of edible ants and records of their consumption in the world

Ants are a common food consumed by humans worldwide (Gahukar, 2020). The high demand for consuming ants is due to the fact that they contain numerous beneficial nutrients for the human body (Chakravorty et al., 2016). Table 1 shows 59 species of ants that can be eaten by humans, along with information on their common names, the stage at which they are eaten, and the countries where they are consumed.

According to a review of the literature, people on every continent except Antarctica consume insects (including ants) (Figure 1). This clearly shows that ants have excellent potential for development as human food (Gahukar, 2020). Nonetheless, despite many scientific studies and professional assertions that ingesting insects is safe, there are several factors in the marketing process that impede their acceptance for human consumption, such as health, environmental, and livelihood considerations (Deka et al., 2021). Over time, factors such as traditional beliefs, consumers' increasing awareness of environmental protection, and regional and seasonal availability have led to certain species, such as ants, being accepted as food (Deka et al., 2021; Gahukar, 2020; Kalita et al., 2022; Nsevolo et al., 2023).

Insects are a historic element of many people's diets worldwide, but many consumers are aware that insect-based foods are also healthy, nutritious, and serve as an alternative source of protein to chicken, beef, pork, and fish (Fernando et al., 2023; Kasza et al., 2023). Insects have a significant nutrition value, including protein, fat, carbohydrates, minerals, and vitamins. Despite their individually small size, ants are extremely nutrient-dense, and humans consume all stages of their life cycle as food (Raheem et al., 2019). Ants are consumed both as a solid food and in a liquid form (frequently served as beverage)

Table 1. Global list of edible ant species.

No	Species	Vernacular name	Stage consumed	Country	Consumption style	Reference
1	*Acromyrmex octospinosus* (Reich)	Leaf-Cutter ants	Reproductive adult	North America: Mexico	NA	(Jongema, 2017; Ramos-Elorduy & Pino Moreno, 2002)
2	*Acromyrmex rugosus* (Smith)	Leaf-Cutter ants	Reproductive adult	North America: Mexico	NA	(Jongema, 2017; Ramos-Elorduy & Pino Moreno, 2002)
3	*Atta bisphaerica* Forel	Leaf-Cutter ants	Winged Adult	South America: Brazil	NA	(Costa-Neto & Ramos-Elorduy, 2006; Jongema, 2017)
4	*Atta capiguara* Goncalves	Leaf-Cutter ants	Adult	South America: Brazil	NA	(Costa-Neto & Ramos-Elorduy, 2006; Jongema, 2017)
5	*Atta cephalotes* (L.)	Leaf-Cutter ants	Winged adult and soldier	South America: Brazil Colombia Guyana Honduras Nicaragua Mexico, Ecuador, Venezuela	Toasting, Frying	(Araujo & Bessera, 2007; Casas Reátegui et al., 2018; Costa-Neto & Ramos-Elorduy, 2006; DeFoliart, 2002; Dufour, 1987; Jongema, 2017; Onore, 2005)
6	*Atta laevigata* (Smith)	Leaf-Cutter ants	Winged adult and soldier	South America: Colombia	Boiled, Frying, Roasted	(Costa-Neto & Ramos-Elorduy, 2006; DeFoliart, 2002; Dufour, 1987; Gahukar, 2011; Jongema, 2017; Kooij et al., 2018)
7	*Atta mexicana* (Smith)	Leaf-Cutter ants	Reproductive adult	North America: Mexico	NA	(DeFoliart, 2002; Jongema, 2017; Ramos-Elorduy & Pino Moreno, 2002)
8	*Atta opaciceps* Borgmeier	Leaf-Cutter ants	Adult	South America: Brazil	NA	(Costa-Neto & Ramos-Elorduy, 2006; Jongema, 2017)
9	*Atta sexdens* (L.)	Leaf-Cutter ants	Winged adult and soldier	South America: Brazil, Colombia, Ecuador	Flour	(Bendezu Ccanto et al., 2022; Costa-Neto & Ramos-Elorduy, 2006; DeFoliart, 2002; Dufour, 1987; Jongema, 2017; Onore, 2005)
10	*Atta texana* Buckley	Leaf-Cutter ants	NA	North America: Mexico	NA	(Jongema, 2017; Katz, 2016)
11	*Camponotus aurocinctus* (Smith)	Golden bearded sugar ants	Honey pot	Oceania: Australia	NA	(DeFoliart, 2002; Jongema, 2017)
12	*Camponotus consobrinus* (Erichson)	Banden Sugar Ants	Pupa	Oceania: Australia	NA	(DeFoliart, 2002; Jongema, 2017)
13	*Camponotus dumetorum* Wheeler	Carpenter ant	Adult	North America: Mexico	NA	(Jongema, 2017; Ramos-Elorduy & Pino Moreno, 2002)
14	*Camponotus inflatus* Lubb.	Honey pot ants	Honey pot	Oceania: Australia	Raw	(DeFoliart, 2002)
15	*Camponotus japonicus* Mayr	Japanese carpenter ant	Egg, larva, pupa, and adult	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
16	*Camponotus maculatus* Fabricius	Carpenter ant	Larva, pupa, and adult	North America: USA	Boiled (beverage), raw, oral medicine	(Jongema, 2017; Schrader et al., 2016)
17	*Camponotus pennsylvanicus* De Geer	Black carpenter ant	NA	North America: USA	NA	(Jongema, 2017; Schrader et al., 2016)
18	*Carebara castanea* Smith	Subterranean ant	Egg and adult	Asia: Thailand	NA	(Hanboonsong et al., 2013; Jongema, 2017; Krongdang et al., 2023)
19	*Carebara lignata* Westwood	Harvester ants	Adult	Africa: Bostwana, Mozambique, Namibia, Sudan, South Africa, South Sudan, Zambia, Zimbabwe. Asia: China	NA	(Chen et al., 2009; Hlongwane et al., 2020; Jongema, 2017; Kelemu et al., 2015)

(*Continued*)

Table 1. Continued.

No	Species	Vernacular name	Stage consumed	Country	Consumption style	Reference
20	*Carebara vidua* Smith	African thief ant	Winged adult	Africa: South Africa, Zambia, Zimbabwe, Malawi, D.R.	Dried, raw, fried, boil, medicine	(Ayieko et al., 2012; Chavanduka, 1976; Gelfand, 1975; Hlongwane et al., 2020; Jongema, 2017; Kelemu et al., 2015; Mbata, 1995; Okia et al., 2017; Silow, 1983; van Huis, 2017)
21	*Cephalotes atratus* (L.)	Common Giant Turtle Ant	Adult	South America: Peru	Roasting	(Casas Reátegui et al., 2018; Jongema, 2017)
22	*Colobopsis gasseri* (Forel)	Plug ants	Pupa	Oceania: Australia	NA	(DeFoliart, 2002; Jongema, 2017)
23	*Crematogaster rogenhoferi* (Mayr)	Cocktail ant	Egg	Asia: Vietnam	Cake, sticky rice, soup	(Pham et al., 2024)
24	*Crematogaster vandermeermohri* Menozzi	Cocktail ant	NA	Asia: Indonesia	NA	(Jongema, 2017; Meer, 1965)
25	*Dinomyrmex gigas* (Latreille)	Giant forest ant	Egg and adult	Asia: Malaysia	Spices	(Chung et al., 2002; Gahukar, 2011; Jongema, 2017)
26	*Dorylus nigricans* Illiger	Driver ant	Pupa	Africa: Cameroun	NA	(Jongema, 2017; van Huis et al., 2013)
27	*Eciton burchellii* (Westwood)	Army ant	Adult	South America: Venezuela	NA	(Araujo & Bessera, 2007; Jongema, 2017)
28	*Formica aquilonia* Yarrow	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
29	*Formica beijingensis* Wu	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
30	*Formica fusca* L.	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
31	*Formica japonica* Motsch	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
32	*Formica rufa* L.	Red wood ant	Adult	Europe: Sweden, Norway, Denmark	Medicine, sandwich, and ant vinegar, beverage (alcohol)	(Svanberg & Berggren, 2019)
33	*Formica sanguinea* Latr.	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
34	*Formica truncorum* F.	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
35	*Formica uralensis* Ruzsky	Wood ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
36	*Lasius flavus* (F.)	Yellow meadow ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
37	*Liometopum apiculatum* Mayr	Escamolera ant or giant velvety ant	Egg, larva, and pupa	North America: Mexico	Escamoles	(DeFoliart, 2002; González-Escobar et al., 2018; Jongema, 2017; Ramos-Elorduy, 2006; Ramos-Elorduy et al., 1998)
38	*Liometopum luctuosum* Wheeler	Escamol ant	Egg, larva, and pupa	North America: Mexico	Escamoles	(DeFoliart, 2002; Jongema, 2017; Pino Moreno et al., 2006; Ramos-Elorduy et al., 1998)
39	*Melophorus bagoti* Lubb.	Honey ants	Honey pot	Oceania: Australia	Raw	(DeFoliart, 2002; Jongema, 2017)
40	*Myrmecia pyriformis* Smith	Bull ants	Pupa	Oceania: Australia	NA	(DeFoliart, 2002; Jongema, 2017)
41	*Myrmecocystus melliger* Forel	Honey ants	Honey pot	North America: Mexico	Raw	(Costa-Neto & Dunkel, 2016; DeFoliart, 2002; Jongema, 2017; Ramos-Elorduy, 2006; Ramos-Elorduy et al., 1998; van Huis et al., 2013)
42	*Myrmecocystus mexicanus* Wesmael	Honeypot ants	Honey pot	North America: Mexico	Raw	(DeFoliart, 2002; Jongema, 2017; Ramos-Elorduy, 2006)
43	*Myrmicaria brunnea* (Saunders)	Short-legged hunchbacked ant	NA	Asia: India	Oral medicine	(Aidoo et al., 2023; Siddiqui et al., 2023)
44	*Odontoponera denticulata* (Smith)	Scavenger ant	Egg, larva, pupa and adult	Asia: Vietnam	Soup	(Pham et al., 2024)

(*Continued*)

Table 1. Continued.

No	Species	Vernacular name	Stage consumed	Country	Consumption style	Reference
45	*Oecophylla longinoda* (Latr.)	Weaver ants	Adult	Africa: Cameroun, Congo, Nigeria	Dried, raw, fried, and boil	(DeFoliart, 2002; Hlongwane et al., 2020; Jongema, 2017; Meutchieye et al., 2016; Tamesse et al., 2016)
46	*Oecophylla smaragdina* (F.)	Green tree ants, red ant, or Asian weaver ant	Egg, larva, pupa, and adult	Oceania: Australia, Papua New Guinea. Asia: Thailand, India, Laos, Vietnam, Myanmar, China	Chutney, paste, frying with oil, and additional ingredient, oral medicine, salt, salad, stir fry	(Barennes et al., 2015; Chakravorty et al., 2011; Chen et al., 2009; Chen & Feng, 1999; DeFoliart, 2002; Durst & Hanboonsong, 2015; Gahukar, 2020; Hanboonsong et al., 2013; Jongema, 2017; Megu et al., 2019; Mitra et al., 2020; Mozhui et al., 2020; Offenberg & Wiwatwitaya, 2010; Pham et al., 2024; Raza et al., 2022; Sangma et al., 2016; Siddiqui et al., 2023; Sribandit et al., 2009; Van Itterbeeck, 2014; Van Itterbeeck et al., 2014; Wetterer, 2017)
47	*Pogonomyrmex barbatus*	Red harvester ants	Larva, pupa, and adult	North America: Mexico	NA	(Jongema, 2017; Ramos-Elorduy, 2006; Ramos-Elorduy et al., 1998)
48	*Pogonomyrmex californicus* (Buckley)	California harvester ants	Larva, pupa, and adult	North America: USA	Oral medicine	(DeFoliart, 2002; Jongema, 2017; Siddiqui et al., 2023)
49	*Pogonomyrmex desertorum* Wheeler	Harvester ants	Larva, pupa, and adult	North America: USA	NA	(DeFoliart, 2002; Jongema, 2017)
50	*Pogonomyrmex occidentalis* (Cresson)	Western harvester ants	Larva, pupa, and adult	North America: USA	NA	(DeFoliart, 2002; Jongema, 2017)
51	*Pogonomyrmex salinus* Olsen	Harvester ants	Larva, pupa, and adult	North America: USA	NA	(DeFoliart, 2002; Jongema, 2017)
52	*Polyrhachis dives* Smith	Black weaver ant, black chinese ant	Egg, larva, pupa, and adult	Asia: China, Bangladesh, Malaysia, Sri Lanka	Medicine, beverages, additional ingredient	(Bhulaidok et al., 2010; DeFoliart, 2002; Guining et al., 2018; Jongema, 2017; Tang & Dai, 2018; van Huis et al., 2013; Wetterer, 2017; Zhang et al., 2022)
53	*Polyrhachis illaudata* Walker	Spiny ant	Larva and pupa	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
54	*Polyrhachis lamellidens* Smith	Spiny ant	Egg, larva, pupa, and adult	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
55	*Polyrhachis proxima* (Roger)	Spiny ant	Egg	Asia: Vietnam	Cake, sticky rice, soup	(Pham et al., 2024)
56	*Polyrhachis vicina* Roger	Chinese black ant	adult	Asia: China	Medicine	Bhulaidok, (Bhulaidok et al., 2010; Jin-Fu & Jue, 2016; Li et al., 2009)
57	*Pseudoneoponera rufipes* (Jerdon)	Black ant	NA	Asia: India	Oral medicine	(Choudhary et al., 2022; Seabrooks & Hu, 2017; Siddiqui et al., 2023)
58	*Tetramorium caespitum* (L.)	Pavement ant	Egg, larva, pupa, and adult	Asia: China	NA	(Chen & Feng, 1999; Jongema, 2017; Yin et al., 2017)
59	*Tetraponera rufonigera* (Jerdon)	Iron ant	NA	Asia: India	Oral medicine	(Aidoo et al., 2023; M. P. Borah & Prasad, 2017; Siddiqui et al., 2023)

(Nordic Food Lab, 2014; Svanberg & Berggren, 2019). In certain cultures, people consume ants for their medicinal benefits (Svanberg & Berggren, 2019). Therefore, it can be concluded that ants serve a variety of purposes, may be ingested at different stages (pupae, larvae, and adults), and can be served with a variety of foods and beverages, depending on the location or nation.

On the Asian continent, many nations, such as Thailand, India, Laos, Vietnam, China, Bangladesh, Malaysia, and Sri Lanka, consume ants at various stages of their life cycles, including eggs, larvae, pupae,

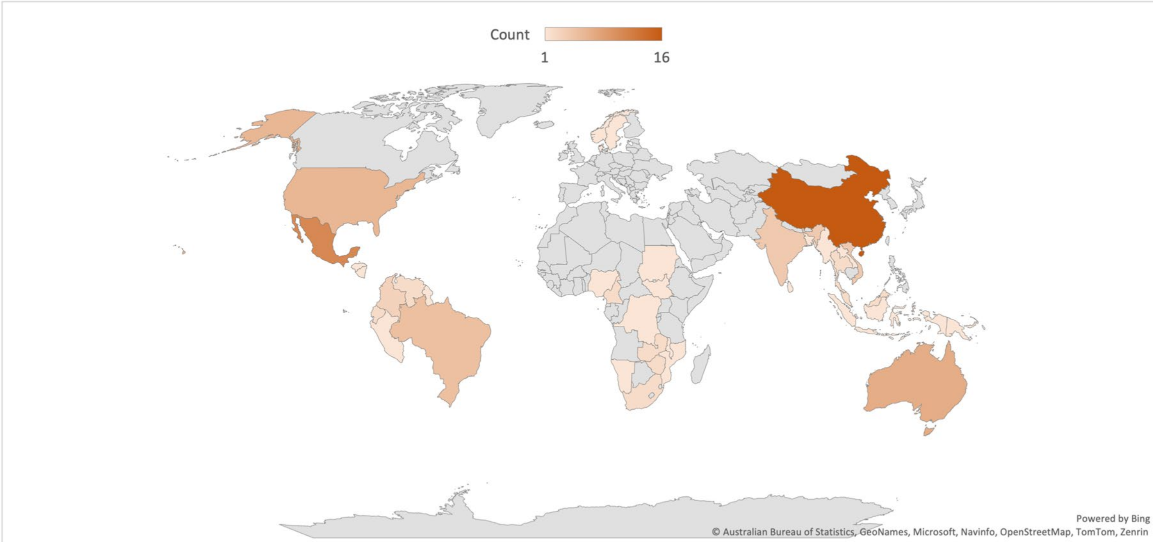

Figure 1. Number indication of edible ant species through heat-map. The redness depth responses to the number of species consumed in each country.

and adults (AntWeb, 2022; Chakravorty et al., 2016; Gahukar, 2020; Megu et al., 2019; Mozhui et al., 2020; Raza et al., 2022; van Huis et al., 2013). The majority of ant species on the Asian continent are *Oecophylla smaragdina* (Thailand, India, Laos, and Vietnam) and *Polyrhachis dives* (India, China, Bangladesh, Malaysia, and Sri Lanka) (AntWeb, 2022; Raza et al., 2022; van Huis et al., 2013). In addition, practically every country in Asia uses ants as an extra component of food preparation (AntWeb, 2022; van Huis et al., 2013). However, in China, ants are also used as medicines because of their kidney-strengthening, anti-inflammatory, antioxidant, natural painkiller, and immune-boosting properties (Clark, 2022; Dragon Herbs, 2022; Oonincx et al., 2010). At the same time, in Thailand and India, *O. smaragdina* can be eaten with a variety of dishes, such as chutney, paste, and oil-frying (Megu et al., 2019; Mozhui et al., 2020; van Huis et al., 2013). In addition, canned food products containing ants have been developed in Thailand (Gahukar, 2020; Van Itterbeeck, 2014). The variety of processed insect-based food products, notably ants, in Thailand is a result of the fact that its residents already see insects as food that is suitable for human consumption and is in great demand (Durst & Hanboonsong, 2015; Gahukar, 2020; Liévano, 2011; Van Itterbeeck, 2014).

Ants are among the insects often eaten in European nations, particularly in Sweden, Norway, and Denmark. *Formica rufa* is a common ant found throughout Europe and is mainly eaten at the adult stage (Nordic Food Lab, 2014; Svanberg & Berggren, 2019). In Sweden, ants are used to prepare sandwiches and vinegars (Svanberg & Berggren, 2019). Norway and Denmark utilize ants as ingredients in beverages (alcohol) (Svanberg & Berggren, 2019). In addition, ants are used as medication in Sweden and Denmark (Nordic Food Lab, 2014; Svanberg & Berggren, 2019). In Sweden, people frequently boil ants and their nests before using them for showering or bathing to relieve rheumatic pain (Svanberg & Berggren, 2019). In Denmark, the oil from ants is extracted and used to treat rheumatism and back pain (Nordic Food Lab, 2014; Svanberg & Berggren, 2019).

Furthermore, ant species in North America vary by nation, such as *Atta mexicana* in Mexico and *Camponotus maculatus* in the US (Raheem et al., 2019; Schrader et al., 2016). Mexican and American natives, particularly "Onondaga," devour ants at all stages, including larvae, pupae, and adults (Raheem et al., 2019; Schrader et al., 2016). However, there is a small variation in how it is consumed in America. In addition to utilizing ants as culinary ingredients and eating them raw, they also boil them in coffee (Schrader et al., 2016). In Mexico, ants are often used as ingredients in sauces; however, they are sometimes roasted or fried and serve as the main basis in main courses (Gallardo-López et al., 2023).

Ants are one of the greatest options for insect-based foods since they are one of the most noticeable and plentiful groups of Hymenoptera in forests, agricultural ecosystems, and urban habitats (Pazmiño-Palomino & Troya, 2022). Because of the abundance of ants and their high nutritional value for humans, some South American nations, including Ecuador, Colombia, and Peru, have begun to use ants as food in their everyday lives (Abril et al., 2022; Casas Reátegui et al., 2018; Kooij et al., 2018). In the markets of Ecuador and Colombia, there is a demand for processed ant products, such as fried ants, because of the growing public awareness of the beneficial substances present in insects, particularly ants (Kooij et al., 2018). In fact, owing to the rising value of ants, many individuals have turned to ant hunting as a profession, since ants are a strong selling point in Ecuador and Colombia (Kooij et al., 2018). In Peru, people often prepare ants as food for themselves and their families, and they do it in a more dynamic cooking style, notably, in addition to frying, they typically roast ants for consumption (Casas Reátegui et al., 2018).

In Africa, edible insects constitute an essential source of food because, aside from having high nutritional value, they are also very affordable in the market, or they can even be acquired from the surrounding environment (Okia et al., 2017). Table 1 shows that many African nations have reported instances of ant consumption. However, the record of how Africans consume or cook ants as food is not well documented academically (Christensen et al., 2006; Ehonou et al., 2018; Hlongwane et al., 2020; Kelemu et al., 2015; Meutchieye et al., 2016; Musundire et al., 2016; Okia et al., 2017; Tamesse et al., 2016). Africans eat ants raw, dried, ground into flour, fried, or boiled (Hlongwane et al., 2020; Kelemu et al., 2015; Raheem et al., 2019). Moreover, the majority of Africans consume ants at the adult stage (Hlongwane et al., 2020).

Following the findings from the list of edible ants, as well as the documented consumption of ants among various cultures and regions, it can be inferred that these practices vary widely, as people incorporate ants into different foods, reflecting the diverse practices and customs of local communities. This global blend demonstrates the extent to which ants can be utilized as a food source and their important role in many ethnic cuisines and traditions.

3. Bioecology of ants

Ants, often considered the unassuming inhabitants of ecosystems, are remarkable creatures of diverse forms and functions. With more than 14,000 identified species (Kass et al., 2022), ants represent a highly successful insect group in terms of ecological dominance. These tiny but highly organized insects have a significant impact on ecosystems, making them a subject of considerable interest to entomologists and ecologists. Ecologically, ants occupy a wide range of habitats, from forests to arid area, concentrated in tropical and subtropical region, displaying remarkable adaptability (Dantas & Fonseca, 2023; Ji, 2024). They build nests underground, in trees, or within vegetation, depending on the species. Ants engage in diverse ecological interactions, including mutualistic relationships with plants, in which they protect plants from herbivores in exchange for food and shelter (Rico-Gray & Oliveira, 2007). As predators, ants regulate arthropod populations, exerting significant control over pest species (Anjos et al., 2022). Additionally, ants contribute to soil aeration, nutrient cycling, and seed dispersal, with certain plant species relying on ants for effective seed dispersal through a mutualistic process (Ortiz et al., 2021).

3.1. Life cycle

Ants are highly organized insects that exhibit a fascinating life cycle, reproductive behavior, and ecological relationships. Their life cycle follows a complete metamorphosis, beginning with the queen laying eggs that hatch into larvae. These larvae are nourished by worker ants and undergo rapid growth. The larvae then enter the pupal stage, during which they undergo significant structural changes, ultimately emerging as adults. The adult ants assume different roles within the colony, including workers, soldiers, or reproductive individuals (queens and males) depending on their caste (Trible & Kronauer, 2017). Reproductive behavior in ants is caste-based, with queens being the primary egg layers, males mating with queens before dying, and workers performing essential colony tasks, such as foraging, nest maintenance, and brood care. In some species, workers may even lay unfertilized eggs that develop into males, adding a level of reproductive flexibility to the colony's structure (Giehr et al., 2020).

3.2. Bioecology of important edible ant species

Edible ants have long been regarded as a culinary delicacy across numerous cultures worldwide, with their consumption tracing back centuries. Depending on local traditions and preferences, they are enjoyed in a variety of forms, such as fresh, roasted, boiled, sun-dried, or incorporated into complex traditional dishes. A wide range of ant species are consumed globally; however, in the present study, we focus on four prominent edible ant species—*Carebara vidua*, *Liometopum apiculatum*, *Oecophylla smaragdina*, and *Polyrhachis vicina*. These species were selected due to their extensive documentation, high number of consumption records, and presence in multiple countries, as well as their frequent discussion in the scientific literature, making the discussion of their specific bioecology particularly important.

3.2.1. Carebara vidua

Carebara vidua (African thief ant) constructs intricate subterranean nests composed of narrow tunnels and chambers near termite mounds, which serve as suitable sites for food sources (van Huis, 2002). The distribution of *C. vidua* spans tropical regions of Africa. Its nests are typically established in warm, undisturbed environments where stable microclimatic conditions support colony development and longevity. A colony has been estimated to contain more than 12,000 adults, 11,000 pupae, 18,000 larvae, and 13,000 eggs. The largest nests, measuring 50 cm in length and 30 cm in width, can contain up to 124,500 adults, 155,300 pupae, 109,400 larvae, and 4,100 eggs (Lepage & Darlington, 1984). Colony foundation in *C. vidua* begins with an alate virgin queen, sometimes accompanied by several workers attached to her. After the nuptial flight, the dealate queen begins burrowing within 10 minutes and forms a round underground chamber measuring 18–25 mm in diameter, where she lays her eggs. The first workers emerge after 28 days, and by 39 days, the colony is estimated to contain more than 1,000 individuals (Lepage & Darlington, 1984).

3.2.2. Liometopum apiculatum

Liometopum apiculatum, commonly known as escamol or escamolera ant, is a highly adaptable ant species distributed throughout arid and semi-arid regions of western North America (García-Sandoval et al., 2022; Hernández-Roldán et al., 2024). Its ecological success is attributed to behavioral plasticity, environmental resilience, and complex social structure (Hoey-Chamberlain et al., 2013). This species primarily inhabits oak-pine woodlands, montane forests, and desert margins, where it nests in decaying logs, beneath rocks, and in soil cavities. Colonies are frequently polydomous, occupying multiple nest sites that are spatially distributed but functionally integrated. Such nesting flexibility enables *L. apiculatum* to persist in fragmented or disturbed habitats (Hoey-Chamberlain et al., 2013). Socially, *L. apiculatum* colonies are large and may be polygynous, with multiple reproductive queens contributing to brood production (Hoey-Chamberlain et al., 2013). Worker ants exhibit pronounced territorial aggression and robust nest defense behavior, which is reinforced by the release of volatile alarm pheromones when threatened. These secretions—comprising compounds such as 6-methyl-5-hepten-2-one, acetic acid, and isovaleric acid—create a distinct and pungent odor often smell like rotten coconut, serving both as a chemical defense and a communication signal (Hoey-Chamberlain, 2012). Nests of *L. apiculatum* are characterized by distinctive honeycombed, carton-like structures, formed by agglomerated soil and oral secretions, providing structural integrity and moisture resistance (Hoey-Chamberlain, 2012). Workers exhibit bimodal allometry, with major workers being nearly four times heavier than minor workers, fulfilling specialized roles such as defense, foraging, and brood care (Grimaldi & Engel, 2005).

The foraging strategy of *L. apiculatum* includes both predation and mutualistic interactions. Workers forage primarily on trees and shrubs, tending various hemipterans for honeydew and some cacti for extrafloral nectar, which constitutes a major component of their carbohydrate intake (Miller, 2007; Rafael-Valdez et al., 2017). These ants are also known to scavenge insect carcasses and hunt live prey, playing an important ecological role as both predators and nutrient recyclers (Van Pelt, 1971). Foraging trails can be long-lasting and are maintained for extended periods, suggesting a high degree of spatial memory and trail fidelity among workers. Colonies exhibit seasonal reproductive cycles. During favorable climatic conditions, nuptial flights occur, during which alates disperse to mate and establish new colonies. Colony founding strategies are less well-documented, but anecdotal evidence suggests that the presence of brood and mature workers during early colony stages may improve success in harsh environments—indicating the potential for dependent colony founding, especially under xeric conditions (Hoey-Chamberlain et al., 2013). *L. apiculatum* forms mutualistic associations with various Hemiptera, which provide honeydew as a primary energy source (Lara-Juárez et al., 2015). Morphologically, *L. apiculatum* workers are covered in dense, velvet-like pubescence that gives them a matte appearance and aids in desiccation resistance—a key adaptation for survival in dry climates. From a bioecological standpoint, *L. apiculatum* contributes to its native ecosystems not only through trophic interactions but also by influencing plant-herbivore dynamics. Their burrowing activity aids soil turnover, and their role as both predator and prey integrates them into multiple food web levels (Gregg, 1963; Lara-Juárez et al., 2015).

3.2.3. *Oecophylla smaragdina*

Oecophylla smaragdina, commonly known as the Asian weaver ant, is a diurnal and arboreal ant species. It is widely distributed across tropical regions of South and Southeast Asia and northern Australia. The species is particularly noted for its sophisticated nest-building behavior, wherein workers use silk secreted by larvae to weave together living leaves into large, suspended nests in the tree canopy (Devarajan, 2016). A mature colony can occupy several neighbouring trees within an area of 800–2500 m^2 (Exélis et al., 2025). The colony structure of *O. smaragdina* is based on a clear caste system, comprising alate and dealate queens, minor and major workers, and alate males (Pimid et al., 2014). While colonies are typically monogynous, instances of polygyny may occur, especially in large colonies where inter-nest distances increase (Hölldobler & Wilson, 1990). Reproduction is initiated through synchronized nuptial flights during the dry season with strong wind, where winged males and virgin queens leave the nest to mate (M. G. Nielsen et al., 2016). After mating, queens shed their wings and initiate new colonies within folded leaves, laying their first batch of eggs. These hatch within 18–20 days, and larval development spans approximately 45 days, after which the first generation of workers emerges and assumes colony duties (Hölldobler & Wilson, 1990). Nest construction involves cooperative behavior, where workers pull together the edges of leaves and secure them with silk produced by larvae. (Hölldobler & Wilson, 1990). These silk-bound leaf nests provide structural resilience and a buffered microclimate that supports colony development. Foraging activity is regulated by temperature and humidity, with peak foraging typically occurring at high temperature and low humidity (Rezki et al., 2023). *O. smaragdina* is a generalist predator, feeding on a variety of arthropods, and is also known to engage in mutualistic interactions with honeydew-producing insects such as aphids, scale insects, and mealybugs (Hölldobler & Wilson, 1990; Offenberg, 2015). *O. smaragdina* is an ecologically significant species due to its role as a dominant canopy predator, influencing arthropod populations and reducing herbivory. However, its aggressive territorial behavior and association with sap-feeding insects may inadvertently reduce beneficial insect visitations (pollinators and natural enemies) and alter plant reproductive success (Offenberg, 2015).

3.2.4. *Polyrhachis vicina*

Polyrhachis vicina, commonly known as the Chinese black ant, is predominantly found in the southern regions of China. The nesting behavior of *P. vicina* is quite adaptable. This ant species can construct and relocate their nests in bush and grass, depending on the temperature conditions and food availability (Jin-Fu & Jue, 2016). This flexibility in nesting is a key factor in the species' success and survival in a wide range of climates and geographical areas. The colonies of *P. vicina* typically favor humid and warm environments in shading place that support their reproductive cycles and foraging activities (Jin-Fu & Jue, 2016). Their ability to thrive in various ecosystems has contributed to their widespread distribution and ecological significance.

4. Nutritional value of some economically important edible ant species

Edible insect-based products are recognized for their high nutritional value, which varies among species and even across different life stages within the same species (Raheem et al., 2019). This section discusses the nutritional composition of several prominent edible ants, including *C. vidua*, *L. apiculatum*, *O. smaragdina*, and *P. vicina*, in terms of proximate composition, fatty acids, amino acids, minerals, and vitamins (Tables 2–6).

From Table 2, it can be seen that each ant species has a different nutritional composition. In general, *P. vicina* has a higher protein content than other edible ants, ranging from 36.1 to 56.6 g/100 g dry weight (Rumpold & Schlüter, 2013; Weru et al., 2021). Conversely, *L. apiculatum* has the lowest protein content, ranging from 34.7 to 40.0 g/100 g dry weight (Cruz-Labana et al., 2018; Escamilla & Ariza, 2021; Rumpold & Schlüter, 2013). The protein content of edible ants is generally comparable to that of pork and beef (Table 2), although edible ants contain relatively lower fat levels. Additionally, differences in the nutritional composition of each edible ant species are also observed in terms of fat, fiber, ash, and total carbohydrates. One reason for these differences is the variation in analysis methods, which may use either a dry basis or a wet basis (fresh samples). For instance, Vidhu and Evans (2015) and Escamilla and Ariza (2021) used a fresh sample basis when analyzing *O. smaragdina* and *L. apiculatum*. The results of proximate analysis vary depending on water content, making it critical to analyze each edible ant carefully, as water content affects the relative proportions of the remaining components. Furthermore, water content may influence insect processing (Costa et al., 2020). Differences in life stage can also affect proximate analysis results. For example, Cruz-Labana et al. (2018) used larvae of *L. apiculatum*, while Melo-Ruiz et al. (2013) analyzed eggs; for *C. vidua*, Ayieko et al. (2012) and Rumpold and Schlüter (2013) used whole-body samples of adult ants, whereas Aguilar-Toalá et al. (2022) analyzed de-winged adults, leading to variation in proximate values. Moreover, Mba et al. (2017) stated that the nutritional content of edible ants may vary depending on developmental stage, geographical origin, diet, and living conditions.

Table 3 shows the varying fatty acid contents of some economically important edible ant species. Almost all edible ants contain both saturated and unsaturated fatty acids, with unsaturated fatty acids being dominated by palmitoleic, linoleic, linolenic, and oleic acids. Among edible ants, *O. smaragdina* has the highest PUFA content, accounting for 68.80% of total fatty acids (Raksakantong et al., 2010). Overall, the proportion of saturated fatty acids is lower than that of unsaturated fatty acids. In insects, phospholipids and triacylglycerols constitute the majority of the lipid composition, which varies depending on life stage and species (Lucas et al., 2020). Insects can therefore be used to augment the nutritional value of a diet by providing essential fatty acids. However, seasonal changes can influence the nutritional content of edible ants. Borgohain et al. (2014) reported that in Assam, India, *O. smaragdina* had the highest lipid content when collected in April, whereas lower levels were recorded between November and February. These findings suggest that collectors can optimize harvest timing by targeting specific seasons and life stages to maximize nutritional value (Meyer-Rochow et al., 2021).

The amino acid profiles of some economically important edible ant species are presented in Table 4. Each species differs in both the type and quantity of amino acids. *L. apiculatum* (eggs) contains all amino acids (Melo-Ruiz et al., 2013), whereas some species, such as *P. vicina* (Weru et al., 2021) and *O. smaragdina* (Vidhu & Evans, 2015), possess a more limited range. Essential amino acids—including histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine—are found in the eggs and larvae of *L. apiculatum* (Cruz-Labana et al., 2018; Melo-Ruiz et al., 2013). Although the quantity of essential amino acids determines protein quality, the amino acid composition of edible ants varies, making it difficult to conclude that one species is superior to another. Moreover, amino acid content can be influenced by several factors, including those that also affect other nutrient levels.

Table 5 presents the mineral composition of several economically important edible ant species. *P. vicina* has the highest calcium content (108.0 mg/100 g), while *L. apiculatum* (eggs) has the lowest (0.97 mg/100 g). The mineral content of edible insects is influenced by factors such as developmental stage and seasonal variation (Chinarak et al., 2020). Overall, *C. vidua*, *L. apiculatum*, *O. smaragdina*, and *P. vicina* provide minerals including calcium, potassium, sodium, iron, zinc, magnesium, and phosphorus, albeit in varying amounts. Incorporating edible ants alongside other food sources may therefore contribute to meeting daily mineral requirements.

The vitamin composition of several economically important edible ant species is presented in Table 6. *O. smaragdina* and *C. vidua* contain the most comprehensive range of vitamins among the species studied, including vitamin A (retinol), vitamin E (α-tocopherol), vitamin B1 (thiamin), vitamin B2 (riboflavin), vitamin B3 (niacin), and vitamin C (ascorbic acid). Vitamin content can be affected by processing

Table 2. Proximate analysis of some economically important edible ant species.

Species	Country of study	Protein	Fat	Fiber	Ash	Total carbohydrate	References
*Polyrhachis vicina**	Nigeria	56.6	9.0	–	6.2	–	(Weru et al., 2021)
*Polyrhachis vicina**	China	45.4	17.4	28.8	4.1	4.1	(Rumpold & Schlüter, 2013)
*Polyrhachis vicina**	China	36.1	18.0	29.1	2.5	14.2	(Rumpold & Schlüter, 2013)
*Oecophylla smaragdina**	Thailand	55.3	15.0	19.8	–	2.6	(Meyer-Rochow et al., 2021)
*Oecophylla smaragdina**	Thailand	53.4	13.4	15.3	6.5	11.1	(Raksakantong et al., 2010)
*Oecophylla smaragdina**	Australia	51.5	13.8	24.0	–	–	(Alagappan et al., 2021)
*Liometopum apiculatum**	Mexico	37.3	42.1	9.6	3.0	–	(Rumpold & Schlüter, 2013)
*Liometopum apiculatum (larvae)**	Mexico	40.0	38.1	1.3	3.6	–	(Cruz-Labana et al., 2018)
*Limotepum apiculatum (egg)**	Mexico	42.2	32.9	1.5	–	14.2	(Melo-Ruiz et al., 2013)
Carebara vidua[a*]	–	53.8	33.3	9.4	2.2	–	(Aguilar-Toalá et al., 2022)
*Carebara vidua**	Kenya	42.5	49.4	7.1	1.6	–	(Rumpold & Schlüter, 2013)
Carebara vidua[b*]	Kenya	44.6	49.7	4.3	0.9	0.2	(Ayieko et al., 2012)
*Carebara viduac**	Kenya	39.7	42.0	10.0	2.0	12.4	(Ayieko et al., 2012)
*Carebara vidua**	Kenya	40.8	47.5	6.9	1.5	6.1	(Ayieko et al., 2012)
*Oecophylla smaragdina***	India	3.4	3.0	–	–	1.1	(Vidhu & Evans, 2015)
*Liometopum apiculatum**	Mexico	34.7	45.5	–	4.3	15.2	(Escamilla & Ariza, 2021)
Pork (NDB number:10219)*	–	48.9	48.2	–	2.5	–	(Tang et al., 2019)
Chicken (NDB number:5332)*	–	64.8	30.2	–	4.3	0.1	(Tang et al., 2019)
Beef (NDB number: 23572)*	–	46.0	57.0	–	2.1	–	(Tang et al., 2019)

Note:
*g/100 g dry basis.
**g/100 g fresh basis.
[a]Without wings.
[b]Abdomen part, [c]thorax part.
NDB number: Searching ID for the chosen sample at the website of USDA.
https://fdc.nal.usda.gov/fdc-app.html#/.

methods (e.g. fresh vs. dried insects) and by developmental stage. For example, retinol is detected in the brood of *O. smaragdina* but not in adults.

Although edible ants are nutrient-rich, they may also contain antinutritional compounds, which warrant careful consideration regarding their consumption. Antinutrients are substances that restrict or inhibit nutrient absorption. Since most edible insects are herbivorous and feed on plants or plant parts, they can accumulate secondary metabolites that plants produce for self-defense. These compounds may persist in the bodies of insects that consume plant material. The considerable variation in antinutrient content among insect species is likely influenced by differences in the chemical composition of the plants they feed on (Meyer-Rochow et al., 2021). For instance, Sailo et al. (2020) reported that *O. smaragdina* contains several antinutritional factors such as tannins, phytates, oxalates, phenols, and flavonoids, although their levels were lower than those observed in other edible insect species, such as Eri silkworm larvae. Similarly, Chakravorty et al. (2016) found that *O. smaragdina* contains phytic acid (171 mg/100 g) and tannins (496.67 mg/100 g), but emphasized that these values are much lower than those typically found in plant-derived foods, thereby supporting the potential of edible ants as a safe and valuable alternative food source. Furthermore, insects are naturally rich in chitin, a structural nitrogen-based carbohydrate present in their exoskeletons, which may act as an antinutrient by impairing protein digestibility (Belluco et al., 2013).

5. Nutraceutical and pharmaceutical properties of edible ant species

Entomotherapy, or the use of insects for medical purposes, has been practiced for millennia in various nations across the world. Humans consume more than 2,100 edible insect species, but little is known

Table 3. Fatty acid composition of some economically important edible ant species (% of total fatty acid).

Fatty acid	*Polyrhachis vicina*	*Polyrhachis vicina*	*Oecophylla smaragdina*	*Oecophylla smaragdina*	*Liometopum apiculatum* (larvae)	*Liometopum apiculatum* (egg)	*Carebara vidua*[a]	*Carebara vidua*[b]	*Carebara vidua*[b]	Pork (NDB number:10219)	Chicken (NDB number:5332)	Beef (NDB number: 23572)
Palmitoleic	8.2	8.9	0.5	4.3	1.1	–	1.8	2.9	3.3	2.1–28	0.2	0.1
Linoleic	2.1	1.7	–	7.0	4.9	67.6	12.1	10.2	10.6	10.7–14.2	–	–
Linolenic	1.0	0.6	0.3	–	0.4	4.6	–	–	–	1.0–1.1	0.6	–
Oleic	63.0	60.5	1.8	52.1	63.2	0.2	51.4	46.7	51.2	32.8–43.7	–	–
MUFA	72.4	71.3	2.3	58.7	–	–	53.3	49.7	54.5	3.2–43.0	46.6	1.5–18.8
PUFA	3.1	3.7	68.8	9.4	–	–	12.1	10.2	10.6	0.6–16.0	20.0	49.0
Palmitic	17.5	19.0	1.19	20.8	19.9	20.1	27.0	28.7	25.9	23.2–27.3	22.6	0.8
Myristic	0.6	0.6	0.2	2.1	1.9	–	1.0	1.8	1.3	1.3–14	1.3	0.1
Stearic	4.3	4.3	27.6	5.8	3.4	2.7	4.8	5.9	5.7	12.2–16.1	–	0.6
Lauric	0.7	–	–	0.9	0.4	–	0.4	2.2	1.7	0.2	–	–
Arachidic	0.3	–	–	1.0	0.1	–	1.1	1.3	–	–	–	–
SFA	23.9	25.5	29.2	31.9	–	–	34.5	40.0	34.8	41.4	33.33	32.2
References	(Rumpold & Schlüter, 2013)	(Rumpold & Schlüter, 2013)	(Raksakantong et al., 2010)	(Oranut et al., 2010)	(Cruz-Labana et al., 2018)	(Melo-Ruiz et al., 2013)	(Rumpold & Schlüter, 2013)	(Rumpold & Schlüter, 2013)	(Rumpold & Schlüter, 2013)	(Tang et al., 2019)	(Tang et al., 2019)	(Tang et al., 2019)

Note:
[a]Thorax part.
[b]Abdomen part.
NDB number: Searching ID for the chosen sample at the website of USDA. https://fdc.nal.usda.gov/fdc-app.html#/.

Table 4. Amino acid composition of some economically important edible ant species (mg/g protein).

Amino acid	*Polyrhachis vicina*	*Polyrhachis vicina*	*Oecophylla smaragdina**	*Liometopum apiculatum* (egg)	*Liometopum apiculatum* (larvae)	*Liometopum apiculatum*	Pork (NDB number:10219)	Chicken (NDB number:5332)	Beef (NDB number: 23572)
Histidine	3.3	3.3	0.4	2.9	1.0	29.0	3.2	4.4	2.9
Isoleucine	2.2	–	0.6	4.6	1.6	44.0	4.9	4.2	5.1
Leucine	3.9	3.9	3.4	7.2	2.5	89.0	7.5	6.9	8.4
Lysine	2.2	2.2	2.3	5.7	2.2	60.0	7.9	7.8	8.4
Mehionine	1.1	-	0.7	3.2	0.6	18.0	2.5	2.1	2.3
Cysteine	1.1	-	–	1.4	0.2	14.0	1.3	–	1.4
Phenylalanine	1.7	-	0.5	6.2	1.3	39.0	4.5	2.5	4.0
Tyrosine	2.8	-	–	7.1	–	68.0	3.0	3.5	3.2
Threonine	2.2	2.2	1.7	4.1	1.3	42.0	5.1	3.7	4.0
Tryptophan	1.1	1.1	0.5	0.8	–	8.0	–	–	–
Valine	3.4	3.4	1.7	6.3	1.8	60.0	5.0	4.5	5.7
Arginine	2.7	-	–	5.7	1.7	50.0	6.4	6.4	6.6
Serine	2.9	-	–	4.7	1.5	–	–	–	–
Proline	2.8	-	–	6.3	2.0	–	–	–	–
Alanine	4.5	-	–	7.5	1.6	–	–	–	–
Glycine	5.6	-	–	6.5	1.3	–	–	–	–
Glutamic acid	7.4	-	–	15.2	5.3	–	–	–	–
Reference	(Shen et al., 2006)	(Weru et al., 2021)	(Vidhu & Evans, 2015)	(Melo-Ruiz et al., 2013)	(Cruz-Labana et al., 2018)	(Rumpold & Schlüter, 2013)	(Tang et al., 2019)	(Tang et al., 2019)	(Tang et al., 2019)

Note:
*g/100 g fresh basis.
NDB number: Searching ID for the chosen sample at the website of USDA.
https://fdc.nal.usda.gov/fdc-app.html#/.

Table 5. Mineral content composition of some economically important edible ant species (mg/100 g dry basis).

Mineral content	*Polyrhachis vicina*	*Polyrhachis vicina*	*Polyrhachis vicina*	*Oecophylla smaragdina*	*Liometopum apiculatum*	*Liometopum apiculatum* (egg)	*Carebara vidua*[a]	*Carebara vidua*[b]
Calcium	108.0	49.1	175.4	61.4	48.0	0.97	22.2	13.1
Potassium	–	–	448.1	0.07	541.0	0.08	51.7	70.4
Sodium	–	–	143.3	0.02	180.0	0.069	26.2	30.2
Iron	53.7	118.0	94.0	21.4	21.8	0.02	10.6	9.7
Zinc	11.9	17.6	227.0	24.1	10.1	0.29	5.6	5.5
Magnesium	67.6	65.3	103.0	79.9	70.0	0.97	10.4	10.5
Phosphorus	417.0	387.7	157.9	0.06	517.0	0.83	106.0	106.9
Refences	(Rumpold & Schlüter, 2013)	(Rumpold & Schlüter, 2013)	(Shen et al., 2006)	(Alagappan et al., 2021)	(Rumpold & Schlüter, 2013)	(Melo-Ruiz et al., 2013)	(Ayieko et al., 2012)	(Ayieko et al., 2012)

Note:
[a]Whole body.
[b]Thorax part.

Table 6. Vitamin content composition of some economically important edible ant species (mg/100 g dry basis).

Vitamin	*Oecophylla smaragdina** (brood)	*Oecophylla smaragdina** (adult)	*Liometopum apiculatum*	*Liometopum apiculatum*	*Liometopum apiculatum*	*Carebara vidua*
Vitamin A (Retinol)	4.7	–	0.88	0.51	0.3024	0.77
Vitamin B1 (Thiamin)	10.3	6.23	0.15	-	-	0.46
Vitamin B2 (Riboflavin)	6.5	7.33	0.34	-	-	20.26
Vitamin B3 (Niacin)	42.0	31.00	0.67	-	-	0.28
Vitamin C (Ascorbic acid)	12.8	10.2	36.16	-	-	0.03
Vitamin E (α-Tocopherol)	17.4	13.5	-	2.22	3.29	0.59
References	(Vidhu & Evans, 2015)	(Vidhu & Evans, 2015)	(Rumpold & Schlüter, 2013)	(Melo-Ruiz et al., 2013)	(Virginia et al., 2016)	(Ayieko et al., 2012)

Note:
*Fresh basis.

about their potential use as an alternative to established medications for disease treatment. Insects are known to be rich in bioactive chemicals, which explains their medicinal properties, such as antibacterial, anti-inflammatory, and antiviral effects (Siddiqui, Li et al., 2023). In total, 235 species have been described in publications summarizing insects used in folk medicine, including those from Latin America, Africa, India, and China. In contrast to folk medicine, contemporary medicine places greater emphasis on the health effects of insects. Traditional folk medicine and market availability appear to have a significant impact on the selection of insects used in disease studies (Guining et al., 2018; Siddiqui, Li et al., 2023).

Based on the literature, edible ants contain active compounds with antioxidant, anticancer, antidepressant, and antibacterial properties (Figure 2). Tibetan, Chinese, and Indian traditional medicine depicts zootherapy with a wide range of insects for therapeutic purposes (Devi et al., 2023). In Kerala, India, ants have been utilized as medication to treat over 15 different maladies, including anemia, asthma, rheumatism, malaria, and ulcers (Wilsanand et al., 2007). *O. smaragdina* can be used to stimulate gastric juices, as an aphrodisiac, and as a remedy for cold- and flu-related headaches (Bani, 1995; Crozier et al., 2009; van Huis, 2002). In addition, it can detoxify blood, prevent hemorrhage during miscarriages, restore the uterus after childbirth, boost pulse and heartbeat, relieve asthmatic symptoms, and reduce dizziness (Yhoung-Aree & Viwatpanich, 2005). *P. dives* is also used to improve the immune system and blood circulation, reduce pain and inflammation, relieve rheumatoid arthritis, increase milk supply in breastfeeding women, treat asthma, and slow aging. This medication can enhance appetite, alleviate pain, improve digestion, and increase white blood cell count in patients (Liu, 1991).

5.1. Antioxidant

Antioxidants are compounds that can prevent or reduce damage to cells caused by free radicals, which are created in the body in response to environmental or other stressors. The adults and broods of *O.*

smaragdina were found to have antiradical activity against DPPH and ABTS. The comparatively high levels of phenolics and flavonoids in *O. smaragdina* may account for the substantial suppression of the tested free radicals (Raza et al., 2022). Furthermore, Raza et al. (2022) stated that *O. smaragdina* can therefore be used as bioactive ingredients for nutraceuticals, or can also be referred to as entomoceuticals.

Antioxidant peptides from *O. smaragdina* hydrolysates demonstrate that the isolated CTKKHKPNC peptide has good antioxidant activity against ABTS and DPPH (Lee et al., 2021). Vidhu and Evans (2015) and Alagappan et al. (2021) also found that the abdominal glands and extracts of *O. smaragdina* exhibited antioxidant activity. In addition, the hydroethanolic extract of the edible *P. vicina* exhibited strong antioxidant and pancreatic lipase inhibitory properties. Naringenin, liquiritigenin, gallic acid, and salicylic acid, the primary phenols in the *P. vicina* extract, interact with pancreatic lipase via hydrogen bonding, hydrophilic or hydrophobic interactions, and pi-cation interactions. Thus, *P. vicina* extract can be used as a nutraceutical to relieve oxidative stress-induced illnesses and regulate obesity (Zhang et al., 2022).

The active fraction of *P. vicina* (AFPR) is known to exhibit anti-hyperuricemic activity due to the inhibition of uric acid generation in the liver and the enhanced urate excretion in the kidney. AFPR comprised 25.04% saturated fatty acids and 71.14% unsaturated fatty acids, including 60.77% octadecenoic acid, 9.31% heptadecenoic acid, and 1.06% linoleic acid. It also has a nephroprotective effect in hyperuricemic rats, owing to its anti-inflammatory and antioxidant properties. AFPR significantly lowered serum uric acid, serum and hepatic malondialdehyde, blood urea nitrogen, serum creatinine, and xanthine oxidase, while increasing superoxide dismutase. AFPR therapy dramatically lowered serum levels of proinflammatory cytokines such as IL-1β, IL-6, and TNF-α (Su et al., 2018).

5.2. Anticancer

Active fraction of *Polyrhachis vicina* (AFPR) exhibits substantial anti-inflammatory activity, indicating its potential anticancer effects. Consequently, AFPR reduced breast cancer cell proliferation, migration, and invasion, and inhibited tumor formation. It is found that AFPR could prevent breast cancer development by modulating the EGR1/NKILA/NF-κB axis (Li et al., 2023). Furthermore, AFPR is also found to be effective in preventing colorectal cancer and inducing cancer cell death due to the presence of the bioactive ingredient elaidic acid (Li et al., 2023).

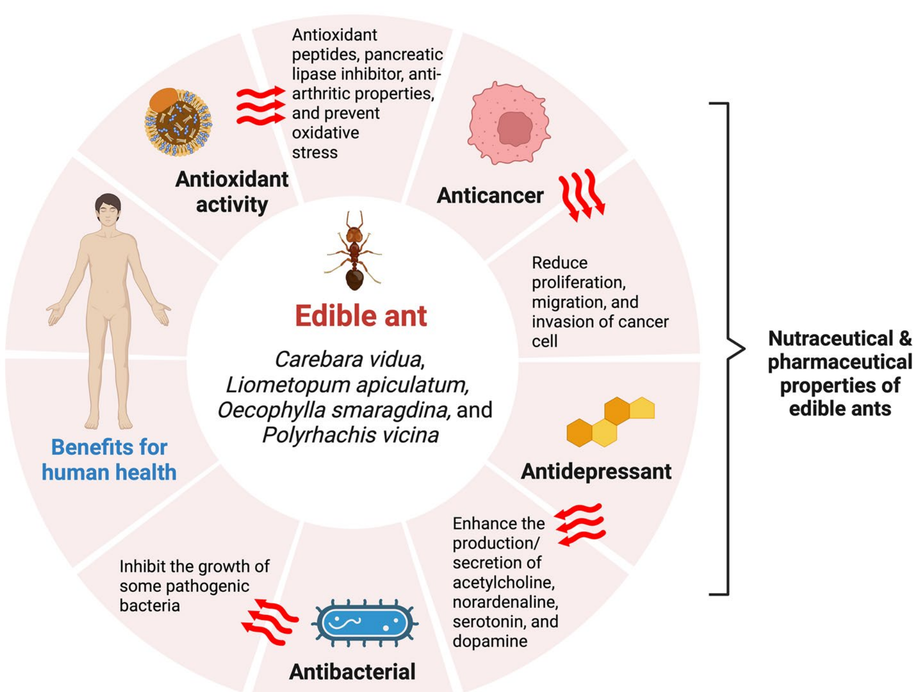

Figure 2. Nutraceutical and pharmaceutical properties of edible ant species for human health. Created with BioRender.com.

5.3. Antidepressant

Active fraction of *Polyrhachis vicina* (AFPR) is evidenced to have antidepressant properties. Administration of AFPR to rats significantly reduced the duration of immobility in the forced swimming test and tail suspension test, but had no effect on locomotor activity in the open field test. AFPR markedly increased monoamine levels, including acetylcholine, noradrenaline, serotonin, and dopamine. AFPR also normalized the metabolism rates of dopamine, serotonin, and noradrenaline, as well as monoamine oxidase activity, which had been altered by prolonged reserpine administration (reserpine-induced depression model). These findings suggest that modification of the monoaminergic neurotransmitter system is likely responsible for the antidepressant-like action of AFPR in rats (Guining et al., 2018).

5.4. Antibacterial

Extracts of *O. smaragdina* have been found to exhibit antibacterial properties against *Staphylococcus aureus* (Alagappan et al., 2021). Another study by Borah et al. (2019) reported that extracts of *O. smaragdina* yielded 74 potential probiotic isolates, among which *Bacillus* sp. PD6 emerged as the most promising candidate. Its cell-free extract (CFE) demonstrated antagonistic activity against *Listeria monocytogenes*, *Escherichia coli*, and *Bacillus cereus* (D. Borah et al., 2019).

5.5. Potential allergy from consuming edible ants

Although edible insects, including ants, are rich in nutrients and studies have validated their health benefits and potential as nutraceuticals, they may also trigger allergic reactions in humans upon consumption. In their study, Taylor and Wang (2018) assessed the prevalence of edible insect allergies in the North-Eastern region of Thailand, where entomophagy is a common practice. They found that allergic reactions caused by the consumption of common edible insects in the region, including the ant *O. smaragdina*, were highly prevalent. Moreover, individuals with confirmed food allergies (such as seafood and shellfish) reported signs of allergic reactions following edible insect intake. The most common symptoms were gastrointestinal, including vomiting and diarrhea (Taylor & Wang, 2018). This allergic potential is often associated with cross-reactivity, as edible insects share allergenic proteins such as tropomyosin and arginine kinase with crustaceans, making individuals with shellfish allergies particularly susceptible (de Gier & Verhoeckx, 2018; Kamemura et al., 2019). Although there are currently no specific studies on the allergenic effects of edible ant species in humans, the numerous reports of allergic reactions caused by other edible insects (De Marchi et al., 2021; Ribeiro et al., 2021) highlight food safety concerns that cannot be overlooked when consuming edible ants.

6. Harvesting and rearing of edible ant species

6.1. Traditional harvesting methods and unsustainability

Traditional harvesting methods for edible ants have been practiced by various indigenous and local communities for generations, typically involving the direct collection of ants from their natural habitats. While these practices have sustained local communities for centuries, the growing modern demand for edible ants has raised concerns about overexploitation and unsustainable harvesting. Additionally, ecosystem degradation, particularly due to urbanization, has contributed to the decline of edible ant populations. For example, *C. vidua*, although edible, is considered endangered in many parts of Kenya due to habitat loss (Ondede et al., 2022). Similarly, in Mexico, the socioeconomically important *L. apiculatum* is being overexploited due to its high market value (up to USD $30/kg), leading to significant population declines and habitat destruction caused by irresponsible overharvesting practices. This problem is further exacerbated by the absence of official regulations governing the collection of *L. apiculatum* in the wild (Lara-Juárez et al., 2015; Romero-Jiménez et al., 2024). A comparable situation has also been reported in Laos, where the overharvesting of *O. smaragdina* has reduced its availability. Deforestation has further decreased the number of nesting sites, prompting collectors to harvest large quantities of ant brood from single colonies without considering conservation consequences (Van Itterbeeck et al., 2014).

Traditional harvesting methods can vary depending on the species and local culture. In Central and West Africa, *C. vidua* is traditionally harvested by foragers who locate ant colonies in their natural habitats. Alate females were collected during nuptial flight where they emerge in large numbers from their nests (van Huis, 2025). In regions where *L. apiculatum* is found, harvesters use sticks or other tools to disturb the ants and encourage them to evacuate their nests. In their nest, there is spongiform and fragile part called trabecula. Harvester took the trabecula because it contains larvae and pupae of *L. apiculatum* (Lara-Juárez et al., 2015). Indigenous communities in tropical Asia and Africa have developed traditional methods for harvesting *O. smaragdina*. Collectors often climb trees where ants have established their nests and carefully plucked leaves with attached ant larvae and pupae. Harvesters may also collect nests using a 4–6 m long bamboo stick with a strong bag or bamboo basket attached to its tip (César, 2004; Sribandit et al., 2009; Van Itterbeeck et al., 2014). The ants are collected by piercing the bamboo stick into the nest and then shaking it so that the nest detaches from the tree and falls into the basket (Van Itterbeeck et al., 2014).

6.2. Semi-natural rearing systems

Among the economically important edible ant species, *O. smaragdina* has received greater attention due to the possibility of rearing it in semi-natural settings. The semi-natural rearing, or semi-cultivation, of the Asian weaver ant *O. smaragdina* has emerged as a promising method to combine edible insect production, biological pest control, and biodiversity conservation within tropical agroforestry systems. This practice is not full domestication, but rather a management approach in which wild colonies are introduced, maintained, and manipulated in orchards or agroforestry plots to optimize their productivity and sustainability (Offenberg & Wiwatwitaya, 2010; Van Itterbeeck et al., 2014).

The first step in semi-cultivation involves the establishment of colonies on suitable host trees, such as mango, cashew, citrus, and teak. Colonies are either relocated from the wild or allowed to colonize prepared sites through the provision of artificial nesting opportunities. Since colonies are polydomous (consisting of multiple nests) identifying and transferring the queen-right nest is critical for colony survival. Farmers often connect adjacent host trees with ropes or bamboo poles to facilitate colony expansion across larger areas and thereby improve coverage of crop canopies (Offenberg & Wiwatwitaya, 2010). Once established, colonies are supported through habitat management and supplemental feeding. Farmers prune branches to minimize canopy gaps, which allow colonies to expand continuously, and sometimes provide sugar water or protein-rich foods such as cat food to boost colony growth and brood production. Supplemental feeding has been shown to significantly increase harvestable brood yield without jeopardizing colony health (Van Itterbeeck et al., 2014).

Sustainable harvesting of brood is a central aspect of semi-cultivation. Collection focuses on the queen brood—large larvae and pupae destined to become virgin queens—which is the most commercially valuable stage consumed by humans in Thailand and Laos. Harvesting is conducted by probing nests with long bamboo poles and catching the brood in bags or baskets. While this method inevitably disturbs the colony and results in the collection of both queen brood and worker brood, study shows that colonies are resilient to moderate brood removal. In fact, harvesting may stimulate additional worker production (Van Itterbeeck et al., 2014).

Boosting early colony growth has been a major challenge for *O. smaragdina* rearing, as naturally founded colonies take 2–3 years to reach maturity, a time span too long for most farmers. Research on intercolony transplantation provides a solution. Krag et al. (2010) demonstrated that larvae transplanted from non-nestmate colonies are accepted and reared successfully. Building on this, Peng et al. (2013) showed that combining multiple founding queens with pupae transplantation from donor colonies significantly accelerates early growth. Colonies receiving 30–60 pupae exhibited 110–200% more brood compared to controls, and four-queen colonies with 60 transplanted pupae produced up to 476% more brood than two-queen colonies without supplementation. Survival rates of transplanted pupae were high (73%–97%), and workers behaved normally, confirming the feasibility of this method. These findings represent a major advance for semi-cultivation, as they reduce the time needed to produce strong, harvestable colonies.

Semi-natural rearing of *O. smaragdina* within agroforestry systems offers multiple sustainability advantages. By integrating food production, pest regulation, and ecosystem services, semi-cultivation enhances both ecological and economic outcomes. Colonies provide a continuous supply of edible queen brood, thereby reducing dependence on destructive wild harvesting. At the same time, their aggressive predation on a wide range of pest species delivers effective biological control and reduces the need for chemical pesticides. Importantly, maintaining colonies for commercial brood harvest incentivizes farmers to conserve host trees, positioning *O. smaragdina* as a potential flagship and umbrella species for biodiversity conservation (Van Itterbeeck et al., 2014). Farmers benefit from diversified income streams, including harvested brood for food and market sales, as well as increased fruit yields resulting from natural pest suppression. Because weaver ants thrive in mixed-tree landscapes and provide these services without external inputs, they represent a low-cost, ecologically friendly strategy particularly well suited to smallholder agroforestry systems (Offenberg & Wiwatwitaya, 2010; Van Itterbeeck et al., 2014).

Despite its potential, semi-cultivation faces important challenges. First, colony transfer and establishment are difficult, as locating and moving the queen nest is labor-intensive and risky; colonies without a queen cannot persist (Van Itterbeeck et al., 2014). Second, seasonality limits brood availability, with queen brood largely restricted to the dry season, reducing year-round harvest opportunities (Van Itterbeeck et al., 2014). Third, colony antagonism presents a problem: *O. smaragdina* colonies are highly territorial and aggressive toward non-nestmates, which complicates transplantation procedures and can limit the density of colonies in a plantation (Peng et al., 2013). Fourth, labor intensity of harvesting is high, as collectors must climb or use long bamboo poles to access nests, which can be time-consuming and potentially damaging to host trees. Fifth, knowledge gaps in queen biology remain—queens are rarely encountered, and their ecology is poorly understood by both farmers and researchers, which hinders efficient colony management (Van Itterbeeck et al., 2014). Lastly, farmer adoption is constrained by delayed returns, since without transplantation, colonies require several years to become productive, which may discourage smallholders unless technical support or community-based management is provided.

7. Processing of edible ants as food products

Edible insects are generally acknowledged as a sustainable source of animal protein, and previous studies have indicated that edible insects have the potential to become viable protein sources to meet global food demand (Liceaga, 2021). Consequently, the global market for edible insects is predicted to reach $104.74 million USD in 2023 and grow 20.66% during the forecast period, reaching $323.28 million USD by 2027 (MarketWatch, 2022). The industry's attention in commercial development has been on the specific type of insects, such as black soldier fly (*Hermetia illucens*) and mealworm (*Tenebrio molitor*) products, because of their potential (i.e. large-scale production) and popularity in the markets (F. K. Nielsen et al., 2025; Thrastardottir et al., 2021); however, ants still occupy a very low niche market in the wider industry of edible insects. Given the great potential of insect-based foods, both private entrepreneurs and business entities have started to access and exploit the insects' nutritional values by cultivating and processing them for human consumption (Guiomar et al., 2019). Additionally, a number of technologies have been developed with the primary goal of employing insects as components in unrecognizable forms, such as powders or flour, to increase consumer willingness to consume insects, especially in the West (Guiomar et al., 2019). These technologies use drying and innovative processing techniques, such as ultrasound-assisted extraction, cold atmospheric pressure plasma, and dry fractionation, to provide superior insect protein, fat, and/or chitin extracts (Guiomar et al., 2019).

Appropriate insect processing is necessary to generate safe and high-quality raw materials, ingredients, and products for human food consumption (Ojha et al., 2021). This is due to the fact that the primary goal of processing is to assure food safety (Ojha et al., 2021). Processing lines vary depending on the nature of the starting ingredients and the intended end product and may incorporate numerous unit processes previously employed in food processing. Harvesting, preprocessing, decontamination, additional processing, packing, and storage may all be part of an insect processing line (Ojha et al., 2021). This section will also go into more detail about the different ways in which edible insects, especially ants, can be turned into food for people after they have been collected.

7.1. Fresh

Due to their rich content of essential nutrients such as protein, fat, vitamins, and minerals, there are several focus on processing ants for human consumption while they are fresh in order to preserve their nutritional value and aroma, ensuring that the quality of nutrients is retained. In certain regions of Africa, edible ants are also eaten raw, and one of the reasons for this is due to ancestors' traditions and culture, which affect how edible insects are consumed (Hlongwane et al., 2020). Consumers commonly process edible ants that can be eaten fresh by roasting, frying, boiling, roasting, and even making sandwiches (DeFoliart, 2002; Hlongwane et al., 2020; Jongema, 2017; Meutchieye et al., 2016; Svanberg & Berggren, 2019; Tamesse et al., 2016). Fresh ants prepared directly by consumers are often used for everyday meals and as ingredients in traditional medicines (Araujo & Bessera, 2007; Ayieko et al., 2012; Casas Reátegui et al., 2018; Chavanduka, 1976; Costa-Neto & Ramos-Elorduy, 2006; Gelfand, 1975; Hlongwane et al., 2020; Jongema, 2017; Kelemu et al., 2015; Mbata, 1995; Okia et al., 2017; Silow, 1983; van Huis, 2017). In brief, when fresh ants are processed as human food, consumers generally employ ants as raw material and process them directly into a meal that is ready to consume.

7.2. Drying

Depending on their species, life stage, and cooking method, insects can be prepared in a variety of ways. In general, they are consumed whole or in an identifiable shape, grilled, or fried as major or supplementary ingredients (Hernández-Álvarez et al., 2021). However, many consumers, particularly in Western nations, do not want to eat insects because they are seen as impoverished, and they are repulsed by the concept of utilizing insects as human food (Caparros Megido et al., 2017). Consequently, several methods or processes are used in the management of insects as human food, such as turning them into flour to manufacture cookies and snacks to boost consumer consumption and purchase intent (Yazici & Ozer, 2021).

Drying is the most common method for extending the shelf life of insects, such as ants, for consumption as a whole and as a component in food preparation, such as being turned into flour to produce snacks (Ohtake et al., 2020). The drying process itself may increase the microbiological quality of insects (reduce spoilage), minimize rancidity, and improve the color and texture (Llavata et al., 2020). There are essentially two forms of drying: the conventional approach of employing sunlight and the modern method, which employs modern technologies such as freeze-drying and microwave drying (Hernández-Álvarez et al., 2021). It has also been shown that insect drying increases the shelf life, sensory quality, and ultimate safety of insects, materials, and their derivatives (Hernández-Álvarez et al., 2021).

Additionally, drying approach has been used for centuries to preserve food and is regarded as a standardized, diversified, and energy-efficient unit operation (Hernández-Álvarez et al., 2021). The drying method is a mass-transfer process involving the evaporation of a liquid (often water) to generate a solid product of the desired grade. The sun drying technique comprises manufacturing, which entails gathering the ants, killing them ethically (e.g. by freezing, boiling, or boiling vapor), and then cleaning them; then, you may begin the drying process using the sun dry method (Hernández-Álvarez et al., 2021).

In addition, a study conducted in China on *P. vicina* revealed that there are 28 organic compounds in fresh and sun-dried edible black ants that are extremely beneficial for health; the major organic compounds of fresh and sun-dried edible black ants are fatty acids and hydrocarbons (Li et al., 2009). However, after sun drying, there was a significant decrease in ketones and total hydrocarbons; thus, it is extremely beneficial to human health because high amounts of ketones increase the risk of developing diabetic ketoacidosis, while excessive levels of hydrocarbons may cause dysrhythmias and hepatotoxicity, and aromatic hydrocarbons may cause suppression of bone marrow and malignancy (American Diabetes Association, 2020; Jeremy et al., 2020; Li et al., 2009). After the ants have dried, they are typically consumed in a variety of ways depending on the country, such as in China, where they are consumed directly as traditional medicine, and in Laos, where they are either added directly to food, such as soup, or ground into a powder and added to the soup to add a sour flavor (Healthline, 2021; D. Li et al., 2009; van Huis et al., 2013).

7.3. Storage treatments, sterilization, and canning

In many cases, processing food products involves treatment to enhance and maximize the quality and safety of food products, and each food requires unique considerations to produce a high-quality product. Food products made from edible ants, such as *L. apiculatum* (also known as escamoles), are quite popular, particularly in Mexico, because of their excellent taste, which is comparable to cottage cheese with a buttery and nutty flavor; however, they have a very limited shelf life (Castillo-Andrade et al., 2015). However, the primary problem with this product is that its quality degrades swiftly during storage, which decreases its economic viability because the product does not last long and its texture is readily changed (Castillo-Andrade et al., 2015). Consequently, effective storage procedures are required to extend the shelf life of products because food storage preserves items in secure containers under regulated conditions, thus preventing deterioration and contamination of foods that may lead to potentially deadly food poisoning (Njunina, 2022). Due to its strong proteolytic activity and microbial growth, *L. apiculatum* food products may only be stored for approximately five days in a refrigerator at a temperature of 4 °C; however, this storage method adds relatively little to the product's longevity (Castillo-Andrade et al., 2015).

As consumer interest in the consumption of insects, particularly *L. apiculatum*, grows, the quality and product safety standards also increase. Therefore, a more sophisticated processing technique is required to improve ant-derived food products' safety and shelf life. Therefore, an innovative alternative is required to extend the shelf life of microbe-free *L. apiculatum* food products.

Reyes-Hernández et al. (2022) stated that to improve the shelf life of ant-based food products such as escamoles, customers often freeze their products at −20 °C; however, after thawing, the structure of the escamol is destroyed and the internal fluids are lost. Additionally, the product's texture and appearance will change throughout the thawing process, causing consumers to reject the product (Reyes-Hernández et al., 2022). Therefore, a more recent technique for storage or preservation, termed sterilization, was developed (Reyes-Hernández et al., 2022). Sterilization is the process of destroying or removing all live organisms (yeasts, fungi, vegetative, and spore-forming bacteria) in sterilized food products to improve their shelf life of the product (Rahman, 2020).

Moreover, Reyes-Hernández et al. (2022) also reported that ant-based canned food products were sterilized at a temperature determined at the geometric centre of the can (cold point or slowest heating point) using a DataTrace MPRF thermocouple placed at the centre of the can bottom with a ring gasket and container locking; the sterilizing procedure is then conducted for 13 to 38 min with saturated steam at a temperature of 121 °C. The sterilization procedure revealed that the results of all microbiological tests were negative, and after that, the structure of the food product did not change, and the shelf life of the product was greatly increased (Reyes-Hernández et al., 2022). As a result, sterilization of canned ants food products can be considered one of the processing of edible ants as food products for building new products without compromising the nutritional and sensory properties of escamole.

7.4. Combining techniques

With the surge in fresher and healthier insect food products, the insect food business faces difficulties in identifying new alternatives and technical advancements in product processing (Ramirez-Garcia et al., 2022). Numerous research has been conducted to enhance product shelf life and limit microbial growth and enzymatic activity in insect food, particularly ant-based food products, with the combination of water activity (aw), pH, temperature, and preservatives proving to be the most effective (Singh & Shalini, 2016).

Furthermore, it has been reported that combining techniques such as water activity (aw), pH, temperature, and preservatives can reduce microbial growth and extend the shelf life of the product by up to 15 days because the product retains the same physical characteristics as escamoles without treatment (1 d after harvest) (Ramirez-Garcia et al., 2022). According to the findings of a previous study, a revolutionary approach based on hurdle technology is known to considerably increase the shelf life of escamoles from 4 to 45 days at 4 °C, which will aid in the growth of the insect food sector, particularly for ants, and satisfy customer demands. seeking items with a long shelf life that are fresh, of excellent quality, and safe to consume (Ramirez-Garcia et al., 2022).

Hurdle technology is a system that attempts to ensure food safety by removing or restricting the development of germs, rendering food safe for eating, and prolonging its shelf life using a combination of technologies and methodologies (Gordon & Williams, 2017). In addition, numerous combination techniques have been demonstrated to extend shelf life and prevent disease growth in insect-based food products, particularly in ants (Ramirez-Garcia et al., 2022). The optimal barrier technology parameters for producing the best result were aw = 0.90, pH 5.0, and 15 s of blanching time. In conclusion, combining techniques may assist customers in obtaining fresh escamoles that can be stored at 4 °C for 45 days. Additionally, this technique can assist the industry in maximizing product shelf life and minimizing economic losses if a product does not sell well before it is exhausted.

7.5. How to maintain the organoleptic and physicochemical properties of edible ants

Texture, taste, and aroma are important factors that influence people's decisions to buy and eat food, including insects (Adámek et al., 2020; Mishyna et al., 2020). Therefore, the insect food business employs various techniques to preserve the organoleptic and physicochemical features of edible insects so that consumers are satisfied with the products they provide (Mishyna et al., 2020).

Some insects, such as ants, normally produce semiochemicals (including pheromones) for protection against predators and communication. In other words, ants have a unique aroma and are valued for their aroma and flavor rather than their texture or protein content (Mishyna et al., 2020). However, organoleptic qualities may vary across species. For instance, *Formica rufa* has a burnt lemon flavor, whereas *Lasius fuliginosus* has a pleasant kaffir lime aroma. Therefore, it is essential to preserve the organoleptic qualities of processed ant foods. Several previous studies have also discovered a way to process or prepare ants so that when they are processed into food, they retain their organoleptic qualities and can also concentrate the aromatic mixture of the ants by adding them to the alcohol used to make gin (Halloran et al., 2014; Münke-Svendsen et al., 2017).

Another method for obtaining and maintaining the organoleptic and physicochemical properties of edible ants, particularly *P. vicina*, is to use supercritical CO_2 at a constant flow rate of 8 kg/h, with an extraction vessel at 50 °C at 30 MPa and a release vessel at 45 °C at 8 MPa (Perez-Santaescolastica et al., 2022). With the advent of technology for processing edible insects, particularly ants for human consumption, excellent food products can be produced because these insects can be transformed into food without sacrificing their organoleptic and physicochemical properties.

8. Consumer acceptance of edible ants as human food

Edible insects, including ants, have gained increasing attention worldwide as potential food sources. Although cultural attitudes and acceptance vary across different regions and countries, there has been a growing interest in consuming edible insects because of their nutritional value, sustainability, and potential as an alternative protein source. It is important to note that the acceptance and popularity of edible insects, including ants, can vary significantly depending on the region and cultural context (House, 2016; Van Itterbeeck & Pelozuelo, 2022). For example, edible *P. vicina* from China and *O. smaragdina* from Thailand were shown to be a good source of unsaturated fatty acids, and the major lipid components were triacylglycerol, followed by phospholipids, diacylglycerol, and cholesterol ester (Oranut et al., 2010). It is evident that insects, including ants, are considered nutrient-rich traditional foods, such as Awajun populations from Amazon, which consume 12 different insect species (Casas Reátegui et al., 2018). Therefore, the acceptance of edible ants is more popular among traditional communities since they thrive on ethnic lifestyles, and their livelihood is more dependent on natural things. However, it can be quite challenging for the modern community to accept edible insects such as ants as dietary sources, and the first barrier is the acceptance towards palatability accompanied by immune system response towards foreign substances; hence, precautions should be taken regarding the consumption of edible insects that are or could be toxic.

An investigation was conducted in the North-Eastern or Isan region of Thailand, where entomophagy is a common practice. The survey included 2,500 respondents from four locations (Nongki, Nang Rong, Nong Bun Mak and Nakhon Ratchasima) that consumed edible insects. In the Isan region, 7.4% of people experienced an adverse reaction related to edible insect allergies, and 14.7% of people experienced multiple adverse reactions. Additionally, 46.2% of patients experienced symptoms indicative of food-based allergy with gastrointestinal problems. Most of the insects consumed include grasshoppers (*Valanga nigricornis*), crickets (*Gryllus bimaculatus*), silk worms (*Bombyx mori*), bamboo worms (*Omphisa fuscidentalis*), water bugs (*Lethocerus indicus*), scorpions (*Heterometrus longimanus*), and Asian weaver ants (*O. smaragdina*) (Taylor & Wang, 2018).

In Mexico, there are five types of edible ants as a part of the diet and economic income in rural communities, *Atta cephalotes*, *A. mexicana*, *Myrmecosistus melliger, M. mexicanus*, and *L. apiculatum*. The regional costs range from 49 USD to 243 USD per kilos. Sometimes, to enhance taste, the ants are dehydrated and butter-fried, for example, escamoles, edible larvae of *L. apiculatum* which are commercially available in Mexico. It has been observed from the study that the dehydration and frying increases lipid content and improved chemical composition of escamoles (Escamilla & Ariza, 2021). In another study, consumer acceptability and profitability were observed in *P. vicina* consumption in the Zhejiang and Guizhou regions of China. They prepare various products, such as wines, powders, and capsules, which are exported to South Korea, Japan, Thailand, and other Southeast Asian countries. According to a previous study, the nutritional composition of *P. vicina* includes phosphorus, iron, and calcium, which are considered alternative food sources that are safe for consumption (Bhulaidok et al., 2010).

Research has confirmed the high nutritive value of edible ants such as *L. apiculatum* ants. This ant harbour a colony of nitrogen-fixing bacteria in their gut, which could be linked with high protein content of the ant. Deep insights into the microbiota through sequencing technologies can help us to understand food safety and the ability to eliminate potentially pathogenic microorganisms to make it highly nutritional and economically important (González-Escobar et al., 2018). There are other methods such as total reflectance mid-infrared (MIR) spectroscopy as a rapid tool for the quantitative analysis of pre-screening the chemical composition of edible insects to evaluate safety and effective storage. For example, this technology has been used to evaluate the chemical composition of *O. smaragdina* in order to study different anatomical parts to monitor and trace elements in green ants (Mantilla et al., 2020). Therefore, similar studies can be used to trace chemicals in other species to satisfy consumption cues and acceptability.

The consumption of edible ants is mainly attributed to the availability of ant species, taboos related to insect consumption, traditional ethno-medicinal knowledge associated with ant species, and market value (Ghosh et al., 2018; Meyer-Rochow, 2009). With the advancement in technology and more commercialized lifestyles, entomophagy practices have been discontinued from many parts of the world in the false belief of acceptance of such practices in civilized and cultured individuals of the modern world (Mariod, 2020; Müller, 2019). It is important to note that apart from protein sources, they have a lower environmental impact owing to lower carbon emissions of greenhouse gases during production and more ecological advantages over meat. Since the mode of consumption and preparation plays an important role, Nagaland tribe in the northeastern part of India prefers insect consumption over meat and is very specific to the way an insect is prepared for consumption, such as by boiling in less water, cooking with local spices, frying in hot oil, cooking over fire, or over hot charcoal (Mozhui et al., 2020).

Neophobia or refusal to try new food is also a factor influencing the acceptability of edible ants. People with neophobia are reluctant to try edible ants as food, and the degree of dislike and disgust is generally associated with cultures from low-income countries. A study has corroborated that low consumer acceptance is mainly attributed to neophobia, social norms, familiarity, experiences of consumption, and knowledge based on existing experiences. At the gender level, men are more willing to consume insects than females in the age group between 40 and 59 years (Ros-Baró et al., 2022). Similarly, a survey among Korean citizens resulted in induced disgust and food neophobia, subjective norms, attitudes, and behavioral intentions (Bae & Choi, 2021).

Research conducted at San Diego State University has explored the flavor profiles of various ant species, such as chicatana ants, common black ants, spiny ants, and weaver ants. Each species offers unique flavors, from the vinegary taste of common black ants due to formic acid to the nutty and woody flavors of chicatana ants. This research indicates that ants could add diverse flavors to dishes, potentially enhancing consumer acceptance through culinary creativity (American Chemical Society, 2024). A cross-sectional study conducted in Western Europe surveyed 1,034 consumers to understand their perceptions and willingness to consume edible insects. The study found that only 13.15% of participants had previously tried insects, with common barriers being disgust, lack of familiarity, and concerns about food safety. The study suggests that increasing familiarity through education about the health, environmental, and economic benefits of insects could improve acceptance (Ros-Baró et al., 2022). Additionally, presenting insects in familiar formats, such as flours, might help overcome initial reluctance. In Australia, a survey of 820 consumers revealed significant barriers to acceptance, such as perceptions of insects as pests and concerns about hygiene and safety. However, younger males with lower food neophobia and environmental concerns were more willing to try edible insects. The study emphasized the importance of familiarity and positive taste experiences in improving acceptance (Wilkinson et al., 2018).

To understand consumer acceptance of edible insects, it is essential to review quantitative studies conducted over the past decade, focusing on more recent data (2018–2024) for relevance and up-to-date insights (Table 7). The rationale for focusing on the latest studies includes consumer preferences and attitudes towards edible insects can change rapidly, influenced by recent trends, and increased awareness of sustainability issues. Recent developments in the processing and presentation of edible insects may influence consumer acceptance differently compared to older studies (Siddiqui et al., 2023).

Table 7. Consumer acceptance of edible insects including ants from the period of 2018–2024.

Sample size	Insect/product	Formulation	Acceptance level	Reasons for not accepting	References
100 students	Cereal bar with ***Atta sexdans*** flour	Four different formulations were prepared with different *Atta sexdens* ant flour concentrations: 13%, 17%, 20%, and 23%	The acceptability index had values above 95 %	Cereal bars presented a high protein content, adequate organoleptic properties, and high acceptability	(Lozada-Urbano et al., 2023)
223 respondents from Huatusco and Puente Jula regions of Mexico	***Atta mexicana* (chicatanas)**	*Atta mexicana*	75.3% declared to consume chicatanas and 24.6% of the total population did not consume chicatanas.	Major motive for consumption was taste	(Gallardo-López et al. 2023)
780 individuals were interviewed in all the Brazilian regions	Crickets, grasshoppers, and **ants**	Fried and roasted styles of preparations	Primary motivation for insect consumption was survival (207 responses)	Flavor and culture; disgust and fear	(Bisconsin-Júnior et al., 2022)
Online survey of 820 consumers	Witchetty grubs, **ants**, grasshoppers, and crickets	Insects into familiar products (e.g. biscuits) or cooked meals	68% of participants had heard of entomophagy, but only 21% had previously eaten insects	Food neophobia	(Wilkinson et al., 2018)
Web-based survey on 1034 consumers in Catalonia (Spain)	Crickets, grasshoppers, mealworms, and others	–	Only 13.15% of participants had tried insects in age group 40–59-year-old age	Lack of custom and food safety were the main reasons for avoiding insect consumption	(Ros-Baró et al., 2022)
101 participants, 73.3% female, 26.7% male	Mealworms and house crickets	Bars without insects, with whole mealworms, with ground mealworms, or with ground crickets	Tastiness (8.0) and smell (8.5) on a scale of 1–10; worst bars were the ones which contained the whole mealworms	Colour of the ground crickets and visible whole pieces of the insects in the edible bars	(Bartkowicz & Babicz-Zielińska, 2020)
35 participants, 54% female and 45.7% male	Freeze-dried locust	Freeze-dried locust	23 decided to eat the insect, while 12 decided not to eat	Social and cultural beliefs	(Berger et al., 2019)
62 participants 47% female; 53% male Age: 18–35	Cricket flour, dried whole crickets, and dried whole mealworms	Tortilla chips with 15% cricket flour; dried whole crickets with salt and vinegar; chocolate bar with figs and 5.5% cricket flour; dried whole mealworms with caramel	Bars (6.95) > Crickets > (6.64), > Chips (6.33) > Worms (6.02) on a scale of 1–9	Appearance received the lowest rating	(Cicatiello et al., 2020)

(*Continued*)

Table 7. Continued.

Sample size	Insect/product	Formulation	Acceptance level	Reasons for not accepting	References
528 participants from age 18–41	Mealworms	Whole and powdered mealworms	Younger participants (18–41 years old) showed more acceptance towards processed mealworms than older participants (≥42 years old): 12%	Aversion and dislike were the most important barriers	(Tzompa-Sosa et al., 2023)
388 participants, 50% female; 50% male; age: 18–34; 55–69	Mealworms	Invisibly processed mealworms	Consumers accepted invisible processed mealworms in energy shakes (60.7%), energy bars (59.6%), burgers (59.3%), soup (56.8%), sandwich spreads (56.2%), unfried snacks (56.2%), and fried snacks (52.7%)	Not willing to eat because of visibility and taste of insects	(Van Thielen et al., 2019)
409 urban dwellers from Belgium (191 males; 218 females) and 412 urban dwellers from Gabon (219 males; 193 females)	Not specified	Insect baguette and insect burger	90% of respondents from both countries were familiar with edible insects	Willingness-to-pay	(Detilleux et al., 2024)
379 participants, 54% female; 46% male	Mealworms locusts and caterpillars	Insects in general	Favors insect consumption at 2.5 on a scale of 6	Sustainability and health argument	(Schlup & Brunner, 2018)
393 participants, 51% female; 49% male; age- 13–82	Product containing whole insects by Snack Insects (unprocessed)	Protein bar by Swarm Protein; Pasta by Plumento Foods; Granola by Snack Insects; Insect burger by Bug Foundation	40% willing to eat processed insects and 22% were willing to eat whole insects	Disgust and food neophobia	(Orsi et al., 2019)
222 participants, 30% female; 67% male; 3% diverse	Crickets and fresh insects	Pancakes with insect powder; burgers with insect powder; insect lime and thyme balls; smoothie bowl with insect powder; insect covered in chocolate; cricket protein snack	48% agreed to consume	Disgust (44%) knowledge (18%), others (16%), food safety (3%), and none of the above (14%)	(Naranjo-Guevara et al., 2020)
630 participants, 50% female; 50% male	Edible insects	Product containing insect powder	63% of Russians disagreed to try; 49% would stop other products from that brand	Disgust and neophobia	(Castro & Chambers, 2019)
Online 268 participants, 53.4% female; 46.6% male, age: 24.6%	Edible insects	Insect in general	55.2% accepted to try in France and Ireland	Less neophobia in males with no strict diet; resist consuming whole insects due to cultural and religious restrictions	(Ranga et al., 2024)

Various legal regulations govern the production and marketing of edible insects worldwide. However, there are no specific regulations for edible ants. According to EU Regulation 2015/2283 of the European Parliament and Council, edible insects and their parts are regarded as novel foods (Scaffardi & Formici, 2022). This regulation introduced edible insects as innovative food in the EU market. Commercialization of products with edible insects is required to conduct a standard food safety assessment called Hazard Analysis and Critical Control Points (HACCP) in European countries to avoid health risks for consumers (Kauppi et al., 2019). Research on consumer acceptance has indicated demographic variations in the rates of acceptance and identified common objectives with perceived benefits. Therefore, future comparative studies are needed to compare multiple novel protein sources to existing sources and to specify target groups for different alternative protein sources. Acknowledgement of cultural diversity within the

Table 8. Factors affecting consumer acceptance of edible ants (Kauppi et al., 2019; Scaffardi & Formici, 2022).

Factors	Description
Cultural attitudes and taboos	Deep-seated beliefs, traditions, or aversions towards consuming ants, which can vary across different cultures.
Familiarity and exposure	The level of familiarity and prior exposure to ants as a food source, which can influence acceptance or reluctance.
Nutritional value and benefits	Awareness of the nutritional value, such as high protein content and essential minerals, and potential health benefits associated with consuming ants.
Taste and flavor	The perception of taste, flavor, and texture of edible ants, which can influence acceptance based on personal preferences.
Environmental sustainability	Knowledge of the sustainability benefits of insect farming compared to traditional livestock farming, which may appeal to environmentally conscious consumers.
Safety and food quality	Consumer confidence in the safety and hygiene of edible ants, including cultivation, processing, and packaging standards.
Psychological factors	Factors such as disgust, fear, or social stigma associated with eating insects, including ants, which can influence acceptance.
Education and awareness	The availability of information, educational campaigns, and initiatives to raise awareness about the benefits and safety of consuming ants.
Culinary innovation and presentation	The introduction of ants in creative, appealing recipes and dishes by chefs and food entrepreneurs, which can enhance acceptance.
Regulatory framework	Clear regulations and standards governing the production, labeling, and sale of edible ants, ensuring consumer safety and quality control.
Social and peer influence	The impact of social norms, peer opinions, and cultural trends on consumer acceptance of edible ants.
Price and affordability	The cost of edible ants relative to other food options, and consumers' willingness to pay for them.

Western world must be focused on as a cross-country comparison. In addition, future research can also focus on substantial disparity among quantitative studies, notably as the number of experimental studies is relatively small compared to the total number of studies on consumer acceptance. A real-life setting to evaluate the behavioral choices of potential consumers could be another way to improve consumer acceptance, especially in modern civilization (Kröger et al., 2021). Some of the major factors affecting the acceptance of edible ants are listed in (Table 8).

9. Future perspectives and conclusions

Ant consumption has been recorded across many countries, with deep cultural and historical roots in several regions where it represents an ancient dietary practice. Today, edible ants are increasingly recognized not only as a traditional food but also as a sustainable and nutritious resource. Proximate analyses confirm that ants provide high-quality protein, beneficial fatty acids, essential amino acids, minerals, and vitamins, making them comparable to conventional protein sources. In addition to their nutritional profile, ants also hold promise as sources of nutraceutical compounds with potential roles in human health. Nevertheless, food safety concerns require careful consideration. The presence of possible antinutritional factors and allergenic compounds in ants has not been thoroughly studied. As edible ants move from traditional to commercialized and globalized markets, specific studies on food safety related to ant consumption are a pressing future need to ensure consumer health.

From a mass production perspective, semi-natural rearing of *O. smaragdina* represents a model of sustainable insect farming that combines edible insect production, biological pest control, and biodiversity conservation. Advances such as pupae transplantation and multi-queen colony founding have greatly improved the feasibility of colony establishment. However, important challenges remain, including difficulties in queen transfer, seasonal brood availability, inter-colony antagonism, and labor-intensive harvesting practices. Addressing these barriers through the integration of indigenous knowledge with scientific innovation will be essential for scaling up semi-cultivation in agroforestry systems. Other economically important ant species such as *C. vidua* and *L. apiculatum* are still harvested exclusively from the wild; research into their bioecology and rearing potential is urgently needed to avoid uncontrolled overharvesting and to ensure long-term sustainability.

Looking forward, the potential of edible ants and ant-based food products in global markets is considerable. Consumer studies indicate that acceptance of insect-based foods is gradually increasing, particularly when edible insects are incorporated into familiar, processed products. Factors such as culinary innovation, improved presentation, education about nutritional and environmental benefits, and the establishment of clear regulatory frameworks will be critical to expand consumer acceptance.

In conclusion, edible ants represent a unique convergence of tradition and innovation. They offer high nutritional and nutraceutical potential, ecological sustainability through semi-natural rearing, and economic opportunities for rural communities. To fully realize their promise, future research must address food safety concerns, optimize rearing techniques, and explore pathways for integrating ants into modern food systems. With proper management and innovation, ants can play an important role in meeting the growing demand for sustainable protein sources in the twenty-first century.

Acknowledgments

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

Authors' contributions

CRediT: **Ito Fernando**: Conceptualization, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing; **Bara Yudhistira**: Visualization, Writing – original draft; **Krishnamanikumar Premachandran**: Writing – original draft; **Shubhra Singh**: Writing – original draft; **Faiz Nashiruddin Muhammad**: Writing – review & editing; **Natalya Pavlovna Oboturova**: Writing – original draft; **Andrey Ashotovich Nagdalian**: Writing – original draft; **M. Bayu Mario**: Writing – review & editing; **Luqman Qurata Aini**: Supervision, Validation; **Widya Satya Nugraha**: Writing – original draft, Writing – review & editing.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Funding

This research received no specific grant from any funding agency.

About the authors

Ito Fernando is a tenured lecturer in the Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya. His expertise lies in agricultural Entomology and Acarology. As a foraging enthusiast, he also takes an interest in researching wild edibles, particularly edible insects.

Bara Yudhistira is a lecturer and researcher in the Department of Food Science and Technology, Sebelas Maret University, Surakarta, Indonesia. He has expertise in non-thermal technology in food processing, post-harvest, and other processes, including drying, thawing, etc. He focuses on the development of pulsed electric fields, cold plasma, and ultrasound.

Dr. Krishnamanikumar Premachandran is a researcher at the Centre for Climate Change Studies, Sathyabama Institute of Science and Technology, Chennai, India. He is a plant molecular biologist specializing in plant–insect–microbe interactions with relevance to sustainable agriculture. His research also explores detoxification mechanisms in insects and gut microbiota shifts in stored product pests.

Shubhra Singh had completed her master's from Dayalbagh Educational Institute, Agra, India, and worked as an assistant scientist at Patanjali Research Institute, Haridwar, India. She received TaiwanI CDF to study for her Ph.D. at the Department of Tropical Agriculture and International Cooperation, National Pingtung University of Science and Technology, Pingtung, Taiwan. Her research focuses on the the beneficial microorganisms and microbial enzymes for plant growth-promoting and biocontrol. She works in Dr. Shyu's functional genomics laboratory on the microorganisms and genes responsible for biocontrol ability and its mechanism for a sustainable and environmentally friendly approach.

Faiz Nashiruddin Muhammad is a researcher at Species Obscura and a doctoral student in Agricultural Sciences at Universitas Brawijaya. His research focuses on the ecology and taxonomy of ants, with particular interest in their role in tropical agroecosystems. He studies ant diversity and their potential as biological control agents in coffee cultivation. Through his work, he seeks to highlight the importance of ants in sustainable agriculture.

Natalya Pavlovna Oboturova is a dean of Faculty of Food Engineering and Biotechnology named after academician A.G. Khramtsov at North-Caucasus Federal University. Her primary research interests focus on food safety management systems, risk assessment methodologies, and innovative approaches to ensuring food security at national and international levels. Dr. Oboturova has made significant contributions to the development of alternative raw material resources for food production, particularly in the areas of functional foods and value-added food products. She is recognized for her expertise in sustainable food systems and has published extensively on topics related to food quality control, safety standards, and alternative food sources.

Dr. Andrey Ashotovich Nagdalian is a dean of Faculty of Agriculture at North-Caucasus Federal University. His scientific interests focus on the development of advanced agrobiotechnologies and nanotechnology applications in agriculture, with a particular emphasis on sustainable farming practices and environmental protection. A significant part of his research is dedicated to exploring alternative protein sources, particularly the use of insects as food and feed, contributing to the development of sustainable food systems.

M. Bayu Mario is an Assistant Professor at the Department of Plant Pest and Disease, Faculty of Agriculture, Universitas Hasanuddin, Makassar, Indonesia. His research expertise lies in urban entomology and stored-product insects, with a particular focus on the biology, ecology, and management of insect pests in both urban environments and post-harvest storage systems. He is actively engaged in advancing research and education in entomology, contributing to the development of sustainable pest management strategies to support food security and environmental health.

Luqman Qurata Aini (PhD) is a plant pathologist specializing in agricultural bacteriology and the application of biotechnology in plant pathology. By utilizing advanced techniques such as genomics and metabolomics, he aims to develop sustainable and effective strategies for disease prevention and management. He also actively conducts community service programs designed to enhance farmers' knowledge and skills in integrated pest management and organic agriculture.

Widya Satya Nugraha received his master's degree from National Chung Hsing University, Taiwan in the Department of International Master Program of Agriculture with agricultural economics and agribusiness specialties. He is now doing his PhD in the food economics department at the Hungarian University of Agriculture and Life Sciences, MATE in Hungary. Moreover, he has professional job experience as a research assistant during his studies and mostly deals with consumer studies (e.g., market research, consumer choice, consumer willingness to pay, consumer preference, etc.). Throughout his Ph.D., he also worked as a member of the Food Economics Research Group (Centre for Food Consumption & Waste Research) at the University of Veterinary Medicine Budapest.

ORCID

Ito Fernando http://orcid.org/0000-0001-6776-4847
Bara Yudhistira http://orcid.org/0000-0001-8945-1454
Krishnamanikumar Premachandran http://orcid.org/0000-0003-4063-2419
Shubhra Singh http://orcid.org/0000-0002-9079-5892
Faiz Nashiruddin Muhammad http://orcid.org/0000-0002-4616-3273
M. Bayu Mario http://orcid.org/0000-0002-3619-3348
Luqman Qurata Aini http://orcid.org/0000-0003-2577-534X
Widya Satya Nugraha http://orcid.org/0009-0008-2718-8927

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

References

Abril, S., Pinzón, M., Hernández-Carrión, M., Sánchez-Camargo, A., & del, P. (2022). Edible insects in Latin America: A sustainable alternative for our food security. *Frontiers in Nutrition*, *9*, 904812. https://doi.org/10.3389/fnut.2022.904812

Adámek, M., Adámková, A., Kouřimská, L., Mlček, J., Vojáčková, K., Orsavová, J., Bučková, M., Faměra, O., & Búran, M. (2020). Sensory evaluation and acceptance of food made of edible insects. *Potravinarstvo Slovak Journal of Food Sciences*, *14*, 921–928. https://doi.org/10.5219/1430

Aguilar-Toalá, J. E., Cruz-Monterrosa, R. G., & Liceaga, A. M. (2022). Beyond human nutrition of edible insects: Health benefits and safety aspects. *Insects*, *13*(11), 1007. https://doi.org/10.3390/insects13111007

Aidoo, O. F., Osei-Owusu, J., Asante, K., Dofuor, A. K., Boateng, B. O., Debrah, S. K., Ninsin, K. D., Siddiqui, S. A., & Chia, S. Y. (2023). Insects as food and medicine: A sustainable solution for global health and environmental challenges. *Frontiers in Nutrition*, *10*, 1113219. https://doi.org/10.3389/fnut.2023.1113219

Alagappan, S., Chaliha, M., Sultanbawa, Y., Fuller, S., Hoffman, L. C., Netzel, G., Weber, N., Rychlik, M., Cozzolino, D., Smyth, H. E., & Olarte Mantilla, S. M. (2021). Nutritional analysis, volatile composition, antimicrobial and antioxidant properties of Australian green ants (*Oecophylla smaragdina*). *Future Foods*, *3*, 100007. https://doi.org/10.1016/j.fufo.2020.100007

American Chemical Society. (2024). *The many flavors of edible ants.* https://www.acs.org/pressroom/presspacs/2024/march/the-many-flavors-of-edible-ants.html

American Diabetes Association. (2020). *Diabetes & DKA (Ketoacidosis).* https://diabetes.org/diabetes/dka-ketoacidosis-ketones

Anjos, D. V., Tena, A., Viana-Junior, A. B., Carvalho, R. L., Torezan-Silingardi, H., Del-Claro, K., & Perfecto, I. (2022). The effects of ants on pest control: A meta-analysis. *Proceedings of the Royal Society B: Biological Sciences*, *289*(1981). https://doi.org/10.1098/rspb.2022.1316

AntWeb. (2022). *Edible Ants*. https://www.antweb.org/project.do?name=edibleants

Araujo, Y., & Bessera, P. (2007). Diversidad de invertebrados consumidos por las etnias Yanomami y Yekuana del Alto Orinoco, Venezuela. *Interciencia*, *32*(5), 318–323.

Ayieko, M. A., Kinyuru, J. N., Ndong'a, M. F., & Kenji, G. M. (2012). Nutritional value and consumption of black ants (Carebara vidua Smith) from the lake Victoria region in Kenya. *Advance Journal of Food Science and Technology*, *4*(1), 39–45.

Bae, Y., & Choi, J. (2021). Consumer acceptance of edible insect foods: An application of the extended theory of planned behavior. *Nutrition Research and Practice*, *15*(1), 122–135. https://doi.org/10.4162/nrp.2021.15.1.122

Bani, G. (1995). Some aspects of entomophagy in the Congo. *Food Insect Newsletter*, *8*.

Barennes, H., Phimmasane, M., & Rajaonarivo, C. (2015). Insect consumption to address undernutrition, a national survey on the prevalence of insect consumption among adults and Vendors in Laos. *PloS One*, *10*(8), e0136458. https://doi.org/10.1371/journal.pone.0136458

Bartkowicz, J., & Babicz-Zielińska, E. (2020). Acceptance of bars with edible insects by a selected group of students from Tri-City, Poland. *Czech Journal of Food Sciences*, *38*(3), 192–197. https://doi.org/10.17221/236/2019-CJFS

Batat, W., & Peter, P. (2020). The healthy and sustainable bugs appetite: Factors affecting entomophagy acceptance and adoption in Western food cultures. *Journal of Consumer Marketing*, *37*(3), 291–303. https://doi.org/10.1108/JCM-10-2018-2906

Belluco, S., Losasso, C., Maggioletti, M., Alonzi, C. C., Paoletti, M. G., & Ricci, A. (2013). Edible insects in a food safety and nutritional perspective: A critical review. *Comprehensive Reviews in Food Science and Food Safety*, *12*(3), 296–313. https://doi.org/10.1111/1541-4337.12014

Bendezu Ccanto, J., Condori Chura, J., & Lozada-Urbano, M, Universidad Privada Norbert Wiener. (2022). Proximate, M icrobiological analysis and digestibility of pepsin in *Atta sexdens* Flour, from the Region of Rioja, Peru. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(115), 21938–21951. https://doi.org/10.18697/ajfand.115.22300

Berger, S., Christandl, F., Bitterlin, D., & Wyss, A. M. (2019). The social insectivore: Peer and expert influence affect consumer evaluations of insects as food. *Appetite*, *141*, 104338. https://doi.org/10.1016/j.appet.2019.104338

Bhulaidok, S., Sihamala, O., Shen, L., & Li, D. (2010). Nutritional and fatty acid profiles of sun-dried edible black ants (*Polyrhachis vicina* Roger). *Maejo International Journal of Science and Technology*, *4*, 101–112.

Bisconsin-Júnior, A., Rodrigues, H., Behrens, J. H., da Silva, M. A. A. P., & Mariutti, L. R. B. (2022). "Food made with edible insects": Exploring the social representation of entomophagy where it is unfamiliar. *Appetite*, *173*, 106001. https://doi.org/10.1016/j.appet.2022.106001

Borah, D., Gogoi, P., Agarwal, D., & Khataniar, A. (2019). Characterization of a newly isolated probiotic strain from *Oecophylla smaragdina*, an edible insect popular among the indigenous communities of Northeast India. *Indian Journal of Microbiology*, *59*(1), 39–50. https://doi.org/10.1007/s12088-018-0758-5

Borah, M. P., & Prasad, S. B. (2017). Ethnozoological study of animals based medicine used by traditional healers and indigenous inhabitants in the adjoining areas of Gibbon Wildlife Sanctuary, Assam, India. *Journal of Ethnobiology and Ethnomedicine*, *13*(1), 39. https://doi.org/10.1186/s13002-017-0167-6

Borgohain, M., Borkotoki, A., & Mahanta, R. (2014). Total lipid, triglyceride and cholesterol contents in Oecophylla smaragdina, Fabricius consumed in Upper Assam of North East India. *International Journal of Scientific and Research Publications*, *4*.

Caparros Megido, R., Desmedt, S., Blecker, C., Béra, F., Haubruge, É., Alabi, T., & Francis, F. (2017). Microbiological load of edible insects found in Belgium. *Insects*, *8*(1), 12. https://doi.org/10.3390/insects8010012

Casas Reátegui, R., Pawera, L., Villegas Panduro, P. P., & Polesny, Z. (2018). Beetles, ants, wasps, or flies? An ethnobiological study of edible insects among the Awajún Amerindians in Amazonas, Peru. *Journal of Ethnobiology and Ethnomedicine*, *14*(1), 53. https://doi.org/10.1186/s13002-018-0252-5

Castillo-Andrade, A., García-Barrientos, R., Ruiz-Cabrera, M. A., Rivera-Bautista, C., Pérez-Martínez, J. D., González-García, R., Fuentes-Ahumada, C., & Grajales-Lagunes, A. (2015). Structural and physicochemical changes due to proteolytic deterioration of escamoles (*Liometopum apiculatum*) a traditional Mexican food. *Journal of Insects as Food and Feed*, *1*(4), 271–280. https://doi.org/10.3920/JIFF2015.0031

Castro, M., & Chambers, E. (2019). Willingness to eat an insect based product and impact on brand equity: A global perspective. *Journal of Sensory Studies*, *34*(2). https://doi.org/10.1111/joss.12486

Césard, N. (2004). Harvesting and commercialisation of kroto (*Oecophylla smaragdina*) in the Malingping area, West Java, Indonesia. In K. Kusters, G. Mulcahy, & B. Belcher (Eds.), *Forest products, livelihoods and conservation. Case studies of nontimber product systems (Vols. 1-Asia, Issue)* (pp. 61–77). Center for International Forestry Research.

Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2011). Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine*, *7*(1), 5. https://doi.org/10.1186/1746-4269-7-5

Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2013). Comparative survey of entomophagy and entomotherapeutic practices in six tribes of Eastern Arunachal Pradesh (India). *Journal of Ethnobiology and Ethnomedicine*, *9*(1), 50. 50. https://doi.org/10.1186/1746-4269-9-50

Chakravorty, J., Ghosh, S., Megu, K., Jung, C., & Meyer-Rochow, V. B. (2016). Nutritional and anti-nutritional composition of *Oecophylla smaragdina* (Hymenoptera: Formicidae) and *Odontotermes* sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, *19*(3), 711–720. https://doi.org/10.1016/j.aspen.2016.07.001

Chavanduka, D. M. (1976). Insects as a source of protein to the Africain. *The Rhodesia Science News*, *9*(7), 217–220.

Chen, X., & Feng, Y. (1999). The edible insects of China. *Science and Technology*,

Chen, X., Feng, Y., & Chen, Z. (2009). Common edible insects and their utilization in China. *Entomological Research*, *39*(5), 299–303. https://doi.org/10.1111/j.1748-5967.2009.00237.x

Chinarak, K., Chaijan, M., & Panpipat, W. (2020). Farm-raised sago palm weevil (*Rhynchophorus ferrugineus*) larvae: Potential and challenges for promising source of nutrients. *Journal of Food Composition and Analysis*, *92*, 103542. https://doi.org/10.1016/j.jfca.2020.103542

Choudhary, P., Kumar Sharma, A., Kumar Mishra, Y., & Nayak, S. (2022). Entomotherapy medicinal significance of insects: A review. *The Pharma Innovation Journal*, *11*(4), 25–29. http://www.thepharmajournal.com

Christensen, D. L., Orech, F. O., Mungai, M. N., Larsen, T., Friis, H., & Aagaard-Hansen, J. (2006). Entomophagy among the Luo of Kenya: A potential mineral source? *International Journal of Food Sciences and Nutrition*, *57*(3-4), 198–203. https://doi.org/10.1080/09637480600738252

Chung, A. Y. C., Khen, C. V., Unchi, S., & Binti, M. (2002). Edible insects and entomophagy in Sabah. *Malaysia. Malayan Nature Journal*, *56*(2), 131–144.

Cicatiello, C., Vitali, A., & Lacetera, N. (2020). How does it taste? Appreciation of insect-based snacks and its determinants. *International Journal of Gastronomy and Food Science*, *21*, 100211. https://doi.org/10.1016/j.ijgfs.2020.100211

Clark. (2022). *Major Herbs*—Polyrhachis *Ant.* https://www.clarkpest.com/residential-service-blog/medicinal-ant-extract

Costa, S., Pedro, S., Lourenço, H., Batista, I., Teixeira, B., Bandarra, N. M., Murta, D., Nunes, R., & Pires, C. (2020). Evaluation of Tenebrio molitor larvae as an alternative food source. *NFS Journal*, *21*, 57–64. https://doi.org/10.1016/j.nfs.2020.10.001

Costa-Neto, E. M., & Dunkel, F. V. (2016). Insect as food: History, and modern use around the world. In A. T. Dossey, J. A. Morales-Ramos, & M. G. Rojas (Eds.), *Insect as sustainable food ingredients: Production, processing, and food application*. Elsevier.

Costa-Neto, E. M., & Ramos-Elorduy, J. (2006). Los insectos comestibles de Brasil: Etnicidad, diversidad e importancia en la alimentación. *Boletín Sociedad Entomológica Aragonesa*. 38, 423–442.

Crozier, R. H., Newey, P. S., Schlüns, E. A., & Robson, S. K. A. (2009). A masterpiece of evolution *Oecophylla* weaver ants (Hymenoptera: Formicidae). *Myrmecological News*, *13*, 57–71.

Cruz-Labana, J. D., Crosby-Galván, M. M., Delgado-Alvarado, A., Alcántara-Carbajal, J. L., Cuca-García, J. M., & Tarango-Arámbula, L. A. (2018). Nutritional content of Liometopum apiculatum Mayr larvae ("escamoles") by vegetation type in north-central Mexico. *Journal of Asia-Pacific Entomology*, *21*(4), 1239–1245. https://doi.org/10.1016/j.aspen.2018.09.008

Dantas, A., & Fonseca, C. R. (2023). Global biogeographical patterns of ants and their abiotic determinants. *Perspectives in Ecology and Conservation*, *21*(3), 237–246. https://doi.org/10.1016/j.pecon.2023.07.003

de Gier, S., & Verhoeckx, K. (2018). Insect (food) allergy and allergens. *Molecular Immunology*, *100*, 82–106. https://doi.org/10.1016/j.molimm.2018.03.015

De Marchi, L., Wangorsch, A., & Zoccatelli, G. (2021). Allergens from edible insects: Cross-reactivity and effects of processing. *Current Allergy and Asthma Reports*, *21*(5), 35. https://doi.org/10.1007/s11882-021-01012-z

DeFoliart, G. R. (2002). *The human use of insects as food resource: A bibliographic account in progress.* http://www.food-insects.com/book7_31/The human use of insects

Deka, B., Tomberlin, J. K., & Babu, A. (2021). Insects as food and feed: A promising agricultural sector with special reference to India. *Journal of Insects as Food and Feed*, *7*(4), 471–482. https://doi.org/10.3920/JIFF2020.0131

Detilleux, L., Bayendi Loudit, S., Le Gall, P., Francis, F., Caparros Megido, R., & Dogot, T. (2024). Consumers of insect-based foods: A cross-cultural study between Belgium and Gabon. *Journal of Insect Science (Online)*, *24*(3). https://doi.org/10.1093/jisesa/ieae051

Devarajan, K. (2016). Correction: The antsy social network: Determinants of nest structure and arrangement in Asian weaver ants. *PloS One*, *11*(7), e0159284. https://doi.org/10.1371/journal.pone.0159284

Devi, W. D., Bonysana, R., Kapesa, K., Mukherjee, P. K., & Rajashekar, Y. (2023). Edible insects: As traditional medicine for human wellness. *Future Foods*, *7*, 100219. https://doi.org/10.1016/j.fufo.2023.100219

Dragon Herbs. (2022). *Changbai mountain ants.* https://www.dragonherbs.com/changbai-mountain-ant

Dufour, D. W. (1987). Insects as food: A case study from the Northwest Amazon. *American Anthropologist*, *89*(2), 383–397. https://doi.org/10.1525/aa.1987.89.2.02a00070

Durst, P. B., & Hanboonsong, Y. (2015). Small-scale production of edible insects for enhanced food security and rural livelihoods: Experience from Thailand and Lao People's Democratic Republic. *Journal of Insects as Food and Feed*, *1*(1), 25–32. https://doi.org/10.3920/JIFF2014.0019

Ehounou, P. G., S. W. M. Ouaii-N 'goran., & S. Niassy. (2018). Assessment of entomophagy in Abidjan (Cote Divoire, West Africa). *African Journal of Food Science*, *12*(1), 6–14. https://doi.org/10.5897/AJFS2017.1589

El Bilali, H., Henri Nestor Bassole, I., Dambo, L., & Berjan, S. (2020). Climate change and food security. *The Journal "Agriculture and Forestry"*, *66*(3). https://doi.org/10.17707/AgricultForest.66.3.16

Escamilla, F., & Ariza, J. (2021). Nutrient and oil profile of Escamol, an edible larva of ants (*Liometopum apiculatum* Mayr). *Future of Food: Journal on Food, Agriculture and Society*, *9*(2), 1–9. https://doi.org/10.17170/kobra-202102163259

Exélis, M. P., Ramli, R., Idris, A. H., Ibrahim, R. W., Clemente-Orta, G. M., Ayra-Pardo, C., & Abdullah Sani, M. S. (2025). Distribution and nest occupancy patterns of *Oecophylla smaragdina* (Hymenoptera: Formicidae) colonies in Southeast Asian oil palm plantations. *Journal of Asia-Pacific Entomology*, *28*(3), 102451. https://doi.org/10.1016/j.aspen.2025.102451

FAO. (2013). Edible insects. Future prospects for food and feed security. *Food and Agriculture Organization of the United Nations*, *171*.

Fernando, I., Siddiqui, S. A., Nugraha, W. S., Yudhistira, B., Adli, D. N., Nagdalian, A. A., Blinov, A. V., & Mario, M. B. (2023). Overview of larvae of red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), as human food. *Journal of Insects as Food and Feed*, *9*(10), 1265–1284. https://doi.org/10.3920/JIFF2022.0095

Gahukar, R. T. (2011). Entomophagy and human food security. *International Journal of Tropical Insect Science*, *31*(3), 129–144. https://doi.org/10.1017/S1742758411000257

Gahukar, R. T. (2020). Edible insects collected from forests for family livelihood and wellness of rural communities: A review. *Global Food Security*, *25*, 100348. https://doi.org/10.1016/j.gfs.2020.100348

Gallardo-López, F., Rendón-Martínez, A., Ramírez-Sandoval, G., Ozuna, C., Paniagua-Martínez, I., & Ramírez-Martínez, A. (2023). Consumption of *Atta mexicana* (chicatanas) in two regions of Veracruz, Mexico: A multifactorial study of the consumption of chicatanas. *Journal of Insects as Food and Feed*, *9*(4), 525–540. https://doi.org/10.3920/JIFF2022.0054

García-Sandoval, V., Tarango-Arámbula, L. A., Escobar-Flores, J. G., Cadena-Iñiguez, J., Martínez-Montoya, J. F., Ugalde-Lezama, S., & Cruz-Labana, J. D. (2022). Indicadores de anidación de la hormiga escamolera (Liometopum apiculatum Mayr) para su manejo y conservación. *Agro-Divulgación*, *2*(4), 13–16. https://agrodivulgacion-colpos.org/index.php/1agrodivulgacion1/article/view/85

Gelfand, M. (1975). Insects. In M. Gelfand (Ed.), *Diet and tradition in African culture* (pp. 163–171). E & S Livingstone.

Ghosh, S., Jung, C., & Meyer-Rochow, V. B. (2018). What governs selection and acceptance of edible insect species? In Halloran, A., Flore, R., Vantomme, P., Roos, N. (Eds.), *Edible insects in sustainable food systems*. Springer. https://doi.org/10.1007/978-3-319-74011-9_20

Giehr, J., Senninger, L., Ruhland, K., & Heinze, J. (2020). Ant workers produce males in queenless parts of multi-nest colonies. *Scientific Reports*, *10*(1), 2152. https://doi.org/10.1038/s41598-020-58830-w

González-Escobar, J. L., Grajales-Lagunes, A., Smoliński, A., Chagolla-López, A., De Léon-Rodríguez, A., & Barba de la Rosa, A. P. (2018). Microbiota of edible *Liometopum apiculatum* ant larvae reveals potential functions related to their nutritional value. *Food Research International (Ottawa, Ont.)*, *109*(February), 497–505. https://doi.org/10.1016/j.foodres.2018.04.049

Gordon, A., & Williams, R. (2017). Case study: Formula safe foods—sauces. In *Food safety and quality in developing countries* (pp. 117–148). Elsevier. https://doi.org/10.1016/B978-0-12-801226-0.00005-0

Gregg, R. E. (1963). The nest of *Liometopum apiculatum* Mayr (Hymenoptera: Formicidae). *Univ. Colo. Stud. Ser. Biol*, *11*, 1–6.

Grimaldi, D., & Engel, M. S. (2005). *Evolution of the insects*. Cambridge University Press.

Guining, W., Shifeng, C., Qibiao, S., Hua, S., Meiyu, L., Fei, H., Wenjie, L., Guoshou, L., Zhoufeng, H., Xiao, T., Xiao, L., Xianbiao, Z., Baowei, W., & Naihong, C. (2018). Antidepressant-like effect of active fraction of Polyrhachisvicina Roger in a rat depression model. *Journal of Traditional Chinese Medicine*, *38*(1), 12–21. https://doi.org/10.1016/j.jtcm.2018.02.001

Guiomar, M.-L., Hernández-Álvarez, A.-J., & Salinas-Castro, A. (2019). Edible insects processing: Traditional and innovative technologies. *Comprehensive Reviews in Food Science and Food Safety*, *18*(4), 1166–1191. https://doi.org/10.1111/1541-4337.12463

Halloran, A., Munke, C., Vantomme, P., Reade, B., & Evans, J. (2014). Broadening insect gast ronomy. In Sloan, P., Legrand, W., Hindley, C. (Eds.), *The Routledge handbook on sustainable food and gastronomy*. Taylor & Francis.

Hanboonsong, Y., Jamjanya, T., & Durst, P. B. (2013). Six-legged livestock: Edible insect farming, collection and marketing in Thailand. *FAO Regional Office for Asia and the Pacific*,

Healthline. (2021). *Eating ants: Nutrition, benefits, downsides.* https://www.healthline.com/nutrition/eating-ants

Hernández-Álvarez, A. J., Mondor, M., Piña-Domínguez, I. A., Sánchez-Velázquez, O. A., & Melgar Lalanne, G. (2021). Drying technologies for edible insects and their derived ingredients. *Drying Technology*, *39*(13), 1991–2009. https://doi.org/10.1080/07373937.2021.1915796

Hernández-Roldán, E., Tarango-Arámbula, L. A., Flores-Ramírez, R., Pimentel-López, J., & Serna-Lagunes, R. (2024). *Volatile organic compounds in the habitat of the escamolera ant (Liometopum apiculatum Mayr) in Zacatecas*. Agro Productividad (pp. 211–224). https://doi.org/10.32854/agrop.v17i17.2817

Hlongwane, Z. T., Slotow, R., & Munyai, T. C. (2020). Indigenous knowledge about consumption of edible insects in South Africa. *Insects*, *12*(1), 22. https://doi.org/10.3390/insects12010022

Hoey-Chamberlain, R. (2012). Food preference, survivorship, and intraspecific interactions of velvety tree ants [Thesis]. UC Riverside.

Hoey-Chamberlain, R., Rust, M. K., & Klotz, J. H. (2013). A review of the biology, ecology and behavior of velvety tree ants of North America. *Sociobiology*, *60*(1), 1–10. https://doi.org/10.13102/sociobiology.v60i1.1-10

Hölldobler, B., & Wilson, E. O. (1990). *The ants*. Harvard University Press.

House, J. (2016). Consumer acceptance of insect-based foods in the Netherlands: Academic and commercial implications. *Appetite*, *107*, 47–58. https://doi.org/10.1016/j.appet.2016.07.023

Jeremy, C., Eric, M., & Shane, R. S. (2020). *Hydrocarbon Toxicity*. https://www.ncbi.nlm.nih.gov/books/NBK499883/

Ji, Y. (2024). Adaptability and strategy of ant society: Analysis of cooperation and defense behavior. *BIO Web of Conferences*, *111*, 03006. 03006. https://doi.org/10.1051/bioconf/202411103006

Jin-Fu, W., & Jue, T. (2016). The spatial pattern on nest and the population dynamics of *Polyrhachis vicina* Roger (Hymenoptera: Formicidae). *Zoological Research*, *17*(2).

Jongema, Y. (2017). *List of edible insects of the world*. Wageningen University & Research. https://www.wur.nl/en/research-results/chair-groups/plant-sciences/laboratory-of-entomology/edible-insects/worldwide-species-list.htm

Kalita, T., Sharma, R., Sengupta, S., & Basumatari, D. (2022). Entomophagy practices in Bodoland Territorial Region, Assam: Nutritional potential and implications for food security. *Journal of Insects as Food and Feed*, *8*(12), 1485–1500. https://doi.org/10.3920/JIFF2021.0141

Kamemura, N., Sugimoto, M., Tamehiro, N., Adachi, R., Tomonari, S., Watanabe, T., & Mito, T. (2019). Cross-allergenicity of crustacean and the edible insect *Gryllus bimaculatus* in patients with shrimp allergy. *Molecular Immunology*, *106*, 127–134. https://doi.org/10.1016/j.molimm.2018.12.015

Kass, J. M., Guénard, B., Dudley, K. L., Jenkins, C. N., Azuma, F., Fisher, B. L., Parr, C. L., Gibb, H., Longino, J. T., Ward, P. S., Chao, A., Lubertazzi, D., Weiser, M., Jetz, W., Guralnick, R., Blatrix, R., Lauriers, J. D., Donoso, D. A., Georgiadis, C., … Economo, E. P. (2022). The global distribution of known and undiscovered ant biodiversity. *Science Advances*, *8*(31), eabp9908. https://doi.org/10.1126/sciadv.abp9908

Kasza, G., Izsó, T., Szakos, D., Nugraha, W. S., Tamimi, M. H., & Süth, M. (2023). Insects as food - Changes in consumers' acceptance of entomophagy in Hungary between 2016 and 2021. *Appetite*, *188*, 106770. https://doi.org/10.1016/j.appet.2023.106770

Katz, E. (2016). Les insectes comestibles en Amérique latine: de nourritures d'Indiens à patrimoine alimentaire. In E. Motte-Florac & P. Le Gall (Eds.), *Savoureux insectes* (pp. 89–118). Presses Universitaires de Rennes.

Kauppi, S.-M., Pettersen, I. N., & Boks, C. (2019). Consumer acceptance of edible insects and design interventions as adoption strategy. *International Journal of Food Design*, *4*(1), 39–62. https://doi.org/10.1386/ijfd.4.1.39_1

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N. K., & Ekesi, S. (2015). African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security. *Journal of Insects as Food and Feed*, *1*(2), 103–119. https://doi.org/10.3920/JIFF2014.0016

Kooij, P. W., Dentinger, B. M., Donoso, D. A., Shik, J. Z., & Gaya, E. (2018). Cryptic diversity in colombian edible leaf-cutting ants (Hymenoptera: Formicidae). *Insects*, *9*(4), 191. https://doi.org/10.3390/insects9040191

Krag, K., Lundegaard, R., Offenberg, J., Nielsen, M. G., & Wiwatwittaya, D. (2010). Intercolony transplantation of *Oecophylla smaragdina* (Hymenoptera: Formicidae) larvae. *Journal of Asia-Pacific Entomology*, *13*(2), 97–100. https://doi.org/10.1016/j.aspen.2009.12.005

Kröger, T., Dupont, J., Büsing, L., & Fiebelkorn, F. (2021). Acceptance of Insect-based food products in western societies: A systematic review. *Frontiers in Nutrition*, *8*, 759885. https://doi.org/10.3389/fnut.2021.759885

Krongdang, S., Phokasem, P., Venkatachalam, K., & Charoenphun, N. (2023). Edible insects in Thailand: An overview of status, properties, processing, and utilization in the food industry. *Foods (Basel, Switzerland)*, *12*(11), 2162. https://doi.org/10.3390/foods12112162

Lake, I. R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A. B. A., Draper, A., Fairweather-Tait, S., Hulme, M., Hunter, P. R., Nichols, G., & Waldron, K. W. (2012). Climate change and food security: Health impacts in developed countries. *Environmental Health Perspectives*, *120*(11), 1520–1526. https://doi.org/10.1289/ehp.1104424

Lara-Juárez, P., Aguirre-Rivera, J. R., Castillo-Lara, P., & Reyes-Agüero, J. A. (2015). Biología y aprovechamiento de la hormiga de escamoles, *Liometopum apiculatum* Mayr (Hymenoptera: Formicidae). *Acta Zoológica Mexicana*, *31*(2), 251–264.

Lee, J. H., Kim, T.-K., Jeong, C. H., Yong, H. I., Cha, J. Y., Kim, B.-K., & Choi, Y.-S. (2021). Biological activity and processing technologies of edible insects: A review. *Food Science and Biotechnology*, *30*(8), 1003–1023. https://doi.org/10.1007/s10068-021-00942-8

Lepage, M. G., & Darlington, J. P. E. C. (1984). Observations on the ant *Carebara vidua* F. Smith preying on termites in Kenya. *Journal of Natural History*, *18*(2), 293–302. https://doi.org/10.1080/00222938400770221

Li, D., Sihamala, O., Bhulaidok, S., & Shen, L. (2009). Changes in the organic compounds following sun drying of edible black ant (*Polyrhachis vicina* Roger). *Acta Alimentaria*, *38*(4), 493–501. https://doi.org/10.1556/AAlim.38.2009.4.9

Li, D., Zhu, F., Wei, J., Xie, J., He, J., Wei, D., Li, Y., Lai, K., Liu, L., Su, Q., Wei, G., Wang, B., & Liu, Y. (2023). The active fraction of *Polyrhachis vicina* Roger (AFPR) activates ERK to cause necroptosis in colorectal cancer. *Journal of Ethnopharmacology*, *312*, 116454. https://doi.org/10.1016/j.jep.2023.116454

Liceaga, A. M. (2021). Processing insects for use in the food and feed industry. *Current Opinion in Insect Science*, *48*, 32–36. https://doi.org/10.1016/j.cois.2021.08.002

Liévano, A. B. (2011). *Insect diet may be the solution for a hungry world*. https://observers.france24.com/en/20110817-insect-diet-hungry-world-eating-insects-food-colombia-japan-thailand-mexico

Liu, D. (1991). Observations on effect of ant powder in the treatment of 808 patients suffering from rheumatoid arthritis. In Z. Wu (Ed.), *Ants and rheumatoid arthritis* (pp. 184–187). Jiangsu Scientific and Technological Publishing House.

Llavata, B., García-Pérez, J. V., Simal, S., & Cárcel, J. A. (2020). Innovative pre-treatments to enhance food drying: A current review. *Current Opinion in Food Science*, *35*, 20–26. https://doi.org/10.1016/j.cofs.2019.12.001

Lozada-Urbano, M., Bendezú Ccanto, J., Condori Chura, J., Rivera-Lozada, O., & Yañez, J. A. (2023). Development and acceptability of a cereal bar with *Atta sexdens* ant flour. *F1000Research*, *12*, 849. https://doi.org/10.12688/f1000research.135516.1

Lucas, A. J. D S., Menegon de Oliveira, L., da Rocha, M., & Prentice, C. (2020). Edible insects: An alternative of nutritional, functional and bioactive compounds. *Food Chemistry*, *311*, 126022. https://doi.org/10.1016/j.foodchem.2019.126022

Mantilla, S. M. O., Alagappan, S., Sultanbawa, Y., Smyth, H. E., & Cozzolino, D. (2020). A mid infrared (MIR) spectroscopy study of the composition of edible Australian green ants (*Oecophylla smaragdina*): A qualitative study. *Food Analytical Methods*, *13*(8), 1627–1633. https://doi.org/10.1007/s12161-020-01783-7

Mariod, A. A. (2020). *African edible insects as alternative source of food, oil, protein and bioactive components*. Springer International Publishing. https://doi.org/10.1007/978-3-030-32952-5

MarketWatch. (2022). *Edible Insects Market Size and Opportunities for New Players with Current Report of 104 Pages is Forecast from 2023 to 2027*. https://www.marketwatch.com/press-release/edible-insects-market-size-opportunities-for-new-players-with-current-report-of-104-pages-is-forecast-from-2023-to-2027-2022-12-12

Mba, A. R. F., Kansci, G., Viau, M., Hafnaoui, N., Meynier, A., Demmano, G., & Genot, C. (2017). Lipid and amino acid profiles support the potential of *Rhynchophorus phoenicis* larvae for human nutrition. *Journal of Food Composition and Analysis*, *60*, 64–73. https://doi.org/10.1016/j.jfca.2017.03.016

Mbata, K. J. (1995). Traditional use of arthropods in Zambia: I. The food insects. *Food Insect Newsletter*, *8*(3), 4–7.

Meer, J. C. V D M. (1965). Insects eaten by the Karo-Batak people (A contribution to entomobromatology). *Entomologische Berichten*, *25*(6), 101–107.

Megu, K., Tukshipa, S. D., Yasung, P., & Chkaravorty, J. (2019). Protein composition of *Oecophylla smaragdina* (Hymenoptera: Formicidae) based on altitudinal variation from Arunachal Pradesh, India. *Dera Natung Government College Research Journal*, *4*(1), 33–40. https://doi.org/10.56405/dngcrj.2019.04.01.05

Melo-Ruiz, V., Quirino-Barreda, T., Calvo-Carrillo, C., Sánchez-Herrera, K., & Sandoval-Trujillo, H. (2013). Assessment of nutrients of escamoles ant eggs *Limotepum apiculatum* M. by spectroscopy methods. *Chemical Engineering Journal*, *7*, 1181–1187.

Meutchieye, F., Tsafo, K. E., & Niassy, S. (2016). Inventory of edible insects and their harvesting methods in the Cameroon Centre Region. *Journal of Insects as Food and Feed*, *2*(3), 145–152. https://doi.org/10.3920/JIFF2015.0082

Meyer-Rochow, V. B. (2009). Food taboos: Their origins and purposes. *Journal of Ethnobiology and Ethnomedicine*, *5*(5), 18. https://doi.org/10.1186/1746-4269-5-18

Meyer-Rochow, V. B., Gahukar, R. T., Ghosh, S., & Jung, C. (2021). Chemical composition, nutrient quality and acceptability of edible insects are affected by species, developmental stage, gender, diet, and processing method. *Foods (Basel, Switzerland)*, *10*(5), 1036. https://doi.org/10.3390/foods10051036

Miller, T. E. X. (2007). Does having multiple partners weaken the benefits of facultative mutualism? A test with cacti and cactus-tending ants. *Oikos*, *116*(3), 500–512. https://doi.org/10.1111/j.2007.0030-1299.15317.x

Mishyna, M., Chen, J., & Benjamin, O. (2020). Sensory attributes of edible insects and insect-based foods: Future outlooks for enhancing consumer appeal. *Trends in Food Science & Technology*, *95*, 141–148. https://doi.org/10.1016/j.tifs.2019.11.016

Mitra, A., Chanda, A., & Raut, S. K. (2020). On the use of red ant Oecophylla smaragdina by the indigenous people of Binpur, Jhargram, West Bengal. *International Research Journal of Basic and Applied Sciences*, *5*, 67–71.

Mitsuhashi, J. (2016). *Edible insects of the world*. CRC Press.

Mozhui, L., Kakati, L. N., Kiewhuo, P., & Changkija, S. (2020). Traditional knowledge of the utilization of edible insects in Nagaland, North-East India. *Foods (Basel, Switzerland)*, *9*(7), 852. https://doi.org/10.3390/foods9070852

Müller, A. (2019). Insects as food in Laos and Thailand. *Asian Journal of Social Science*, *47*(2), 204–223. https://doi.org/10.1163/15685314-04702003

Münke-Svendsen, C., Flore, R., Halloran, A., Ayieko, M., & Roos, N. (2017). Technical Brief # 4: Edible Insect Gastronomy in Kenya. https://doi.org/10.13140/RG.2.2.11054.82249

Musundire, R., Zvidzai, C. J., Chidewe, C., Samende, B. K., & Chemura, A. (2016). Habitats and nutritional composition of selected edible insects in Zimbabwe. *Journal of Insects as Food and Feed*, *2*(3), 189–198. https://doi.org/10.3920/JIFF2015.0083

Naranjo-Guevara, N., dos Santos, L. A. O., Chiarina Pena Barbosa, N. C., e Castro, A. C. M. C., & Fernandes, O. A. (2020). Long-term mass rearing impacts performance of the egg parasitoid *Telenomus remus* (Hymenoptera: Platygastridae). *Journal of Entomological Science*, *55*(1), 69. https://doi.org/10.18474/0749-8004-55.1.69

Nielsen, F. K., Hansen, R. J., Eriksen, N. T., Muurmann, A. T., & Bahrndorff, S. (2025). Metabolic performance of mealworms and black soldier fly larvae reared on food and agricultural waste and by-products. *Animals: An Open Access Journal from MDPI*, *15*(2), 233. https://doi.org/10.3390/ani15020233

Nielsen, M. G., Peng, R., Offenberg, J., & Birkmose, D. (2016). Mating strategy of Oecophylla smaragdina (Hymenoptera: Formicidae) in northern Australia. *Austral Entomology*, *55*(3), 261–267. https://doi.org/10.1111/aen.12182

Njunina, V. (2022). *Safe and long-term food storage for food businesses.* https://www.fooddocs.com/

Nordic Food Lab. (2014). *Anty Gin—Nordic food lab.* https://nordicfoodlab.org/blog/2014/10/anty-gin/

Nsevolo, M. P., Kiatoko, N., Kambashi, M. B., Francis, F., & Megido, R. C. (2023). Reviewing entomophagy in the Democratic Republic of Congo: Species and host plant diversity, seasonality, patterns of consumption and challenges of the edible insect sector. *Journal of Insects as Food and Feed*, *9*(2), 225–244. https://doi.org/10.3920/JIFF2022.0024

Offenberg, J. (2015). Ants as tools in sustainable agriculture. *Journal of Applied Ecology*, *52*(5), 1197–1205. https://doi.org/10.1111/1365-2664.12496

Offenberg, J., & Wiwatwitaya, D. (2010). Sustainable weaver ant (*Oecophylla smaragdina*) farming: Harvest yields and effects on worker ant density. *Asian Myrmecology*, *3*(1), 55–62.

Ohtake, S., Izutsu., & K., Lechuga-Ballesteros. (2020). *Drying technologies for biotechnology and pharmaceutical applications*. Wiley. https://doi.org/10.1002/9783527802104

Ojha, S., Bußler, S., Psarianos, M., Rossi, G., & Schlüter, O. K. (2021). Edible insect processing pathways and implementation of emerging technologies. *Journal of Insects as Food and Feed*, *7*(5), 877–900. https://doi.org/10.3920/JIFF2020.0121

Okia, C. A., Odongo, W., Nzabamwita, P., Ndimubandi, J., Nalika, N., & Nyeko, P. (2017). Local knowledge and practices on use and management of edible insects in Lake Victoria basin, East Africa. *Journal of Insects as Food and Feed*, *3*(2), 83–94. https://doi.org/10.3920/JIFF2016.0051

Ondede, D. A., Ochuodho, D. O., & Ayieko, M. A. (2022). Eco-climatic factors influencing the distribution of black ants (Carebara vidua) in Western Kenya. *Advances in Entomology*, *10*(03), 233–251. https://doi.org/10.4236/ae.2022.103017

Onore, G. (2005). Edible insects in Ecuador. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock* (pp. 343–352). Science Publishers, Inc.

Oonincx, D. G. A. B., van Itterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. J. A., & van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PLoS One*, *5*(12), e14445. https://doi.org/10.1371/journal.pone.0014445

Oranut, S., Subhachai, B., Shen, L., & Li, D. (2010). Lipids and fatty acid composition of dried edible red and black ants. *Agricultural Sciences in China*, *9*(7), 1072–1077. https://doi.org/10.1016/S1671-2927(09)60192-9

Orsi, L., Voege, L. L., & Stranieri, S. (2019). Eating edible insects as sustainable food? Exploring the determinants of consumer acceptance in Germany. *Food Research International (Ottawa, Ont.)*, *125*, 108573. https://doi.org/10.1016/j.foodres.2019.108573

Ortiz, D. P., Elizalde, L., & Pirk, G. I. (2021). Role of ants as dispersers of native and exotic seeds in an understudied dryland. *Ecological Entomology*, *46*(3), 626–636. https://doi.org/10.1111/een.13010

Payne, C., & Van Itterbeeck, J. (2017). Ecosystem services from edible insects in agricultural systems: A review. *Insects*, *8*(1), 24. https://doi.org/10.3390/insects8010024

Pazmiño-Palomino, A., & Troya, A. (2022). Ants of Ecuador: New species records for a megadiverse country in South America. *Revista Brasileira de Entomologia*, *66*(2). https://doi.org/10.1590/1806-9665-rbent-2021-0089

Peng, R., Nielsen, M. G., Offenberg, J., & Birkmose, D. (2013). Utilisation of multiple queens and pupae transplantation to boost early colony growth of weaver ants Oecophylla smaragdina. *Asian Myrmecology*, *5*(1), 177–184.

Perez-Santaescolastica, C., De Winne, A., Devaere, J., & Fraeye, I. (2022). The flavour of edible insects: A comprehensive review on volatile compounds and their analytical assessment. *Trends in Food Science & Technology*, *127*, 352–367. https://doi.org/10.1016/j.tifs.2022.07.011

Pham, D. L., Bao, H. Q., Nguyen, D. D., van Trong, L., Le Tra, T. T., Phuc, K. T., Thu, N. T. M., & Chi, N. M. (2024). Edible ants in Vietnam: Identification and indigenous knowledge. *Ecologica Montenegrina*, *73*, 208–220. https://doi.org/10.37828/em.2024.73.19

Pimid, M., Hassan, A., Tahir, N. A., & Thevan, K. (2014). Colony structure of the Weaver ant, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae). *Sociobiology*, *59*(1), 1. https://doi.org/10.13102/sociobiology.v59i1.662

Pino Moreno, J. M., Ramos-Elorduy, J., & Costa-Neto, E. M. (2006). Los insectos comestibles comercializados en los mercados de Cuautitlán de Romero Rubio, Estado de México, México. *SITIENTIBUS Série Ciências Biológicas*, *6*, 58–64. https://doi.org/10.13102/scb8148

Rafael-Valdez, J., Tarango-Arambula, L. A., Ugalde-Lezama, S., Lozano-Cavazos, E. A., Ruíz-Vera, V. M., & Bravo-Vinaja, á. (2017). Sustratos forrajeros y de anidación de la hormiga escamolera (*Liometopum apiculatum* Mayr, Himenoptera: Formicidae) en Villa González Ortega, Zacatecas, México. *Agrociencia*, *51*(7), 755–769.

Raheem, D., Carrascosa, C., Oluwole, O. B., Nieuwland, M., Saraiva, A., Millán, R., & Raposo, A. (2019). Traditional consumption of and rearing edible insects in Africa, Asia and Europe. *Critical Reviews in Food Science and Nutrition*, *59*(14), 2169–2188. https://doi.org/10.1080/10408398.2018.1440191

Raheem, D., Raposo, A., Oluwole, O. B., Nieuwland, M., Saraiva, A., & Carrascosa, C. (2019). Entomophagy: Nutritional, ecological, safety and legislation aspects. *Food Research International (Ottawa, Ont.)*, *126*, 108672. https://doi.org/10.1016/j.foodres.2019.108672

Rahman, M. S. (2020). *Handbook of food preservation*. CRC Press. https://doi.org/10.1201/9780429091483

Raksakantong, P., Meeso, N., Kubola, J., & Siriamornpun, S. (2010). Fatty acids and proximate composition of eight Thai edible terricolous insects. *Food Research International*, *43*(1), 350–355. https://doi.org/10.1016/j.foodres.2009.10.014

Ramirez-Garcia, G. L., Ruiz-Cabrera, M. A., Abud-Archila, M., & Grajales-Lagunes, A. (2022). Use of hurdle technology to extend the shelf life of escamoles (*Liometopum apiculatum* Mayr). *International Journal of Food Science & Technology*, *57*(10), 6298–6305. https://doi.org/10.1111/ijfs.15929

Ramos-Elorduy, J. (2006). Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. *Journal of Ethnobiology and Ethnomedicine*, *2*(1), 10. https://doi.org/10.1186/1746-4269-2-51

Ramos-Elorduy, J., & Pino Moreno, J. M. (2002). Edible insects of Chiapas, Mexico. *Ecology of Food and Nutrition*, *41*(4), 271–299. https://doi.org/10.1080/03670240214081

Ramos-Elorduy, J., Pino-M, J. M., & Correa, S. C. (1998). Edible insects of the state of Mexico and determination of their nutritive values. *Anales Del Instituto de Biologia Universidad Nacional Autonoma de Mexico Serie Zoologia*, *69*(1), 65–104.

Ranga, L., Vishnumurthy, P., & Dermiki, M. (2024). Willingness to consume insects among students in France and Ireland. *Irish Journal of Agricultural and Food Research*, *62*(1). https://doi.org/10.15212/ijafr-2023-0106

Raza, M., Tukshipa, S. D., & Chakravorty, J. (2022). *Oecophylla smaragdina* (Hymenoptera: Formicidae) and *Odontotermes* sp. (Isoptera: Termitidae) a potential source of antioxidant: The two most preferred edible insects of Arunachal Pradesh, India. *Discover Food*, *2*(1), 3. https://doi.org/10.1007/s44187-021-00005-1

Reyes-Hernández, M., Ruiz-Cabrera, M. A., Álvarez-Salas, C., De Anda-Salazar, A., González-Suarez, L., la Rosa, A. B., Reyes-Agüero, J. A., & Grajales-Lagunes, A. (2022). Inclusion of typical Mexican ingredients in canned escamoles (*Liometopum apiculatum*): Thermophysical and physicochemical properties. *Journal of Insects as Food and Feed*, *8*(1), 85–93. https://doi.org/10.3920/JIFF2021.0041

Rezki, R., Aoliya, N., Fadliansyah, F., Wulandari, S. L., Jesajas, D. R., & Raffiudin, R. (2023). Variasi perilaku mencari makan pada semut rangrang *Oecophylla smaragdina* (Fabricius) pada habitat yang berbeda. *Jurnal Entomologi Indonesia*, *20*(2), 141. https://doi.org/10.5994/jei.20.2.141

Ribeiro, J. C., Sousa-Pinto, B., Fonseca, J., Fonseca, S. C., & Cunha, L. M. (2021). Edible insects and food safety: Allergy. *Journal of Insects as Food and Feed*, *7*(5), 833–847. https://doi.org/10.3920/JIFF2020.0065

Rico-Gray, V., & Oliveira, P. S. (2007). *The ecology and evolution of ant-plant interactions*. University of Chicago Press. https://doi.org/10.7208/chicago/9780226713540.001.0001

Romero-Jiménez, H., Tarango-Arámbula, L. A., Peredo-Rivera, E., Del Rosario-Arellano, J., Olmos-Oropeza, G., Hernández-Roldán, E., & Lopez-Martínez, L. A. (2024). *Productive characteristics, nesting substrates, and colonies of the escamolera ant (Liometopum apiculatum M.) in Zacatecas, Mexico* (pp. 17. No. 6). Agro Productividad.

Ros-Baró, M., Sánchez-Socarrás, V., Santos-Pagès, M., Bach-Faig, A., & Aguilar-Martínez, A. (2022). Consumers' acceptability and perception of edible insects as an emerging protein source. *International Journal of Environmental Research and Public Health*, *19*(23), 15756. https://doi.org/10.3390/ijerph192315756

Rumpold, B. A., & Schlüter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Molecular Nutrition & Food Research*, *57*(5), 802–823. https://doi.org/10.1002/mnfr.201200735

Sailo, S., Bhagawati, S., Sarmah, K. S. B., & Pathak, K. (2020). Nutritional and antinutritional properties of few common edible insect species of Assam. *Journal of Entomology and Zoology Studies, April*.

Sangma, R. H. C., Pal, R., & Singh, D. R. (2016). Edible insects of Northeast India. In *Bioprospecting of indigenous bioresources of North-East India* (pp. 253–267). Springer. https://doi.org/10.1007/978-981-10-0620-3_15

Scaffardi, L., & Formici, G. (2022). *Novel foods and edible insects in the European Union*. Springer International Publishing. https://doi.org/10.1007/978-3-031-13494-4

Schlup, Y., & Brunner, T. (2018). Prospects for insects as food in Switzerland: A Tobit regression. *Food Quality and Preference*, *64*, 37–46. https://doi.org/10.1016/j.foodqual.2017.10.010

Schrader, J., Oonincx, D. G. A. B., & Ferreira, M. P. (2016). North American entomophagy. *Journal of Insects as Food and Feed*, *2*(2), 111–120. https://doi.org/10.3920/JIFF2016.0003

Seabrooks, L., & Hu, L. (2017). Insects: An underrepresented resource for the discovery of biologically active natural products. *Acta Pharmaceutica Sinica. B*, *7*(4), 409–426. https://doi.org/10.1016/j.apsb.2017.05.001

Shen, L., Li, D., Feng, F., & Ren, Y. (2006). Nutritional composition of *Polyrhachis vicina* Roger (edible Chinese black ant). *Songklanakarin Journal of Science and Technology*, *28*(Suppl 1), 107–114.

Siddiqui, S. A., Li, C., Aidoo, O. F., Fernando, I., Haddad, M. A., Pereira, J. A. M., Blinov, A., Golik, A., & Câmara, J. S. (2023). Unravelling the potential of insects for medicinal purposes: A comprehensive review. *Heliyon*, *9*(5), e15938. https://doi.org/10.1016/j.heliyon.2023.e15938

Siddiqui, S. A., Tettey, E., Yunusa, B. M., Ngah, N., Debrah, S. K., Yang, X., Fernando, I., Povetkin, S. N., & Shah, M. A. (2023). Legal situation and consumer acceptance of insects being eaten as human food in different nations across the world–A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety*, *22*(6), 4786–4830. https://doi.org/10.1111/1541-4337.13243

Silow, C. A. (1983). Notes on Ngangela and Nkoya Ethnozoology. *Ants and Termites. Etnologiska*, *36*.

Singh, S., & Shalini, R. (2016). Effect of hurdle technology in food preservation: A review. *Critical Reviews in Food Science and Nutrition*, *56*(4), 641–649. https://doi.org/10.1080/10408398.2012.761594

Sribandit, W., Wiwatwitaya, D., Suksard, S., & Offenberg, J. (2009). The importance of weaver ant (*Oecophylla smaragdina* Fabricius) harvest to a local community in Northeastern Thailand. *Asian Myrmecology*, *2*(1), 129–138.

Su, Q., Su, H., Nong, Z., Li, D., Wang, L., Chu, S., Liao, L., Zhao, J., Zeng, X., Ya, Q., He, F., Lu, W., Wei, B., Wei, G., & Chen, N. (2018). Hypouricemic and nephroprotective effects of an active fraction from *Polyrhachis vicina* Roger on potassium oxonate-induced hyperuricemia in rats. *Kidney & Blood Pressure Research*, *43*(1), 220–233. https://doi.org/10.1159/000487675

Svanberg, I., & Berggren, Å. (2019). Ant schnapps for health and pleasure: The use of *Formica rufa* L. (Hymenoptera: Formicidae) to flavour aquavit. *Journal of Ethnobiology and Ethnomedicine*, *15*(1), 68. https://doi.org/10.1186/s13002-019-0347-7

Szmigiera, M. (2022). *World population—forecast until 2100 | Statista*. Statista.

Tamesse, J. L., Kekeunou, S., Tchatchouang, L. J., Ndegue, O. L. M., Aissatou, L. M., Tombouck, D., & Youssa, B. (2016). Insects as food, traditional medicine and cultural rites in the west and south regions of Cameroon. *Journal of Insects as Food and Feed*, *2*(3), 153–160. https://doi.org/10.3920/JIFF2015.0088

Tang, C., Yang, D., Liao, H., Sun, H., Liu, C., Wei, L., & Li, F. (2019). Edible insects as a food source: A review. *Food Production, Processing and Nutrition*, *1*(1), 8. https://doi.org/10.1186/s43014-019-0008-1

Tang, Q., & Dai, Y. (2018). Immunomodulatory effects of edible Chinese black ant, *Polyrhachis vicina* roger extract by using supercritical CO2. *Indian Journal of Experimental Biology*, *56*(6), 411–418.

Taylor, G., & Wang, N. (2018). Entomophagy and allergies: A study of the prevalence of entomophagy and related allergies in a population living in North-Eastern Thailand. *Bioscience Horizons: The International Journal of Student Research*, *11*. https://doi.org/10.1093/biohorizons/hzy003

Thrastardottir, R., Olafsdottir, H. T., & Thorarinsdottir, R. I. (2021). Yellow Mealworm and Black Soldier Fly Larvae for Feed and Food Production in Europe, with Emphasis on Iceland. *Foods*, *10*(11), 2744.https://doi.org/10.3390/foods10112744

Trible, W., & Kronauer, D. J. C. (2017). Caste development and evolution in ants: it's all about size. *The Journal of Experimental Biology*, *220*(Pt 1), 53–62. https://doi.org/10.1242/jeb.145292

Tzompa-Sosa, D. A., Sogari, G., Copelotti, E., Andreani, G., Schouteten, J. J., Moruzzo, R., Liu, A., Li, JIE., & Mancini, S. (2023). What motivates consumers to accept whole and processed mealworms in their diets? A five-country study. *Future Foods*, *7*, 100225 https://doi.org/10.1016/j.fufo.2023.100225

van Huis, A. (2002). Medicinal and stimulating properties ascribed to arthropods and their products in Sub-Saharan Africa. In E. Motte-Florac & J. M. C. Thomas (Eds.), *Insects in oral literature and traditions* (pp. 367–382). PeetersSELAF.

van Huis, A. (2017). Cultural significance of termites in sub-Saharan Africa. *Journal of Ethnobiology and Ethnomedicine*, *13*(1), 8. https://doi.org/10.1186/s13002-017-0137-z

van Huis, A. (2025). Edible ants: Exploring species and their utilisation. *Journal of Insects as Food and Feed*, *11*(3), 429–434. https://doi.org/10.1163/23524588-110301ED

van Huis, A., van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). *Edible insects: Future prospects for food and feed security.* FAO Forestry Paper. https://www.fao.org/3/i3253e/i3253e.pdf

van Huis, A., Van Itterbeeck, J., Klunder, K., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insect future prospect for food. *FAO Forestry Paper*, *171*.

Van Itterbeeck, J. (2014). Prospects of semi-cultivating the edible weaver ant *Oecophylla smaragdina* [Wageningen University]. https://core.ac.uk/download/pdf/29211056.pdf

Van Itterbeeck, J., & Pelozuelo, L. (2022). How Many edible insect species are there? a not so simple question. *Diversity*, *14*(2), 143. https://doi.org/10.3390/d14020143

Van Itterbeeck, J., Sivongxay, N., Praxaysombath, B., & Van Huis, A. (2014). Indigenous knowledge of the edible weaver ant *Oecophylla smaragdina* Fabricius Hymenoptera: Formicidae from the Vientiane Plain, Lao PDR. *Ethnobiology Letters*, *5*, 4–12. https://doi.org/10.14237/ebl.5.2014.125

Van Pelt, A. (1971). Trophobiosis and feeding habits of *Liometopum apiculatum* (Hymenoptera: Formicidae) in the Chisos Mountains, Texas. *Annals of the Entomological Society of America*, *64*(5), 1186–1186. https://doi.org/10.1093/aesa/64.5.1186

Van Thielen, L., Vermuyten, S., Storms, B., Rumpold, B., & Van Campenhout, L. (2019). Consumer acceptance of foods containing edible insects in Belgium two years after their introduction to the market. *Journal of Insects as Food and Feed*, *5*(1), 35–44. https://doi.org/10.3920/JIFF2017.0075

Vidhu, V. V., & Evans, D. A. (2015). Ethnoentomological values of *Oecophylla smaragdina* (Fabricius). *Current Science*, *109*(3), 572–579.

Virginia, M.-R., Tomás, Q.-B., Rafael, D.-G., & César, G.-U. (2016). Consumption of escamoles (*Liometopum apiculatum* M.): A source of vitamins A and E. *Journal of Applied Life Sciences International*, *9*(1), 1–7. https://doi.org/10.9734/JALSI/2016/28797

Weru, J., Chege, P., & Kinyuru, J. (2021). Nutritional potential of edible insects: A systematic review of published data. *International Journal of Tropical Insect Science*, *41*(3), 2015–2037. https://doi.org/10.1007/s42690-021-00464-0

Wetterer, J. K. (2017). Geographic distribution of the weaver ant *Oecophylla smaragdina*. *Asian Myrmecology*, *9*. https://doi.org/10.20362/am.009004

Wilkinson, K., Muhlhausler, B., Motley, C., Crump, A., Bray, H., & Ankeny, R. (2018). Australian consumers' awareness and acceptance of insects as food. *Insects*, *9*(2), 44. https://doi.org/10.3390/insects9020044

Wilsanand, V., Varghese, P., & Rajitha, P. (2007). Therapeutics of insects and insect products in South Indian traditional medicine. *Indian Journal of Traditional Knowledge*, *6*(4), 563–568.

Yazici, G. N., & Ozer, M. S. (2021). *Using edible insects in the production of cookies, biscuits, and crackers: A review* [Paper presentation]. The 2nd International Electronic Conference on Foods - "Future Foods and Food Technologies for a Sustainable World," 80. https://doi.org/10.3390/Foods2021-10974

Yhoung-Aree, J., & Viwatpanich, K. (2005). Edible insects in the Laos PDR, Myanmar, Thailand, and Vietnam. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock* (pp. 415–440). Science Publishers, Inc.

Yin, W., Liu, J., Liu, H., & Lv, B. (2017). Nutritional value, food ingredients, chemical and species composition of edible insects in China. Future foods. InTech. https://doi.org/10.5772/intechopen.70085

Zhang, Z., Chen, S., Wei, X., Xiao, J., & Huang, D. (2022). Characterization, antioxidant activities, and pancreatic lipase inhibitory effect of extract from the edible insect *Polyrhachis vicina*. *Frontiers in Nutrition*, *9*, 860174. https://doi.org/10.3389/fnut.2022.860174