

EDIBLE INSECTS

Assist. Prof. Dr. Mehmet BEKTAŞ (Ph. D)



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INTRODUCTION

Scientists observe annually that the growing human population on our planet leads to nutritional challenges. Approximately 1 in 9 people suffer from hunger due to food shortages caused by significant increases in population growth and uncontrolled migration. This situation has prompted entrepreneurs and scientists to explore alternative food sources, such as cell-cultured meat, artificial meat, edible algae and insects.

Insects are also called hexapods. They are the most diverse and many group of living organisms on Earth. These creatures have a high biomass and diversity. They are rich in high-quality protein, unsaturated fats, vitamins, minerals and bioactive substances. They need less feed, water and space to grow than other animal sources. These creatures are significant. Their bioactive substances can improve health and prevent diseases. Today, many companies produce insect products, and it is known that a market worth 55 million dollars has been established. Edible insects are also discussed in this book due to their microbiological, parasitological and allergic risks, as well as toxicological research.

The work titled "Edible Insects" is considered an important resource for undergraduate and graduate students, especially those in the fields of Gastronomy, Food Engineering, Biology and Medicine, because of its relevance to people's lives. This book is expected to capture the interest of scientists and influential individuals in society due to its up-to-date information. It provides a comprehensive overview of insects, including their life cycles and habitats. Ecological disasters are depleting food resources. Agricultural areas are shrinking. In response to these problems this book also emphasizes the importance of studying entomophagy (insect consumption). However, because entomophagy is not universally accepted, insects are not consumed directly but are instead used in the feed rations of farm animals and transformed into edible forms under laboratory conditions to ensure they do not irritate. New ideas and qualifications in research and development are essential to conduce to the country's economy by exporting to nations where entomophagy is accepted. It is expected to shed light on new projects and investments.

Dr. Mehmet Bektaş

SECTION 1

INCREASING HUMAN POPULATION AND THE SEARCHING OF ALTERNATIVE FOOD

Scientists estimate that there are 10 quintillion insects on earth, which corresponds to 10^{18} . In other words, they are practically everywhere. The thought of blood-sucking parasites and venomous bites may send shivers down your spine, but the vast majority of these insects are harmless to humans. Even better, many of these abundant insects can help us survive. We just need to be open to the idea of eating them (by Anonymous, a, b, c; Özkan, 2019; Chakravorty et al., 2013; Wikispecies, 2021; Worldometers, 2021; Sabri et al., 2023; O'Connor et al., 2023; Krongdang et al., 2023).

Many foods containing insects are already sold daily in some countries such as Thailand and Cambodia. Tequila-flavoured worm candies and sugar-coated ants are readily available in these areas. Australopithecines' bones and tooth enamel show marked enrichment of the isotope ^{13}C . This appears in stable carbon isotope analysis. This suggests that their diet consisted of animals that fed on grasses. It also included insects. Termites are also reported to have been part of the diet of Plio-Pleistocene hominins. An analysis of fossils from caves in the USA and Mexico revealed that coprolites from caves in Mexico contained ants, beetle larvae, lice, ticks and mites. This provides further evidence of entomophagy in human history. At least 2 billion people now include insects in their traditional diet, experts estimate. They have reported using more than 1900 species as food. Researchers report that beetles (Coleoptera) are the most consumed insects worldwide, accounting for 31% of consumption. Caterpillars (Lepidoptera) follow at 18%; and bees, wasps, and ants (Hymenoptera) at 14%. Locusts, grasshoppers, and crickets (Orthoptera) make up thirteen percent of the total. Cicadas, leafhoppers, grasshoppers, scale insects and bugs (Hemiptera) make up 10%; termites (Isoptera) make up 3%; dragonflies (Odonata) make up 3%; flies (Diptera) make up 2%; and other orders make up 5%. Countries in Africa, Asia and Latin America limit the consumption of edible insect species as a food source, despite their wide variety. In Western countries, the idea of eating insects is often met with disgust (by Anonymous, b; Özkan, 2019; Chakravorty et al., 2013; Wikispecies, 2021;

Worldometers, 2021; Sabri et al., 2023; O'Connor et al., 2023; Krongdang et al., 2023).

Trends for the year 2050 predict a durable increase in population to 9 billion people (Figure 1). This will increase demand for food and feed from agro-ecosystems. It will put even greater pressure on the environment. Agricultural land, water, forests, fisheries resources and biodiversity are expected to become scarce. So are nutrients and non-renewable energy sources (by Anonymous e, f; Prosekov and Ivanova, 2018; Krongdang et al., 2023)

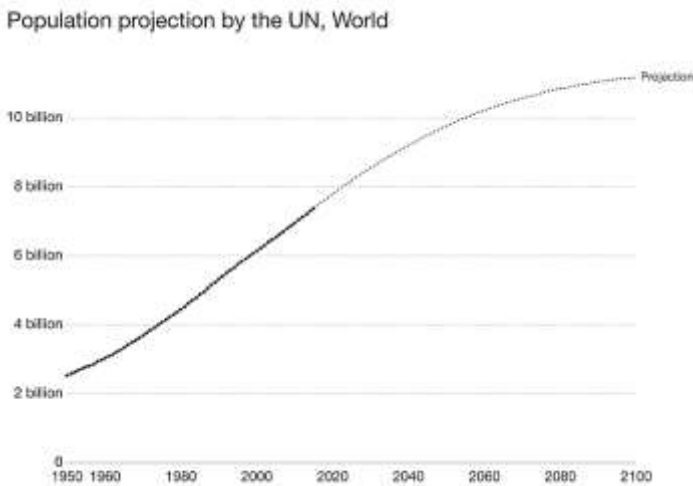


Figure 1. Shown is the total populations since 1950 and the medium variant projections by the UN population division until 2100 (by Anonymous i).

In 2017, the global production volume of the main food categories was set at 117 grams (g) of meat or meat products, 303 g of milk or dairy outputs, 406 g of cereals and 117 g of fat per person per day. To maintain the current rate of food production and feed the growing population, production will need to increase by 75% by 2050 (Prosekov and Ivanova, 2018; Krongdang et al., 2023).

This implies the need to increase global food reserves by 14% overall, 8% in Latin American countries, 14% in developing countries, 14% in Asian countries and 30% in African countries (by Anonymous e, f; Özkan, 2019; Chakravorty et al., 2013; Wikispecies, 2021; Worldometers, 2021; Sabri et al., 2023; O'Connor et al., 2023; Krongdang et al., 2023).

SECTION 2

SEARCH FOR ALTERNATIVE FOOD

People have to eat to survive. The daily energy requirement of the human body is 1800 kilocalories (kcal). People cannot be fed due to the distribution of food resources and ecological problems (Van Eelen et al., 1999; Feng et al., 2001; Otaviano, 2023).

The growing demand for food, driven by the rapid increase in the world population (Otaviano, 2023) and the looming threat of famine (Figure 2), has prompted humanity to explore unconventional new food sources and to enhance existing resources. The alternative food options are as follows:

- Making non-food products usable as food for humans,
- Evaluation of food waste,
- Producing large quantities of microorganisms and using food residues as nutrients,
- Food production from cellulose using bio-fermentation technology,
- Protein manufacture from various microbial sources (single-cell protein),
- Meat produced under laboratory environments,
- Dairy drinks that are not farm products,
- Assuring the utilization of insects, which are consumed as part of the diet in some countries around the world, as a food source by developing new food processing techniques (Van Eelen et al., 1999).

United Nations data shows that agricultural production must increase by 75% by 2050. This is to meet the food needs of the world population. Modern technologies aim to enhance crop production by harnessing the biological resources of seas and ocean waters. They also use solar energy. They also use genetic advances to breed more productive animals. These technologies also seek to boost global food production by enhancing soil fertility (Van Eelen et al., 1999; Feng et al., 2001; Otaviano, 2023).



Figure 2. Traditional foods and packaged edible insects (by Anonymous j)

For this reason, developers intend to improve the well-being of a broad spectrum of people, including those suffering from malnutrition, through the development of modified organisms (GMOs) and GMO products. However, some believe that research on GMOs will benefit a select group of experts in this area (Van Eelen et al., 1999; Feng et al., 2001; Otaviano, 2023).

They also believe that the use of GMOs foods may lead to ecological problems. The world population is growing faster. There is a growing demand for food. This is due to the threat of famine. This has prompted people to explore unconventional new food sources. It raises significant concerns for the future. Many materials and methods are being developed as alternatives to traditional foods (Van Eelen et al., 1999; Feng et al., 2001; Otaviano, 2023).

2.1. Edible Micro And Macro Algae

Microalgae are microscopic organisms. They transform solar energy into chemical energy by using carbon dioxide (CO₂). Most of the microalgae biomass is a valuable resource for obtaining a wide range of high-value products, including polyunsaturated fatty acids, carotenoids, phycobiliproteins, polysaccharides and phytotoxins. However, companies use products derived from microalgae as high-protein supplements for human nutrition, aquaculture and nutraceutical purposes (by Anonymous, d; Sathasivam et al., 2019; Nowruzi et al., 2020).

While 800,000 tons, which constitute 6% of macroalgae (multicellular eukaryotic organisms), are collected from nature, the remaining 94% are cultivated through aquaculture. However, it has not yet begun to be commercially cultivated in our country (Ak, 2015; Sathasivam et al., 2019; Nowruzi et al., 2020). The economic contributions of algae to humans can be classified as follows (by Anonymous, d; Öztürk, 1996; Del-Campo et al., 2007; Raja et al., 2008; Sathasivam et al., 2019; Nowruzi et al., 2020):

► As food: More than a hundred species, mostly Phaeophyceae and *Phodophycea species* (spp), are consumed as food because of their rich macro and micronutrient contents.

► As animal feed: Some varieties of algae are utilized as animal feed.

► A study stated that beta (β)-glucans are a diverse group of polysaccharides naturally found in algae, including seaweed and Phaeophyceae. Although not all types of β -glucans exhibit similar immunomodulatory effects, they have demonstrated anti-tumor and immunomodulatory effects in laboratory conditions.

► The study also found that providing piglets with a diet containing β -glucan reduced the frequency of diarrhea over the entire experimental period, improved intestinal integrity, alleviated diarrhea in pigs infected with F18 *Escherichia coli* (*E. coli*), and enhanced the immune system's response to *E. coli* infection.

► As fertilizer: In a study, a microbiologist from the United States Agricultural Research Service utilized algae to reclaim nearly 100% of the nitrogen and phosphorus nutrients in fertilizer. Based on his findings, he proposed that dried algae could be used as a fertilizer.

► Experiments have shown that algae can retain 60 to 90 percent of nitrogen and 70 to 100 percent of phosphorus from a manure-freshwater mixture. The United States Department of Agriculture proved this at four dairy farms.

► Additionally, one of the most well-known edible algae is *Porphyra* spp, a type of red algae known as nori in Japan. It is used in sushi presentation,

in rice sandwiches called onigiri, and in the creation of a delicacy known as tsukudani aonori (by Anonymous, d; Öztürk, 1996; Del-Campo et al., 2007; Raja et al., 2008; Sathasivam et al., 2019; Nowruzi et al., 2020).

2.2. Wild Mushrooms

Fungi belong to the plant kingdom because they are immobile, their cells have chitin walls and they reproduce by spores. They differ from bacteria because they have a membrane around the cell nucleus and a nucleolus. They differ from algae because they do not contain chlorophyll. Fungi belong to the group of heterotrophic and chlorophyll-free plants. As they cannot assimilate, they obtain the nutrients they need to survive from their environment. For this reason, most cultivated fungi are saprophytes. As they have no chlorophyll, they cannot produce organic substances such as sugar, fat and starch themselves in order to survive. Therefore, they obtain the nutrients they need from other living organisms and dead remains. The way they obtain their food is similar to that of animals. They found that mushrooms are rich in fibre, protein and minerals, have a low caloric value due to oil and fat (Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Barutçıyan, 2012; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000).

Wild mushrooms are known as a good source of fiber. They contain chitin, hemicellulose, mannan and beta-glucan. The β -glucan in particular plays an important role in lowering blood cholesterol and blood sugar levels and in preventing many infections (Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Barutçıyan, 2012; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000).

The best-known edible mushroom species is *Agaricus campestris* (Figure 3). It is popularly known as the meadow mushroom and red inside, it grows in pastures and meadows. In early fall, it can be seen in large quantities in meadows where sheep, cattle or horses graze. Meadow mushrooms are healthy and delicious, provided they are cooked properly and eaten in moderation (Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Barutçıyan, 2012; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000).



Figure 3. *Agaricus campestris* fungus species (by Anonymous k).

Wild mushrooms commonly consumed in Türkiye include *Boletus edulis*, *Russula virescens* and *Lactarius deliciosus*. It is the most commonly consumed wild mushroom species in the country. It is typically found under coniferous trees during the rainy summer and autumn seasons. Its hat is orange and has a powdery texture (Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Barutçıyan, 2012; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000).

2.3. Single Cell Protein

In today's diet, proteins are obtained from both plant and animal sources. Factors such as soil quality, climate, and weather conditions influence agricultural production. Since animal production is closely tied to agricultural output, the quantity of products obtained cannot surpass a certain level. 62% of the world's protein is derived from plants, while 38% comes from animals. However, this amount only fulfills 80% of the production demand (Dennis, 2001; Boland et al., 2003; Zubi, 2005; Nasseri, 2011).

Single-cell protein (SCP) is utilized as an alternative nutrient to fulfill the daily nutritional requirements of animals like cattle, poultry and marine animals intended for human consumption. In food production, it is used in the preparation of ready meals because of its flavor-enhancing and emulsifying properties. SCP is obtained by cultivating and drying large quantities of algae, bacteria, yeast and molds. Their main advantage is that they contain high levels of protein (Dennis, 2001; Boland et al., 2003; Zubi, 2005; Nasseri, 2011).

These proteins are abundant in essential amino acids. Single-cell proteins multiply easily and rapidly. Additionally, the production costs are low. Large areas are not required for their production and they are not affected by climatic

conditions. Approximately 10% of the protein required by the global population can be produced in a fermenter with an area of about 1 square kilometer (km²) (Dennis, 2001; Boland et al., 2003; Nasser, 2011).

2.4. In Vitro Meat

The emerging field of tissue engineering forms the basis for producing in vitro meat. Vladimir Mironov wrote one of the proposals for NASA. Willem van Eelen, who holds a worldwide patent for this system, wrote the other. Both systems function by cultivating myoblasts in suspension in a culture medium (Dennis and Kosnik, 2000; Kosnik, 2001; Benjaminson et al., 2002; Wolfson, 2002; Bhat et al., 2014).



Figure 4. In vitro meat (by Anonymous 1).

2.5. Tissue Culture

This can be done by creating muscle tissue spontaneously, as in tissue engineering. It can also be done by multiplying existing muscle tissue in cultures of Goldfish (*Carassius auratus*) muscle explants. Tissue culture techniques offer the advantage of using explants that contain all the tissues present in meat. They are in the correct proportions and closely mimic meat under normal conditions. However, there is limited control over the production process (Figure 5). Tissue engineering techniques can be used to create a fully artificial muscle by developing an edible porous polymer network. This network allows for the perfusion of nutrients and the attachment of myoblasts and other cell types muscles (by Anonymous, m; Wolfson, 2002; Zandonella, 2003; Bhat et al., 2014).

A proposal has been made for using artificial capillaries in tissue engineering purposes. Like myoids, it is possible to co-culture myoblasts with other cell types. This creates a more realistic muscle structure that can be organized like real muscles (Wolfson, 2002; Zandonella, 2003; Bhat et al., 2014).

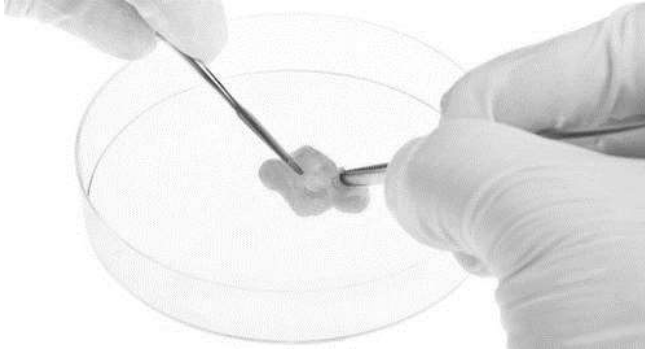


Figure 5. Tissue culture (by Anonymous m).

2.6. Edible Insects

Insects have been consumed by humans since ancient times. Well, the following question comes to mind:

"Why are insects eaten?"

- Health: Insects are healthy and nutritious alternatives to traditional staples like chicken, pork, beef and fish. Many insects are rich in protein, good fats, high in calcium, iron and zinc (Hoare, 2007; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019).

- Environment: Insects offered as food emit much fewer greenhouse gases than most animals. For example, termites and cockroaches are only a few groups of insects. They produce methane. Insect farming is not limited to soil-based activities and does not need soil clearing to expand production. Ammonia emissions are lower in comparison to conventional animal husbandry. Insects are cold-blooded creatures. They are highly efficient at converting feed into

protein. For example, crickets need 12 times less feed than cattle. They also need 4 times less feed than sheep. Crickets require half as much feed as pigs and broiler chickens to produce the same amount of protein. Insects may feed on organic waste materials (Hoare, 2007;TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019).

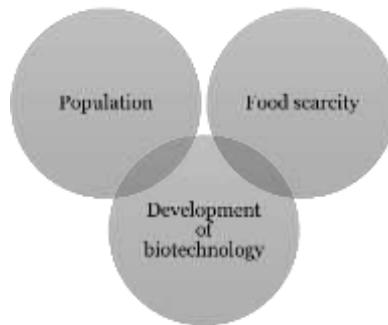
· Livelihood: Insect producing and breeding require low capital and technology investment, providing opportunities for even the poorest segments of society (Hoare, 2007;TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019).

2.6.1. Reasons why edible insects are trending

♣ *The increase in human populations*

♣ *The decline in agricultural production*

♣ *Easy separation of toxic and harmful substances using advanced Technologies*



The sustainability of food resources is becoming important. This is due to the growing world population. It is also due to inefficient resource use and constant changes in living conditions. Factors such as climate change and limited agricultural land consider edible insects sustainable food sources. Gastronomic trends, the etymology of entomophagy, and the past development of edible insects as a sustainable food alternative have led to the growth of insect farming around the world (Hoare, 2007;TAGEM, 2018; Tarımsal

Ekonomi ve Politika GeliŐtirme Enstitüsü, 2018; Kamanlı and Türkođlu, 2018; BektaŐ and Güler, 2019).

Most edible insects are rich sources of protein. They also provide energy, vitamins, essential fatty acids and minerals. They can also serve as a source of bioactive compounds. Therefore, the functional food industry can use derived peptides from edible insects (Hoare, 2007;TAGEM, 2018; Tarımsal Ekonomi ve Politika GeliŐtirme Enstitüsü, 2018; Kamanlı and Türkođlu, 2018; BektaŐ and Güler, 2019).

SECTION 3

LET'S GET TO KNOW INSECTS

When assessed from a nutritional standpoint, edible insects seem to be abundant sources of protein, fat, dietary fiber and minerals. Among these nutrients, the quantity and quality of protein are particularly noteworthy. In contrast, cultivating edible insects in smaller areas requires less feed and water than traditional animal resources and produces minimal waste. The breeding of these insect species is considered edible. However, it's a relatively new practice. It poses some risks in terms of both food safety and ecological balance. Hence, it is essential to know about insects (Smith and Pryor, 2014).

3.1. Arthropods and Subdisciplinary Branches of Arthropods

Zoologists divide the animal kingdom into 30-35 large groups or phyla. A phylum (plural: phyla) is the taxonomic rank that falls between "kingdom" and "class" and is equivalent to the term "division" in botany. The nine largest phyla: Porifera, Cnidaria (Coelenterata), Platyhelminthes, Nematoda, Annelida, Mollusca, Arthropoda, Echinodermata and Chordata contain the majority (98%) of extant animal species (Güçlü, 1999; Adli Entomoloji, 2024).

The body is composed of non-homogeneous segments. These segments are divided into two or three very distinct groups, forming body parts. Their body protrusions, or extremities, are segmented. Their names are derived from the words "Arthro" (meaning joint) and "Poda" (meaning leg). Their bodies exhibit bilateral symmetry. They have a chitinous exoskeleton (integument) that is periodically shed and renewed. The digestive system is tube-shaped, beginning with the mouth and ending with the anus. The circulatory system is open (Güçlü, 1999; Adli Entomoloji, 2024).

- ▶ Crustacea
- ▶ Arachnoidea (Arachnida)
- ▶ Myriapoda
- ▶ Hexapoda (Insecta)

3.2. Insects (Hexapoda)

Insects make up the largest class the number of species in the animal kingdom. They have a significant impact on living organisms. This impact relates to their numbers and efficiency. They are the primary actors in pollination. They also maintain ecological balance and the food chain pyramid (Kinyuru and Ndung'u, 2020; Klein et al., 2022). Insects are the most species-rich group among animals. Approximately four-fifths of the described species belong to this class. Today, the number of known insect species exceeds one million. Several thousand new species are being discovered. Insects are abundant not only the number of species, but also in the number of individuals. Ecosystems group insects into aquatic and terrestrial categories. This depends on their reliance on water areas (Demirsoy, 2006; Bektaş, 2015).

3.2.1. Terrestrial insects

In insects adapted to terrestrial life, the tracheal system is more developed and their exoskeletons are stronger, enabling them to excrete uric acid and prevent water loss through their integuments (Cummings, 2024).

3.2.2. Aquatic insects

Aquatic insects are classified as such because they inhabit areas near water. Various factors such as nutrition, reproduction, mating and protection from enemies influence their choice to live near the water or in specialized galls within the water. They differ from terrestrial insects in having swimming hairs on their legs and excreting a more diluted substance (Demirsoy, 2006; Bektaş, 2015).

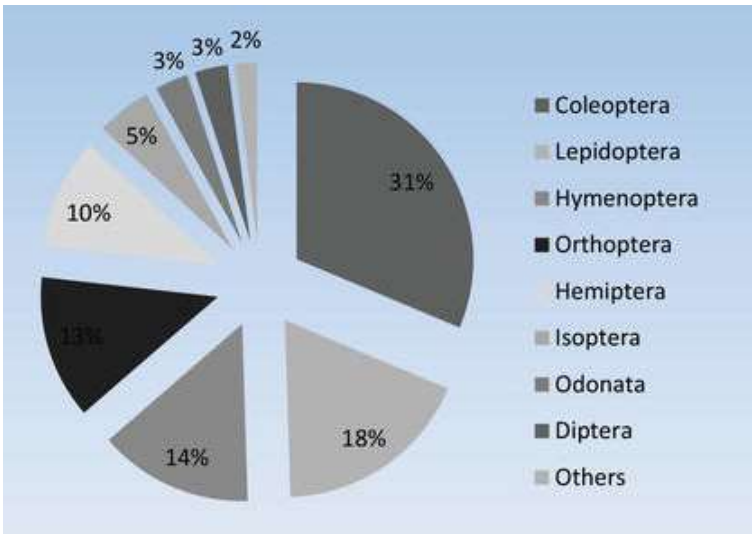


Figure 6. Commonly consumed edible insects (by Jongema, 2014).

SECTION 4 SYSTEMATICS OF INSECTS

4.1. Nomenclature of Insects

In taxonomic studies, the general structure and symmetry of the insect body, the size of the head relative to the body, posture, the ratio of various body lengths to each other and skeletal structure are important. Structures such as exoskeletons and shells are particularly distinctive. Most aquatic insects are categorized based on the shape of their exoskeletons (Güçlü, 1999; Adli Entomoloji, 2024).

Zoological nomenclature refers to the naming of animals. Zoology is the study of different groups of known animals. It is a technique for assigning names. It facilitates the scientific study of insects by classifying them according to specific rules. Some important insect orders include (Güçlü, 1999; Adli Entomoloji, 2024):

4.2. Ordo: Protura – Coneheads

They are apterygota and undergo ametabolic metamorphosis. They prefer to live in moist habitats with a mixture of soil and leaves (humus). Protura is considered the most primitive order of Hexapoda. Protura is the smallest order within Arthropoda, with a total of 500 species, ranging in size from 0.5 to 2.0 mm (Figure 7). They are typically found in forests with deciduous trees, under leaves and humus and in moist areas. Both adult and pre-adult stages feed on decomposing organic matter. Species of the order Protura lack eyes and antennae. They always shed their skin (by Anonymous, n; Güçlü, 1999; Adli Entomoloji, 2024).

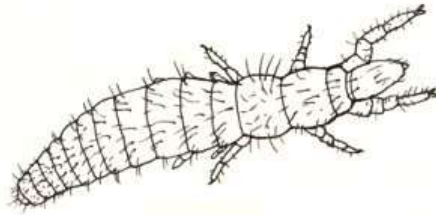


Figure 7. Protura (by Anonymous n).

4.3. Ordo: Collembola – Springtails

Like other wingless insects (Figure 8) that undergo ametabolism, Collembolas continue to molt after reaching reproductive maturity. Springtails play an important role as decomposers, recycling organic waste. Springtails are the most abundant creatures among those that dwell on the ground. Many species are less than 6 millimeters long and are highly sensitive to drought (by Anonymous, o; Güçlü, 1999; Adli Entomoloji, 2024).

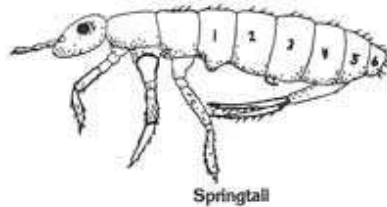


Figure 8. Collembola (by Anonymous o).

4.4. Ordo: Plecoptera – Stoneflies

Stoneflies (Plecoptera) diverged and evolved approximately 300 million years ago, leading to a dead end. Plecoptera nymphs are aquatic organisms. They usually live under rocks. They move swiftly and inhabit clean, well-oxygenated waters. They feed on various types of algae or aquatic plants. They are highly sensitive species to water pollution (Figure 9) (by Anonymous, p; Güçlü, 1999; Adli Entomoloji, 2024).



Figure 9. Plecoptera (by Anonymous p).

4.5. Ordo: Orthoptera – Grasshoppers, Crickets

The order Orthoptera comprises the dominant creature in many terrestrial habitats. Species belonging to this order feed on nearly all types of plants and can result in significant economic losses. Each species produces its unique sounds. Many species of grasshoppers produce sounds at ultrasonic levels, which are higher than the frequencies audible to humans. Some species produce sounds as high as 100 kHz, while the human ear can hear sounds up to 20 kHz (Figure 10) (by Anonymous, h; Güçlü, 1999; Adli Entomoloji, 2024).

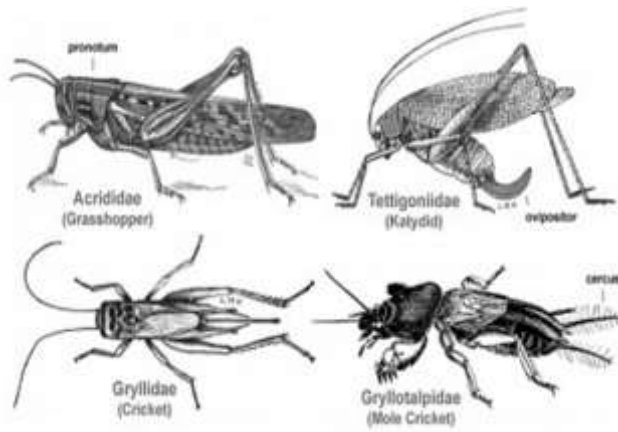


Figure 10. Orthoptera (by Anonymous r).

4.6. Ordo: Dermaptera – Earwigs

Earwigs, which hide in dark places during the day and are active at night, are scavengers that feed on carrion and grass. It has a diverse range of food preferences. Several species are predators (Figure 11) (Berenbaum, 2009).

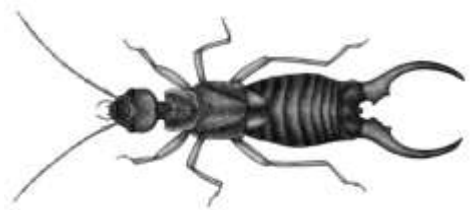


Figure 11. Earwig (by Berenbaum 2009; Encyclopedia Britannica).

4.7. Ordo: Isoptera – Termites

Termites are the only hemimetabolous insect order that exhibits true social behavior. Species belonging to this order construct very large nests and the entire colony resides within them. Each nest has a king and a queen responsible for reproduction. They are found quite abundantly in tropical and semi-tropical climates (Figure 12) (by Anonymous, s; Güçlü, 1999; Adli Entomoloji, 2024).

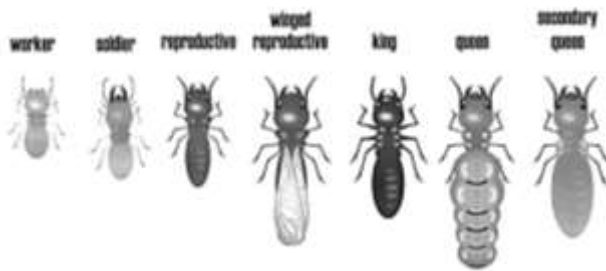


Figure 12. Termites (by Anonymous s).

4.8. Ordo: Ephemeroptera – Mayflies

The pre-adult stages of species belonging to the order Ephemeroptera are aquatic and they typically inhabit clean, flowing freshwater. It is the only example in the insect kingdom that molts despite having wings (Figure 13). Many adults have a relatively short lifespan. Since adults only have vestigial mouthparts, they do not feed. Some species emerge, reproduce and die within one day. Ephemeroptera species are popular baits among fishermen (by Anonymous t; Szent-Ivany and Ujhfizy, 1973).



Figure 13. Mayflies (by Anonymous t).

4.9. Ordo: Hemiptera – True Bugs

Insects belonging to the suborder Heteroptera are known as true bedbugs. Their front wings are very striking. Half of this wing has a chitinous structure, while the other half has a membranous structure (Figure 14). It consists of insect species that are widely distributed and can thrive in various types of habitats. Plant-feeding species are significant pests of numerous field crops (Güçlü, 1999; Adli Entomoloji, 2024).



Figure 14. True bugs (by Australian museum, 2024).

4.10. Ordo: Homoptera – Aphids, Cicadas, Leafhoppers, Scale Insect

The mouthparts of these species have a stinging-sucking structure, allowing them to extract sap from vascular plants. Homopterans are the most widespread group of insects (Figure 15). They feed on herbivores in terrestrial habitats (Güçlü, 1999; Adli Entomoloji, 2024).

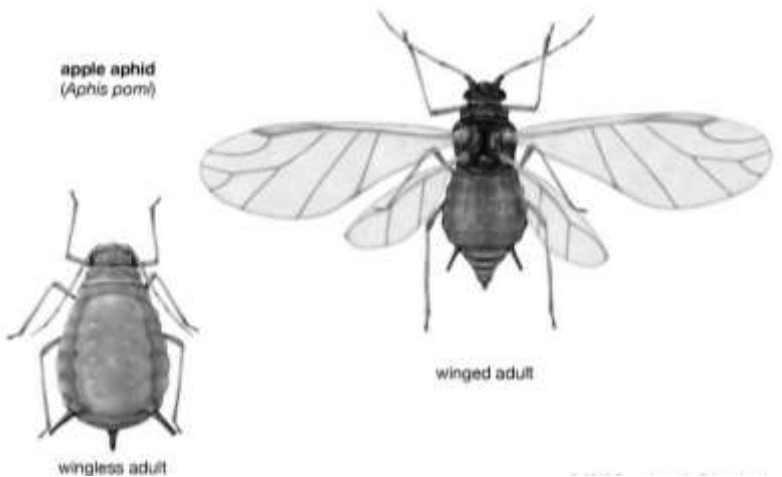


Figure 15. Aphids (by Britannica, 2024).

4.11. Ordo: Odonata – Dragonflies, Damselflies

Both the adult and nymph stages of dragonflies (Anisoptera) and damselflies are predators (Figure 16). Adult individuals can fly quickly and are agile. These characteristics make them easier to hunt and they are a highly valuable group for the ecosystem. They hunt small arthropods like mosquitoes and midges (Güçlü, 1999; Adli Entomoloji, 2024).



Figure 16. Odonata (by Britannica, 2024).

4.12. Ordo: Coleoptera – Beetles

Coleoptera is the most numerous order within insects. Most adult members of the order Coleoptera have a durable, thick exoskeleton that covers and protects the majority of their bodies (Figure 17). The front wings, known as elytra, are as hard as the exoskeleton and protect the body when struck. Also, they are the largest order in the animal kingdom. Species of the order Coleoptera constitute 40% of all insects and 30% of all animals. Some species within this order are significant pests of stored products and plants (Güçlü, 1999; Bektaş, 2015; Adli Entomoloji, 2024).

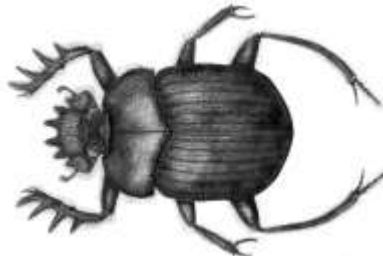


Figure 17. Coleoptera (by Britannica, 2024).

4.13. Ordo: Siphonaptera – Fleas

Adult fleas are blood-sucking external parasites. They feed on a variety of mammal species and occasionally birds (Figure 18) (Güçlü, 1999; Adli Entomoloji, 2024).



Figure 18. Fleas (by Britannica, 2024).

4.14. Ordo: Diptera – True Flies

The order Diptera includes all true flies. This order of insects is easily distinguished from other orders by the fact that their hind wings turn into small structures called halteres. The halter organ vibrates during flight, allowing the insect to maintain balance in the air (Figure 19) (Güçlü, 1999; Adli Entomoloji, 2024).

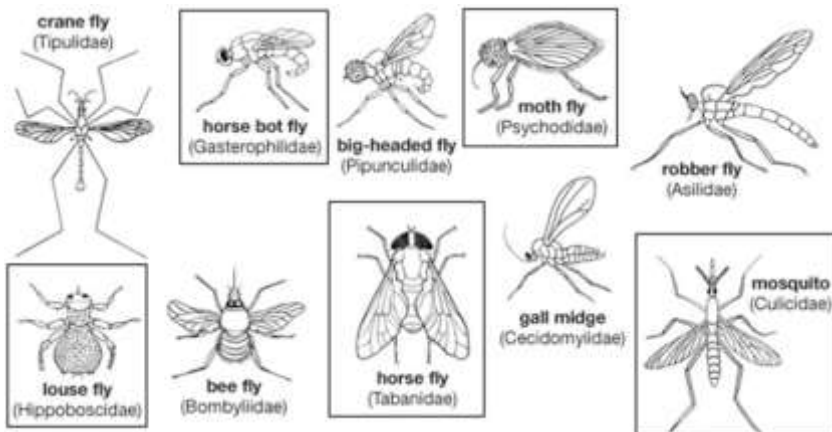


Figure 19. True flies (by Britannica, 2024).

4.15. Ordo: Lepidoptera – Moths, Butterflies

Butterflies and moths, order Lepidoptera, have the second-largest number of species in the insect kingdom. Almost all butterfly larvae are called "caterpillars." Despite their beauty and the economic value of some species (such as the silkworm, *Bombyx mori*), butterflies are of great importance to humans (Figure 20) (Güçlü, 1999; Adli Entomoloji, 2024).



Figure 20. Butterflies (by Britannica, 2024).

4.16. Ordo: Hymenoptera – Ants, Wasps, Bees

The species in the order Hymenoptera are the only family that possesses a stinger and is capable of stinging. Parthenogenesis reproduction occurs. Honey bees (*Apis mellifera*) and ants belong to the same order (Figure 21) (Silici and Özkök, 2009).



Figure 21. Bees (by Britannica, 2024).

SECTION 5

BIOLOGY OF INSECTS

5.1. Insects and the Food Pyramid

For the sustainability of the ecosystem, the food pyramid system must be capable of long-term maintenance and meeting current needs without jeopardizing the demands of future generations. The lower part of the food pyramid consists of organic material, photosynthesizing plants, algae, bacteria, fungi, microorganisms and detritus (Kinyuru and Ndung'u, 2020; Klein et al., 2022).

Herbivores and omnivores occupy the middle part of the food pyramid. These are crustaceans, hoofed animals, planarians and diplopods. Predators occupy the top level of the food pyramid. These include centipedes, cave spiders, salamanders and more (Kinyuru and Ndung'u, 2020; Klein et al., 2022).

5.2. General Anatomy of Insect

The insect body consists of three parts: the head, thorax and abdomen (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

5.2.1. General Dermatology of Insects

5.2.1.1. Insect Integument

The integument that covers the body organs from the outside is composed of ectoderm (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024):

- * It helps protect insects from various external factors.
- * Prevents water loss.
- * It prevents harmful external events from entering the body.
- * Sensory perception of impact, contact and environmental changes.

5.2.1.2. Epidermis

The epidermis is the outermost layer of cells in an insect. This layer is also known as the hypodermis. It is one cell thick. When inactive, cell boundaries become blurred. Cuboidal and plasma membranes, as well as external secretions such as epicuticle and chitin, form the plasma membrane plates (Figure 22) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

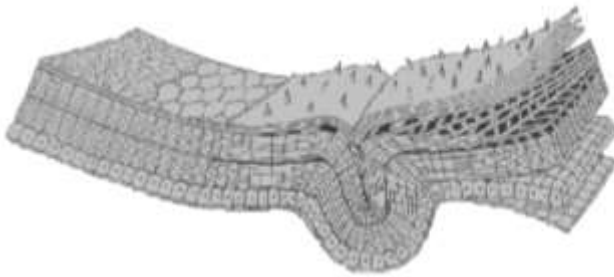


Figure 22: Epidermis (by Meyer, 1998).

5.2.1.3. Molting and Ecdysis

Molting is the period that occurs from the end of the laying cycle until the old layer is shed. Insect muscles must be attached to the exoskeleton. During the ecdysis process, muscles and appendages are also renewed. At this moment, the insect is defenseless. The muscles extend from the procuticle to the base of the cuticle and are anchored there. The base of the epidermis is connected to the muscles, which helps anchor the muscles to the cuticles (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

Ecdysis is molting occurs as a result of a series of actions by epidermal cells. Besides, dermal glands and oenocytes also play a role in this process at specific stages. After the shirt change event, wax and endocuticle secretion continue. After sheathing the exoskeleton, the insect forms the outer layers of the epicuticle. After changing its shirt, the hardening process (chitinization) occurs (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

5.2.1.4. Cuticular Protuberances

It is classified in two ways: mobility (they are immobile; move; spurs are movable) and relationship (with the underlying epidermal cell-hairs and scales are single-celled) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

5.2.2. Body segments, genital organs and extremities

Generally, body of insect consists of a head, thorax and abdomen (Figure 23) (by Anonymous, g; Kornoşor, 1985; Borror, 1992; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

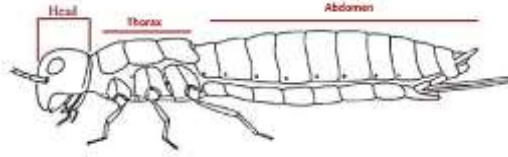


Figure 23. Body of insect (by Borror, 1992).

4.2.2.1. Head, Caput

The head capsule, a hard and round structure located at the front of the insect body, is embryonic. The compound has six segments: pre-antennal, antennal, labral, mandibular, maxillar and labial. On the head, there are organs such as antennae, mouthparts, compound and simple eyes (Figure 24) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

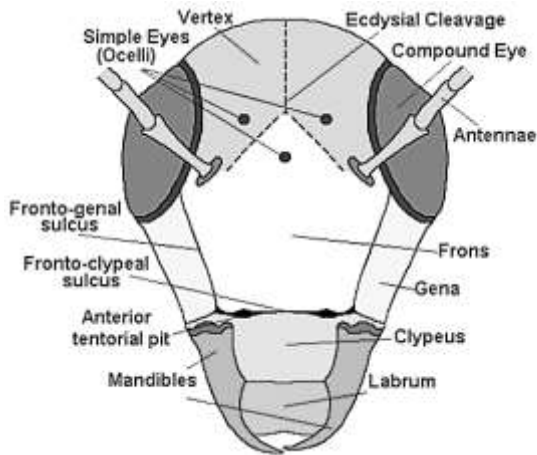


Figure 24. Insect head at frontal (by nl. wikipedia, 2024)

4.2.2.2. Thorax

The thorax is connected to the head by a membranous neck structure called the cervix. There are usually one or two cervical sclerites (CVS) on each side of the neck, connecting the head to the episterna of the prothorax. Each thoracic segment consists of four parts. One of them covers the upper part of the segment (tergum), while another covers the lower part (sternum), and both cover the side parts (pleura). Generally, there are three pairs of legs in the thorax, with one pair in each segment. Adult insects usually have one or two pairs of wings, except for Apterygota and some Pterygota adults, which have no wings (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

4.2.2.3. Abdomen

The adult insect is completely limbless and has 6-12 segments during the embryo period. During the development period unique or a few segments at the end have atrophied and transformed into a sexual organ. Dorsal parts of the abdominal tergites are called tergites, and the ventral parts are called sternites. Tergites and sternites are connected other, with stigmas present in their respective locations. Various appendages emerge from the end of the abdomen, exhibiting different shapes and structures depending on the insect groups (Figure 23) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

4.2.2.4. Genital Segments

In insects, the genital segments (8th and 9th) are the parts through which the reproductive organs open to the outside. It generally forms in the 9th segment in men. In females, the sexual organs are formed in the 8th and 9th segments and typically consist of an ovipositor (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

4.2.2.5. Legs and Wings

The legs have a segmented structure. Typically, an insect leg consists of six parts: coxa, trochanter, femur, tibia, tarsus, pretarsus and arolium. However, pretarsus, which is considered the final part of the leg, is sometimes regarded as part of the tarsus. All six segments of the leg have their set of muscles. Therefore, these segments are considered real (Figure 25 a) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024). Insect wings are formed by the outward extension of the body wall located between the notum and pleuron. First, the wing grows in the shape of a balloon, then its upper and lower surfaces flatten and harden, causing them to stick together. Folds occur only in the areas where the wing veins are located, resulting in the formation of veins (Figure 25 b) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024; Triplehorn and Norman, 2005).

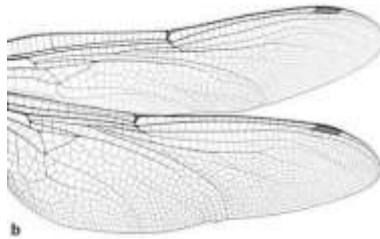
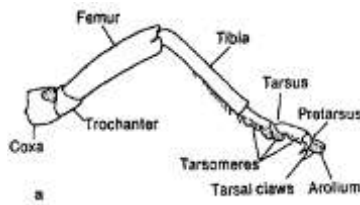


Figure 25. Legs (a) and wings (b) (by Anonymous u).

5.3. Internal Morphology

Although all insect muscles are striated, their function varies. There are significant differences in their structure, biochemical properties and communication with the nervous system. Insect muscles can be divided into two sections based on their structure (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024):

- (1) Skeletal muscles move one part of the body wall relative to another.
- (2) Visceral muscles are layer-shaped tissues that surround the internal organs.

4.3.1. Nervous and Endocrine Systems

The basic elements of the nervous system are nerve cells, i.e. neurons. Neurons; A body part (perikaryon) is quite elongated and consists of cytoplasmic filaments (axons), which are usually branched at the end, and short-branched extensions (dendrites). The body part contains a cell nucleus, many mitochondria and other organelles. Neurons are not directly connected to each other. The axon terminals or dendrites of two neurons meet in a capsule-shaped space containing a fluid called a synapse, but they do not touch each other. The secretory system of insects is divided into two parts: the endocrine (internal secretion) and the exocrine (external secretion) system. The secretions secreted by the endocrine glands and mixed with the blood that regulate the physiological activities of insects are called hormones (Figure 26). Glands of insects (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024);

1. Neurosecretory cells and corpora cardiaca

They are found in all ganglia of the central nervous system. They are secretory nerve cells. The secretions they produce flow directly into the hemolymph (blood). The secretions secreted by the subesophageal ganglion are stored in the corpora cardiaca and mixed directly with the blood in the aorta through thin channels, as required by the corpora cardiaca.

2. Corpora allata

It consists of a pair of glands. It is in contact with the corpora cardiaca and the brain. In some Diptera larvae, the corpora allata and corpora cardiaca are fused together, which is known as the Wiesmann ring. The hormone secreted by the corpora allata is called juvenile hormone. It is secreted during the larval and nymphal stages of the insects and regulates metamorphosis. It ensures that the juvenile phase of the insect continues (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024).

3. Molting tissues

This task is performed by secretory cells, which are usually found in the thoracic ganglia and sub-oesophageal ganglia. The hormone secreted here is called ecdysone (molting hormone). The fundamental components of the nervous system are nerve cells, specifically neurons. Neurons are elongated cells consisting of a perikaryon, which contains cytoplasmic filaments known as axons. These axons are usually branched at the end and the neuron also has short and branched extensions called dendrites. The cell contains a nucleus, numerous mitochondria and other organelles. Neurons are not directly connected. The axon ends or dendrites of two neurons meet in a capsule-shaped space containing a fluid called a synapse, but they do not physically touch each other (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024).

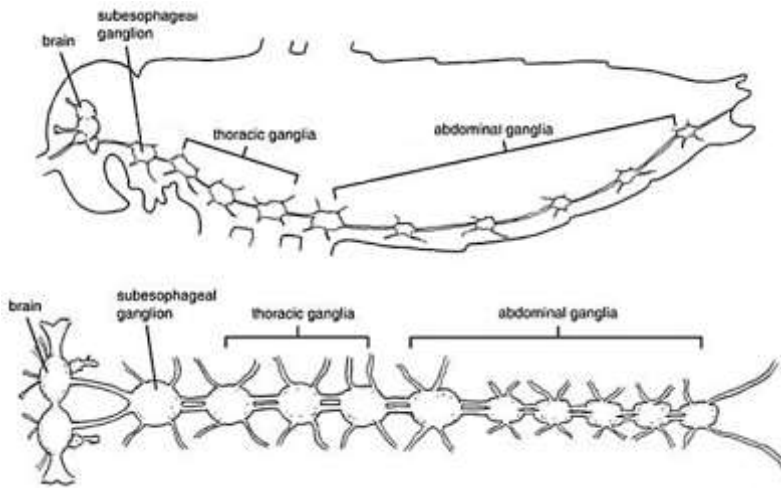


Figure 26. Nervous and Endocrine Systems of Insect (by Minnesota University, 2022).

4.3.2. Excretive System

The excretory system of insects works in different ways;

- 1) With the whole-body integument,
- 2) With the characteristic glands of the integument,
- 3) With the capillary ends of the tracheal system,
- 4) With the surfaces of the digestive system,
- 5) Excretion takes place via special malpighial tubes that open into the proctodeum.

In addition, excretion is also carried out by cells called nephrocytes, which are found in groups in different parts of the body (Figure 27) (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024; Cummings, 2024).

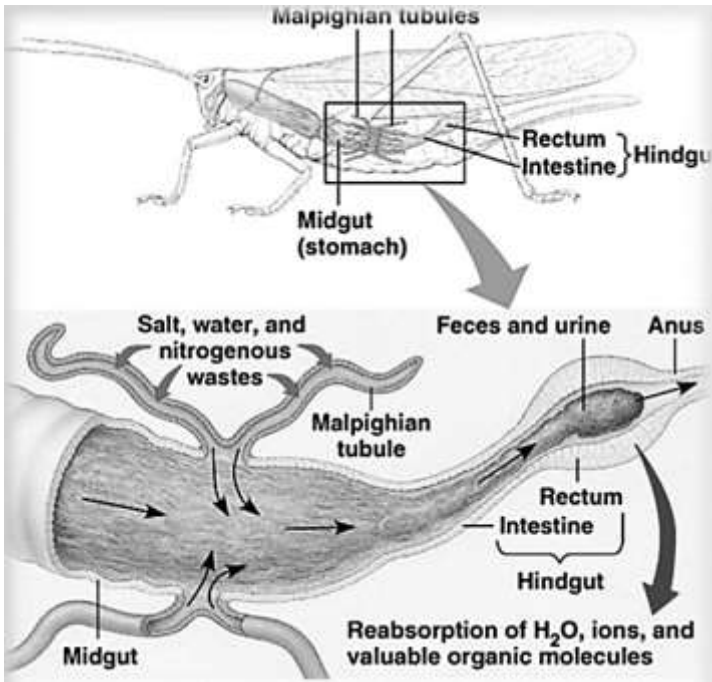


Figure 27. Malpighian tubules of insects (by Cummings, 2024).

4.3.3 Reproduction Sytem

Insects are sexually separate, with male and female individuals. Insects generally reproduce by mating. Male reproduction occurs via a mechanism such as sperm production and sperm transfer. Gonads (testes) They are located in pairs, on both sides. They produce sperm through spermatogenesis in a large number of seminiferous tubules. They ensure sperm transfer through the vas deferrens, the seminal vesicle, the aedeagus and the ejaculate tube. Spermatozoa consist of a head, a neck and a tail. In some insects, however, it can also occur in many different ways (Figure 28 a) (Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024; Purdue University, 2024).

The first parts of the ovarioles are connected to the body by a thin fiber. The small cells that follow are called germarium cells. Below these are rows of egg cells. These are located in egg chambers called follicles, which are

surrounded by epithelial-like cells, and the developing egg leaves this chamber. The follicle, which is an oily and yellowish mass, remains in the body. It is assumed that the insect has laid eggs when you see this layer left behind. The most mature egg is at the bottom. The canal that leads from the ovarioles to the ovary is called the oviduct. Two oviducts fuse to form the vagina. In some insects, there is a sac in the vagina into which the sperm is placed during mating. This is called the bursa copulatrix (receptaculum seminis). The mature eggs are fertilized by the sperm, which are released as they pass through the vagina to ovulate. The testicles and ovary also contain accessory glands. The reproductive structure of the female is gonads, lateral oviducts, middle oviduct, genital chamber, spermathecal structures and it consists of accessory glands (Figure 28 b) (Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024; Purdue University, 2024).

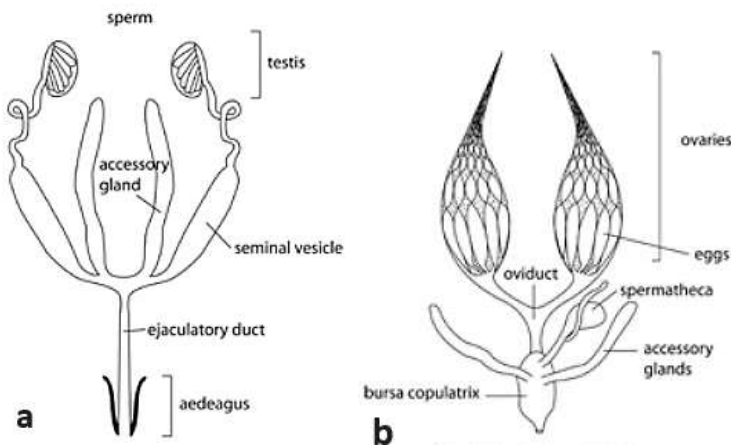


Figure 28. Male reproductive system (a) and female reproductive system (b) of insects (by Purdue University, 2024).

4.3.4. Digestive System

Since the digestive system consists of the integument (body skin), which folds inwards, it has the same structure as the skin. In the inner cavity there is a layer of cells (intestinal epithelium) on the main membrane and the cuticle above it. Especially the part of the cuticle is well developed in the stomodaeum and proctodaeum. The entire digestive system is covered with muscles from the mesoderm (Figure 29). The digestive system of insects is a straight or curved

tube with different shapes. This system consists of three main parts. These are: 1) foregut (stomodaeum), 2) midgut (mesenteron) 3) rectum (proctodaeum). The foregut and hindgut consist of ectoderm, while the midgut is made up of endoderm. The length of the digestive system depends on the food ingested. It is generally long in protein-fed animals and short in carbohydrate-fed animals (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Minnesota University, 2022; Adli Entomoloji, 2024).

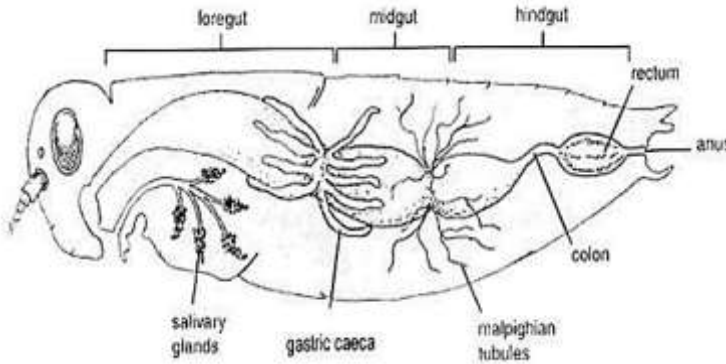


Figure 29. Digestive system of insect (by Adli entomoloji, 2024).

4.3.5. Circulatory System

Insects have an open circulatory system and the body cavity has become part of the circulatory system. The circulatory system generally consists of a tube that pumps the blood and various compartments that allow the blood to move along a specific path within the body. Pumping system, which enables the movement of hemolymph in the body is located in the dorsal part of the body, below the terga and extends throughout the body. The pumping system, which consists of the heart and the aorta, is connected to the dorsal body wall and the surrounding organs by connective tissue. The total number of hemocytes in insects varies according to body size. While the adult mosquito, for example, has a total of 10,000 hemocytes, the cockroach has more than 9,000,000. The number of hemocytes per microliter of blood varies between 25-30 thousand and 100-125 thousand, depending on the species (by Anonymous, g; Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Adli Entomoloji, 2024).

4.3.6. Respiratory System

Insects breathe with the help of lined inner tubes known as the tracheal system. (Figure 30) (by Anonymous, w; Güçlü, 1999; Adli Entomoloji, 2024)

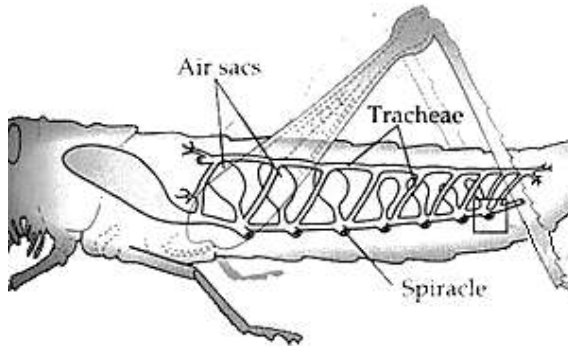


Figure 30. Respiratory system of insect (by Anonymous w).

4.3.7. Sensory Organs

The sensory organs are essentially located in the body wall, and most of them are so large that they can only be seen with a microscope. A sensory organ with a simple or compound structure that serves as a sensory organ is called a sensillum (pl., sensilla). The number of honeycombs (ommatidia) that make up a compound eye varies greatly (Figure 31). In an ant of the genus *Ponera* (Hymenoptera), for example, the compound eye consists of only one honeycomb; this number is 100-600 in workers, 200-830 in females, 400-1200 in males; 4000 in *Musca* (Diptera); 12,000-17,000 in Lepidoptera; in Odonata it can reach 28,000. In general, there are two types of sensors in insects. These are (Kornoşor, 1985; Meyer, 1998; Güçlü, 1999; Pretorius, 2011; Meyer-Rochov, 2015; Adli Entomoloji, 2024):

A. Mechanosensory cuticle organs: These consist of sensory hairs located in a socket in the integument and campaniform organs with a dome-shaped structure.

B. Chemical sensory organs: Chemical sensory organs (chemoreceptors) are organs that perceive taste and smell. These are; light receptors of the skin, ocelli (these are also called parietal eyes or dorsal ocelli), stemmata (these are

also called lateral punctate eyes or lateral ocelli) and compound eyes [these consist of a number of ommatidia (plural: ommatidia)].

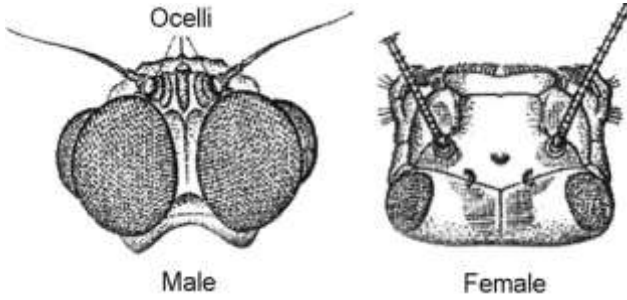


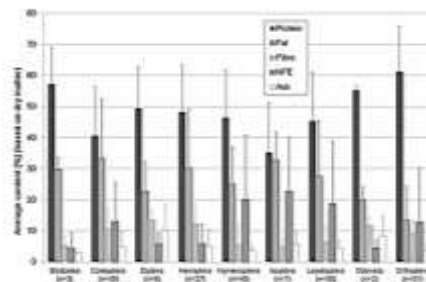
Figure 31. Senrory organs of insects (by Meyer-Rochov, 2015).

SECTION 6

ENTOMOPHAGY AND INSECT NUTRITIONAL VALUES

The consumption of insects (entomophagy) goes back thousands of years. There were communities that lived in the warmer regions of the earth and fed on various insects throughout the year. The need for food will increase with population growth. Traditional animal protein sources like beef, pork and chicken may not meet the demand. This is because of population growth. This could open the door to alternative sources (Tekeli, 2014; Kourimská and Adámková, 2016; Czaja, 2019; Keçińska-Pacelik et al., 2023).

Edible insects have great potential as a friendly alternative for future food systems. Using insects as a sustainable food source has many positive aspects. They have high nutritional content (Figure 32). In conventional livestock farming, insects need less water and land than vertebrates. However, they have a higher food conversion efficiency and produce less greenhouse gases. Therefore, eating insects makes a positive contribution to the environment. It also benefits food and nutrition security. It also promotes a healthy life for present and future generations. Insects are consumed either as whole insects or as an ingredient in various foods around the world. For example, they are eaten in Asian, African and South American countries. The consumption of insects in Western cultures seems to be a new trend that requires change. Nutrition is one of the basic human needs. It is also one of the most important factors influencing human health (Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Imatu, 2020; Andaç and Tuncle, 2023).



*n: number of insect samples

Figure 32. Average nutrient contents (%) of some edible insects (by Rumpold and Schlüter, 2013).

The importance of an adequate and balanced diet, i.e. the intake of the nutrients necessary for the human body in the right proportions and at the right time for growth, development and survival, is increasing. Approximately 2/3 of the world's population does not get enough protein and is undernourished. A balanced and adequate diet for the growing world population is of great importance (Gessain and Kinzler, 1975; Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Imatu, 2020; Andaç and Tuncle, 2023).

Throughout human history, there have been large-scale dietary changes. One example: in the 19th century, lobster was considered an undesirable creature. Today, lobster is a luxury food that is widely accepted by consumers. A similar trend is possible with edible insects by adding alternative proteins to foods that do not irritate them after they have undergone certain processes (Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Imatu, 2020; Andaç and Tuncle, 2023).

6.1. Protein

The digestibility of their amino acids is also very high (87-99%). Insects are useful because they have high protein and mineral content. However, they can also produce toxins. In some cases, their mineral content can be toxic. Therefore, special care should be taken before including them in poultry feed (Veldkamp et al., 2012). One can process edible insects into a food component and/or a traditional food product. In this context, insect-derived proteins could be widely used in food and beverages. Countries are starting to see the potential of insects as a protein source. They need regulations to help insect farmers and industry follow good food practices. See Figure 33. It is known to contain crude protein. In general, it has been observed that the protein ratio in a dry insect varies between 13% and 77%. Protein ratios in insects (Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Caner, 2017; Akhtar and Isman, 2018; Imatu, 2020; Aksoy and El, 2021; Liceaga et al., 2022; Andaç and Tuncle, 2023; Bugsolutely, 2024):

- * 50.7% in yellow mealworm
- * 62.2% in African Migratory locust
- * Mealworm has an average of 44-69%.

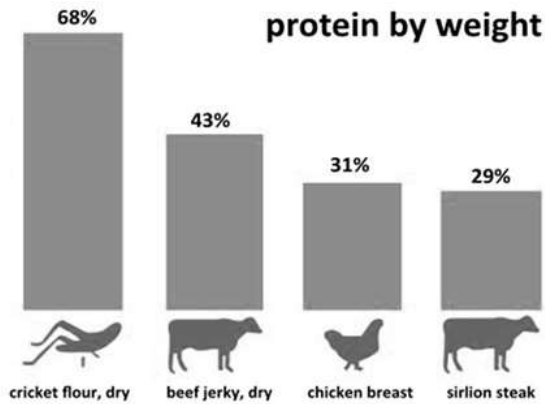


Figure 33. Protein levels in grasshoppers and other livestock (by Bugsolutely, 2024).

6.2. Fat

Significant variation in fat content is seen among insects. In general, female insects contain more oil than male insects. Edible insects contain an average of 10% to 60% oil in dry form. This value is higher in the larval stage of the insect than in adult insects. Caterpillars are among the insects with the highest fat content. The fat content in caterpillars has been measured to range from 8.6 to 15.2 g per 100 g. In grasshoppers, this rate varies between 3.8 g and 5.3 g per 100 g. The fat content of an insect species called *Oxya chinensis* (grasshopper species) in its adult stage was measured to be 2.2%. In several edible forms, have a higher oil content (Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Caner, 2017; Akhtar and Isman, 2018; Imatu, 2020; Aksoy and El, 2021; Liceaga et al., 2022; Andaç and Tuncle, 2023);

* *Gossypeilla* sp. (pink worm) 49.48%

* *Ostrinia furnacalis* (Asian corn borer) 46.08%

It has been reported that termites are rich in oleic acid and palmitic acid. They also contain linoleic acid, a type of fatty acid. However, termites are poor in myristic acid, lauric acid and palmitoleic acid. The termite contains 39.35% saturated fatty acids and 60.64% unsaturated fatty acids. Edible insects have more essential fatty acids than animal fats. They can provide the body with more nutrients. See Figure 32. (Felger and Moser, 1985; Banjo et al., 2006;

Finke, 2008; Hatipoğlu, 2010; Caner, 2017; Akhtar and Isman, 2018; Imatu, 2020; Aksoy and El, 2021; Liceaga et al., 2022; Andaç and Tuncle, 2023).

6.3. Vitamins

Vitamins are a group of organic compounds. They are necessary for metabolic activities in the human body. The human body cannot make vitamins. They must be constantly supplied with food. Edible insects have a high vitamin content. Each species contains large amounts of vitamins A, B₂ and C. White ant species contain significant amounts of vitamins B₁, B₃, A and C. Many insect larvae contain significant amounts of vitamin A (retinol). Vitamin B₁₂ is abundant in yellow mealworm larvae (0.47 g per 100 g). It has been observed that a caterpillar weighing 100g meets 76% of a person's protein needs and all of his vitamin needs. In research, vitamin E was found in the larvae of the red palm plant. Escamoles and Formicidae eggs have been shown to be good sources of vitamins A, D and E. Edible insects are rich in carotene and vitamins A, B₁, B₂, B₆, D, E, K and C. Insects are generally rich in riboflavin and pantothenic acid and are seen as efficient sources of vitamins A and C. Due to their rich vitamin content, some insects are shown as foods that represent health. See Figure 32. (Felger and Moser, 1985; Banjo et al., 2006; Finke, 2008; Hatipoğlu, 2010; Caner, 2017; Akhtar and Isman, 2018; Imatu, 2020; Aksoy and El, 2021; Liceaga et al., 2022; Andaç and Tuncle, 2023).

6.4. Fiber Foods

Edible insects contain significant amounts of fiber. See Figure 32. Also, chitin is the most common type of fiber found in the bodies of insects. Insects have this fiber in their exoskeletons (shells). The amount of chitin in insects has been found to vary between 2.7 and 49.8 mg per 1 kg. Chitin plays an important role in the body's defense against various parasites, infections and allergic diseases (Van Soest et al., 1991).

6.5. Mineral Nutrients

Most edible insects have very rich mineral content. Insects contain many minerals such as iron (Fe), zinc (Zn), potassium (K), sodium (Na), calcium (Ca), phosphorus (P), magnesium (Mg), manganese (Mn) and copper (Cu). For example, Mopani worm, a large species of caterpillar, has a high iron content

(31-77 mg per 100 g of dry insect). *Migratoria* sp., a species of grasshopper, contains 8-20 mg of iron in 100 g of dry form. Caterpillars (14 mg per 100 g of dried insect) are a good source of zinc (Bourne, 1953; Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000; Kouřimská and Adámková, 2016; FAO 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Żuk-Gołaszewska et al., 2022; Kępińska-Pacelik et al., 2023; Krongdang et al., 2023).

Insects are important sources of iron and zinc, as well as containing phosphorus. Additionally, some edible insects contain sufficient manganese and copper for human nutrition. In addition, these insect species contain significant amounts of calcium, iron, phosphorus and magnesium. Researchers found that edible insects contain more calcium than cow's milk. It serves as an alternative solution for people with lactose intolerance. It is also for those allergic to calcium-rich foods. Edible insects contain many minerals. They can provide the nutrients needed by the human body (Bourne, 1953; Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Sarıtaş, 2015; Manzi and Pizzoferrato, 2000; Kouřimská and Adámková, 2016; FAO 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Żuk-Gołaszewska et al., 2022; Kępińska-Pacelik et al., 2023; Krongdang et al., 2023).

It has been observed that 100 g of dried termite (white ant) contains an average of 53% protein, 15% fat and 3.5% carbohydrate, in addition to a significant amount of phosphorus, iron, sodium and potassium. For example, nutritional content in 100 grams of crickets and mealworms;

**436-472 calories, 55-58 grams of protein, 18-24 grams of fat (Omega-6 from polyunsaturated fats 7.3-6.8 gr.), 15-8 grams of carbohydrates, 149-228 milligrams of cholesterol, 620 milligrams of vitamin A, 810-1100 milligrams calcium (Ca⁺), 37-25 milligrams of iron (Fe⁺⁺), 11 milligrams of potassium (K⁺), Detected as 1.8-3.1 milligrams of sodium (Na⁺) (by Kępińska-Pacelik et al., 2023*

Some edible insects have good nutritional values comparable to meat and fish; They contain higher nutritional values than other protein sources in terms of protein, fat and energy values (Table 1). Research has shown that many societies have had the habit of consuming insects since ancient times. Insects are among the indispensable dishes of many countries. This eating habit, which is mostly seen in Latin America, Asia and Africa, has not yet reached a sufficient level in Europe, and it is known that insects will enter European cuisine in the coming years (Bourne, 1953; Sümer, 1987; Cheung, 1998; Rajarathnam et al., 1998; Saritaş, 2015; Manzi and Pizzoferrato, 2000; Kouřimská and Adámková, 2016; FAO 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Żuk-Gołaszewska et al., 2022; Kępińska-Pacelik et al., 2023; Krongdang et al., 2023).

Table 1. Energy value of some edible insects (by Kouřimská and Adámková, 2016; FAO 2018).

Insect name	Latin name	Country of location	Energy (kCal/100g)
Sicada	<i>Chortoicetes terminifera</i>	Austraila	499
Weaver ant	<i>Oecophylla smaragdina</i>	Austraila	1272
Mealworm	<i>Tenebrio molitor</i>	USA	206
Mexican leafcutter ant	<i>Atta mexicana</i>	Mexica	404
Two-spotted grasshopper	<i>Gryllus mimaculatus</i>	Tailand	120
Japanese grasshopper	<i>Oxya japonica</i>	Tailand	149
Black-spotted cicada	<i>Cyrtacanthacris tatarica</i>	Tailand	89
Silkworm	<i>Bommyx mori</i>	Tailand	94
African immigrant cicada	<i>Locusta migratoria</i>	Holland	179

SECTION 7

BENEFITING FROM INSECTS IN FEED RATIOS OF FARM ANIMALS

Chickens are omnivorous animals. They can eat and digest the living insect species they find in the places they visit (flies and larvae of other insects, maggots, grasshoppers, ticks, etc.) without digestive problems. The poultry industry has become an important sector with the developments in many areas from production to consumption, e.g. genetics, breeding, biotechnology, machinery-equipment, medicine, vaccines, feed production-additives,

marketing, slaughterhouse and product processing. When discussing mass production, cheap labor, low cost, high market share and profitability in today's animal husbandry; chicken farming comes to mind. Feed raw materials are the most important cost factor in the poultry industry (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

Insects have high protein content and quality. Poultry farmers use them as an alternative feed additive. Poultry bred for egg production can also serve as an alternative protein source for some insect species. In particular, it can be mixed with different proportions of insects (Coleoptera) feed types. It is used in chicken feed rations (daily feed mixtures). In laying Lohmann-Brown hybrids, mealworm larvae, black soldier fly larvae and floating insects are used in chicken rations. It is known that these rations increase quality characteristics such as live weight, feed consumption, feed conversion ratio and egg production in chickens (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

Insects are cheap to obtain as a food source, but it can be thought that insect consumption will be low or not at all in countries that determine their food according to religious rules, such as Muslim countries. In this context, a justification can be put forward for the use of insects as animal feed, at least in such countries, in order to indirectly meet the nutritional needs of the increasing population. In addition, the fact that poultry and humans are competitors in grain consumption leads to a more limited use of grains in poultry rations, increasing the cost of other feed components and leading to deficiencies (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018;

Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

The increase in demand for fishmeal in recent years has caused the price of fishmeal to rise rapidly. This increase continues rapidly today and the increase in fish meal prices has led breeders to search for alternative protein sources (Taşkın, 2019). A healthy digestive system in farm animals means that they are also healthy and have high productivity potential. Digestive system health depends on the balance between the presence and type of intestinal microorganisms in this system, the intestinal barrier (microscopic structure) and foreign microorganisms. It is known that edible insects make positive improvements in microbiota balance. After chemical analysis of edible insects, different rations used experimentally were found to have positive effects on productivity criteria (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Bektas et al., 2020; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021; Bektas et al., 2021).

The use of dried insect meal instead of fish meal in chicken diets increased egg productivity by 2.4%. At the same time, the solution to the rapidly growing environmental pollution problem caused by water, air pollution and household waste brought about by industrialization is still pending. Insect worms are known to increase the growth rate in some birds when used as a biological treatment of chicken manure. The growth of poultry enterprises by consuming the waste and feces of various insect larvae and the use of these growing maggots as poultry feed can provide effective recycling and biological cleaning of environmental waste. However, the use of poultry by-products for feeding poultry has been banned since January 2017 as part of the European Union harmonization process. The industry is concerned that this situation will increase poultry meat prices due to high production costs. It requests that the Ministry of Food, Agriculture and Livestock reconsider this ban. The main inputs in these feeds are corn and soybeans. When chicken egg parities (ratios of country currencies to each other) are examined in 2020, it is seen that the

egg/soy parity decreased the most. The 39.5% increase in soybean prices in 2020 explains the decrease in egg/soy parity (28.3%). Many insects, such as flies (Diptera), mealworms (Tenebrionidae), moths, silkworms (*Bombyx mori*), grasshoppers (*Schisocerca gregaria*), cockroaches (Blattodea), crickets (*Gymnogryllus lucens*) and termites (*Macrotermes bellicosus*) are used in animal feeding (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

Insects are involved in human life in various fields, such as the food, medicine and textile sectors. It is known that insect products (E120-carmine, E904, etc.) such as *Dactylopius coccus* and Shellac (*Coccus lacca*) are used as colorants, dyes, edible films and coatings, especially in the food industry. Meat of chickens grazing in pastures with a dense population of locusts in Tibet has stronger antioxidant potential and a longer shelf life. In chickens, it has been observed that the fat content of their eggs increases due to insect consumption. The use of *Cirina forda* (Diptera) larva as a poultry feed raw material can replace traditional fishmeal. These fly maggots are an ideal source of protein that can be used in both poultry meat production and egg production. By including poultry in the meadow grazing system, the animals consume seeds, insects and worms, reducing the feed cost by up to 30% (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

Additionally, when fed a diet containing 5 to 20% maggots, the chest muscles increase significantly. The necessity of using qualified feeds with high nutritional content in poultry feeds leads to higher feed costs. In our country, corn is primarily used as the feed raw material and soybean is used as the protein source in chicken mixed feeds. It creates new markets, such as insect breeding, in the economically alternative food sector to develop new alternative

methods for low cost and high efficiency in poultry nutrition. With population growth, it makes some additional contributions to solving human and animal nutrition problems. It is expected to become widespread in the next century for alternative food searches and studies. As a result, the use of insects expected to be supplied by insect farms in rations and their appropriate economic results will contribute greatly to the country's economy (DeFoliart, 1989; Khusro et al., 2012; OTE, 2013; Şahin et al., 2004; Yıldırım and Eleroğlu, 2014; Türkoğlu and Sarıca, 2014; Uçar and Türkoğlu, 2018; TAGEM, 2018; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2018; Kamanlı and Türkoğlu, 2018; Bektaş and Güler, 2019; Yılmaz, 2019; Syampurnomo et al., 2019; Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, 2021).

SECTION 8

GROWING INSECTS AS AN ALTERNATIVE FOOD SOURCE UNDER LABORATORY CONDITIONS

From an ecological perspective, via way of means of 2050, about one hundred fifty million humans can be vulnerable to nutritional protein because of growing atmospheric CO₂ levels, already full-size threats to the steadiness of the worldwide meal chain were created. In this context, it's been concluded that region of breeding insects can provide an alternative method to the worldwide protein deficit (Büyükgüzel et al., 2010; Altunsoy and Başaran, 2011; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022).

Model bugs are used as experimental fashions in lots of fields which include medicinal drugs, forensic medicinal drugs, pharmacy and veterinary medicinal drugs because of their low manufacturing cost, moral problems and clean lifestyle in laboratory situations. Standardizing insect manufacturing regions beneath laboratory situations may be very vital in getting rid of the direct or oblique consequences of feasible infection at the improvement of larvae. The maximum not unusual place hassle at some point of the manufacturing of version bugs in synthetic meals media beneath laboratory situations is bacterial, yeast and mildew infection. Breeding bugs in laboratories takes area in 3 stages. These (Büyükgüzel et al., 2010; Altunsoy and Başaran, 2011; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022);

8.1. Preparation of Stock Insect Cultures

The closing instar larvae of the bugs which might be essential in forensic medicinal drugs that we need to raise (when they attain the 7th instar) are positioned in widespread ml glasses. Using synthetic food, the applicable insect larvae are raised in continuously darkish surroundings in an incubator set at certain temperature and humidity. In jars with a synthetic weight-reduction plan, a well-known weight-reduction plan 420 g of bran, one hundred fifty ml of filtered honey, one hundred fifty ml of glycerol, 20 g of floor darkish honeycomb and 30 ml of distilled water are added (Büyükgüzel et al., 2010;

Altunsoy and Başaran, 2011; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022).

15 newly emerged person girls are positioned in jars and a chunk of antique comb is supplied for the weight-reduction plan. The techniques used permit newly hatched larvae to put eggs and feed. To achieve eggs, their weight-reduction plan is ready and allotted into the container. Insect larva, pupa and person tiers are acquired below laboratory situations the usage the strategies utilized in preceding studies, 5 people from every larva, pupa and person tiers are taken and vortexed in 10 ml isotonic answer and samples are prepared (Büyükgüzel et al., 2010; Altunsoy and Başaran, 2011; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022).

8.2. Feeding Experiments

Two or three newly emerged females and males are located in plastic, and a pitcher and sieve cowl are used for egg laying (Figure 34). These cups are stored below the identical laboratory situations and ladies are allowed to put eggs inside the cups for inventory tradition. For experimental uses, all eggs are accrued and newly hatched larvae are transferred within 24 hours (Büyükgüzel et al., 2010; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022)..

For feeding experiments, an antiviral drug analogs are introduced to synthetic diets containing various tiers of exceptional brush and herbal diets dealing with this antiviral agent. Control larvae had been fed an aciclovir-unfastened diet; For herbal diets, preferred an antiviral drug concentrations are organized as g/one hundred ml with distilled water. Concentrations are carried out through spray to a floor with attention of an antiviral drug in one hundred ml of distilled water. Each test is repeated ten to 4 instances to traditional larvae in keeping with replication below the identical laboratory situations as inside the inventory condition (Büyükgüzel et al., 2010; Altunsoy and Başaran, 2011; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022).

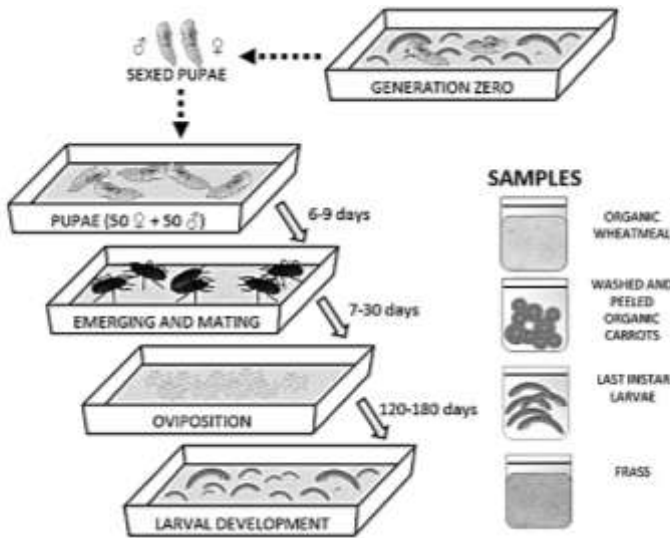


Figure 34. Feeding of some edible insects (by Osimani et al., 2018).

8.3. Measuring Antimicrobial Effects of Edible Insects

Substances including an antiviral drug may be used to manipulate the increase of microorganisms inside the diet. The outcomes of an antiviral drug at the microbial vegetation of synthetic vegetation and herbal diets, bacteria, yeast and molds also are determined, microbiological checks of the diets are reviewed. After the energetic feeding length of the larvae, the boxes containing the final synthetic and herbal diets are firmly covered. The glasses are wiped clean with ethanol (95%). Under aseptic conditions to prevent surface contamination, 1 g of the ambient pattern must be combined with nine ml of sterile distilled water and a pattern must be plated immediately. Additionally, the suspension of microbiological diets is suggested in the insect intestine with common for symbiotic bacteria, coliform bacteria and molds, which can be critical microbial contaminants (Büyükgüzel et al., 2010; Büyükgüzel and Büyükgüzel, 2016; Osimani et al., 2018; Preisinger, 2018; Mohan et al., 2022).

SECTION 9

BIOTECHNOLOGICAL ADVANCES ON ENTOMOPHAGY

Carmines: red dye comes from half-winged insects (Order: Hemiptera). They grow on pear cacti and are edible in some countries. People use carmine to color textiles and products like honey and silk.

Shellac: it is a resinous material. Many other products use it in their production, including paint and varnish. The Indian lac insect secretes Shellac to produce it.

Cochinil: it is a red dye used to color food, medicine, and cosmetics. The Mexican cactus scale obtains it from the female. The scale's scientific name is *Dactylopius coccus* or *Coccus cacti*.

Kermes (also known as *Granum tinctum*): It is a red dye like cochineal. The females of *Kermes ilicis* (*Coccus ilicis*) produce it.

People use beeswax in China and India. People make candles and medicinal preparations from it. Many Far Eastern species produce beeswax. Examples include *Ericerus pela* and *Ceroplastes ceriferus* (Kaya, 1983; Zhang et al., 2008; Devi et al., 2022).

9.1. Market Developments on Entomophagy

In Asian and African countries, half the food people eat comes from insects. In Europe and America, this rate is very low. It's prohibited in most places and not considered appropriate by experts. The Swiss Ministry of Health was the first in Europe to break this ban. They gave official approval to the market for mealworms, crickets and grasshoppers. This year, Coop in Switzerland has sold "Inseken Burgers" for 8 euros (Figure 35). They've been on the shelves since May. The country's second-largest supermarket chain sells them (Setz, 1991; Chakravorty et al., 2011; Rumpold and Schlüter, 2013; Doğan and Çekal, 2022; Openfoodfact, 2023; Skinner, 2024).



Figure 35. “Insekten Burger ads” (by Openfoodfact, 2023).

Sugar-coated grasshoppers, known as **inago**, are a popular cocktail snack in Japan (Figure 36) (Amazon, 2024).



Figure 36. Inago ads (by Amazon, 2024).

FAO (Food and Agriculture Organization of the United Nations) foresees that insect production can solve world hunger. They say it can be like ordinary meat production. This approach is compatible with ecological balance. "Insects to Feed the World" conference took place in 2014. At the event, FAO called on the private sector to "help" fight world hunger. It also demanded that governments remove legal obstacles to producing insects as food. It also demanded that governments remove legal obstacles to consuming insects as food. (Setz, 1991; Chakravorty et al., 2011; Rumpold and Schlüter, 2013; FAO, 2018; Doğan and Çekal, 2022; Openfoodfact, 2023; Skinner, 2024; FAO, 2024).



Figure 37. Ynsect, the world's largest insect farm is in France (by Anonymous z).

More than 100 biotech companies in 28 countries work with edible insects. Australia (9), Austria (2), Belgium (6), Canada (11), Colombia (2), China (1), Czech Republic (1), Denmark (3), Finland (1), France (9), Germany (11), Italy (3), Indonesia (1), Israel (1), Japan (1), Mexico (3), Netherlands (1), New Zealand (2), Norway (3), Spain (1), South Africa (1), South Korea (1), Sweden (2), Switzerland (2), Thailand (1), United Kingdom (7) and USA (23) have located these companies. Several companies take part in the edible insects market. They are Kreca Ento-Food BV, Nordic Insect Economy Ltd., Tayland Unique, Entomo Farms Ltd., Enviro Flight, LLC, Proti-Farm, Exo Inc., ENTOTECH, Deli Bugs Ltd., Eat Grub Ltd., HaoCheng Mealworm Inc., Reese Finer Foods Inc., Protein Technologies, Kreca V.O.F., Bugsolutely China, CrikNutrition and Ynsect (Figure 37). Currently, in populous countries like Nigeria, entomophagy is part of the daily diet. Drying consumes these insects. They do not lose high-quality proteins and nutrients, such as minerals and vitamins (by Anonymous, z; Bourne, 1953; Setz, 1991; Chakravorty et al., 2011; Rumpold and Schlüter, 2013; FAO, 2018; Żuk-Gołaszewska et al., 2022; Doğan and Çekal, 2022; Openfoodfact, 2023; Krongdang et al., 2023; Skinner, 2024; FAO, 2024).

9.2. Enzymatic Studies on Entomophagy

Researchers have investigated the protein techno-functionality of proteolytic enzymes in protein-rich edible insects. They have determined the biotechnical functional properties. These include antioxidant, antihypertensive,

solubility, emulsifying, foaming and thermal stability properties (Table 2) (Song et al., 2020; Aguilar-Toalá et al., 2022).

9.3. Production of Bioactive Peptides From Edible Insects

Bioactive peptides (BP) have a specific protein fragment that has a biological function and has a positive effect on human health. BP plays an important role in the human digestive, endocrine, cardiovascular, health, immune and nervous systems. Some forms of edible insects are produced by the enzymatic hydrolysis of insect proteins as well as naturally occurring peptides. BPs with antihypertensive, antimicrobial potential and antioxidant properties that reduce health risks and strengthen the immune system have been obtained from edible insects (Devi et al., 2022; Aguilar-Toalá et al., 2022).

Table 2. Health benefits of different edible insect (by Aguilar-Toalá et al., 2022)

Insect Species	Sample Used or Bioactive Compound Identified	Type of Study	Bioactivities
Mealworms (<i>Tenebrio molitor</i>), buffalo worms (<i>Alphitobius diaperinus</i>), Palm worm larvae (<i>Rhynchophorus ferrugineus</i>), Evening cicada (<i>Tinnia japonica</i>), Black ants (<i>Lasius niger</i>), African caterpillars (<i>Heliothis cyanescens</i>), Silkworm (<i>Bombyx mori</i>), Grasshoppers (<i>Calliptamus italicus</i>), Crickets (<i>Acheta domestica</i>), Mini crickets (<i>Acheta domestica</i>), Giant water bugs (<i>Lethocerus indicus</i>), Scolopendra gigantea (<i>Scolopendra</i>)	Water and liposoluble extracts	In vitro	Antioxidant
Crickets (<i>Gryllodes sigillatus</i>)	Bioactive peptides	In vitro	Antimulant, antihypertensive, antidiabetic, antihypoxic, anti-inflammatory, anti-inflammatory, immunosuppressive, renoprotective
Weaver ants (<i>Polyrhachis dioeca</i>)	Thirteen non-peptide nitrogen compounds (most were identified as alkaloids)	In vitro	Hypolipidemic, antimicrobial
House cricket (<i>Acheta domestica</i>) and tropical banded cricket (<i>Gryllodes sigillatus</i>)	Chitin and chitosan	In vitro	Antioxidant and antimicrobial
Mealworms (<i>Tenebrio molitor</i>) and Chinese beetle (<i>Allostreptus dermestoides</i>)	Extract with main components of saponins, carbohydrates, and proteins	In vitro	Immunomodulatory
Bee pupae	Polypeptide components	In vitro and in vivo	Antioxidant and immunomodulatory
Mealworms (<i>Tenebrio molitor</i>)	Supercritical fluid CO ₂ extract	In vivo	Antioxidant and immunomodulatory
Green beetle (<i>Mircus</i> sp.)	Aqueous extract	In vivo	Anti-adipogenic and antibesity
Mealworms (<i>Tenebrio molitor</i>)	Ethanol extract	In vitro and in vivo	Anti-Farnesinase activity
Silkworm (<i>Bombyx mori</i>)	Powder	In vitro	Antioxidant
Crickets (<i>Gryllodes sigillatus</i>)	Bioactive peptides	In vitro	Antioxidant and antibesity
House cricket (<i>Acheta domestica</i>) and mealworms (<i>Tenebrio molitor</i>)	Polyphenolic ethanol and ethanolic water extracts	In vitro	Antioxidant
House cricket (<i>Acheta domestica</i>)	Polyphenolic methanolic extracts	In vitro	Antioxidant and antihypertensive
Mealworm (<i>Tenebrio molitor</i>) and grasshopper (<i>Sphenocranus purpurascens</i>)	Flour fermented with <i>Lactobacillus lactis strains</i>	In vitro	Antioxidant and anti-dyslipidemia
Silkworm (<i>Bombyx mori</i>)	CEI	In vitro	

SECTION 10

ENTOMOTOXICOLOGY

Toxicology research uses molecular and cellular biology. It helps us understand how exposure to chemical, physical, or biological agents causes phenotypic changes. It also studies how drugs, chemicals, toxins and similar substances work at the cellular and biochemical levels. Entomotoxicology is a specialized field. It deals with the exposure of toxic substances in edible insects. The history of entomotoxicology is quite dark. In 1970, Sohal and Lamb finally showed that different metals accumulate in the tissues of adult house flies (*Musca domestica*). They found metals such as copper, iron, zinc and calcium. Nuorteva identified mercury in the larva, pupa and adult forms of Calliphoridae species. They were feeding on fish tissues with known mercury content. In 1985, Leclerq and Brahy detected arsenic in dipters. It was from a French case of arsenic poisoning (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Researchers have shown that larvae can accumulate drugs or poisons. They can check them when the amount absorbed exceeds the elimination rate. However, researchers have not yet elucidated the effects of substances on larval metabolism. Additionally, researchers have not elucidated the effects on larval development. Researchers have found that some Diptera flies contain malathion. It does not kill the maggots but it delays their development. Pioneering studies showed that metals and drugs accumulate in insects. This has led to increased research into the effects of drugs on dipteran development. True entomotoxicology refers to this. This has been happening in recent decades. Increased knowledge about drug and addictive substance metabolism in Diptera has made entomotoxicological data important in forensic entomology. This helps determine the cause of death (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Entomotoxicological analysis methods are performed with some devices, such as radioimmunoassay. Researchers found that antioxidant enzymes

regulate oxygen toxicity in the larvae of *Trichoplusia ni*, *Spodoptera eridania* and *Papilio polyxenes*. The insects have linked their natural feeding habits to the enzymes superoxide dismutase, catalase, glutathione transferase, peroxidase activity and glutathione reductase. It has been observed *Bacillus thuringiensis* isolates for their oral toxicity against silkworm larvae (*Bombyx mori*), mosquitoes (*Aedes aegypti*) and some beetle adults. In insects, heavy metals (Hg^{++} , Fe^{++} , etc.) harm development. After comparing the weights of larvae, pupae and adults, it has been found significant differences between the control and experimental groups. Researchers have reported that larvae accumulate toxic substances (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

The insect's gut is the main part where digestion occurs. It also contains a structure called the peritrophic matrix. This extends as a tube along the digestive tract and consists of chitin and protein. The peritrophic matrix protects gastric epithelial cells against food-induced mechanical damage. It also guards against toxic substance passage and pathogen entry. It also coordinates the digestive function. The analyses revealed the existence of a total of 138 proteins. Other proteins have various functions. For example, we identified all peritrophic matrix proteins in the larval stage of the potato insect using a method called liquid chromatography-tandem mass spectrometry. Additionally, insecticides are insecticidal toxic substances. Insect toxicology studies the chemical and biological relationships between insects and insecticides. Edible insects may not have insecticide residue if collected from natural environments (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Insects, like other living things, have antioxidant defense systems. These systems reduce the effects of exogenous and endogenous oxidative stress agents. The defense system is divided into two: enzymatic and non-enzymatic systems. Insects have enzymes like, catalase, glutathione peroxidase, glutathione-S-transferase and superoxide dismutase. The enzymatic defense system involves these enzymes. Besides these, there are also some enzymes found only in insects. These are the ascorbate peroxidase and thioredoxin

peroxidase enzymes. The cell membrane and other cellular lipid structures form aldehyde derivatives. This happens because lipid peroxidation creates malondialdehyde. Superoxide radical molecules remove a hydrogen atom from unsaturated fatty acids (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Scientists have reported that extracts of the *Lepisma saccharina* species in the order Tysanura, also known as the paper pest, cause allergies in the respiratory system of humans. Researchers have reported that termites in tropical regions emit methane gas. This causes discomfort in the intestinal fauna of people. Some members of the Epemeroptera order cause allergies, such as asthma. Some species of cockroaches (Blattodea) are vectors of various infectious diseases. Researchers have identified these species. Some species of the order Psocoptera cause allergic reactions in humans. Some species of the Psocoptera order carry *Rickettsia* sp. bacteria. Tyysanoptera bites humans, causing entomodermatitis. It is a cutaneous lesion on the skin caused by insects (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Researchers have shown that some members of the Cimicidae family (*Cimex lectularius*) cause Q-fever diseases. Forensic entomologists use some beetles to estimate the time between discovering a corpse and death. They study swelling and active decomposition. Some species of the Neuroptera order bite people in gardens, causing redness and papules that last for a few days. *Hippelates pallipes* (Chloropidae) is a reservoir for *Treponema pallidum* bacteria. This bacteria is the causative agent of Yaws disease. Some dipterans (Simuliidae and Ceratopogonidae) and *Culicoides* spp. Researchers have reported that sandflies transmitted *Mansonella ozzardi*, a filarial nematode species, to humans. Mosquito species found all over the world serve as vectors for the transmission of many pathogens to humans and some vertebrates (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

Currently, researchers have identified approximately 700 million mosquitoes. They belong to 3500 species. They cause diseases such as malaria, yellow fever and dengue fever (Becker and Petric, 2004). For example, *Anopheles* species carry *Plasmodium* species that cause malaria. Tsetse flies are the vectors of *Trypanosoma congolense*, *T. vivax* and *T. brucei*. These parasites cause Nagana disease (Ohba and Aizawa, 1986; Ahmad and Pardini, 1990; Gagliano-Candela and Aventaggiato, 2001; Türkez et al., 2010; Gao et al., 2018; Çim, 2018; Şen, 2018; Kasurka, 2019; Bektaş et al., 2022).

SECTION 11

ETHICAL PRINCIPLES OF ENTOMOPHAGY

Many factors, such as culture, religion, economy and culinary experiences, they create food choices and degrees of appreciation. A person's eating and drinking preference is shaped based on their taste, health, social status, economic situation, personal and social factors, eating habits, the environment in which they live, and other psychological factors. Meat can no longer be considered a sustainable food source due to the large amount of land and water required for meat production. There are opinions that the problems that arise in traditional animal breeding are not seen in insect breeding and that insect farms can be a solution to the problems. Insect farms are referred to as “sustainable protein businesses” (Kurt, 2010; Ole, 2013; Karaman, 2019; Baysal, 2003; Berger et al., 2018; Çaycı, 2019; Hacıoğlu, 2019; Boran, 2020; Sabri et al., 2023).

People nowadays discuss halalness. Insects are important for nutrition and religious reasons. It is planned to create an impact on conscious consumers and the commercial field by creating a view or awareness of the products that are assumed to be produced by many companies that produce halal products or products that are purchased without reading the contents. Biotechnological methods in laboratory environments remove proteins and fatty acids from insect tissues. Then, they turn these into edible formulations. These can be used as supplements in halal foods. They can also be used as imitations of cultural dishes and sweeteners in the halal food category (Kurt, 2010; Ole, 2013;

Karaman, 2019; Baysal, 2003; Berger et al., 2018; Çaycı, 2019; Hacıoğlu, 2019; Boran, 2020).

Socially and culturally, individuals tend to eat insects and must be ready for this idea, and for this, awareness needs to be raised in every field. As with raising awareness, advantages and disadvantages should be given and guidance should not be given to evaluate insect consumption. In addition, the expectations of the increasing conscious Muslim population in the world have increased the importance given to halal food by affecting their behavior. In this case, consumers of Islamic faith are not allowed to entomophagy. In four sects of Islam, locust was deemed halal to eat it. During the period of the Companions (who saw the Prophet), it was common to eat. But, nowadays, the grasshopper known as grasshopper is not widely used as food except in some regions (Kurt, 2010; Ole, 2013; Karaman, 2019; Baysal, 2003; Berger et al., 2018; Çaycı, 2019; Hacıoğlu, 2019; Boran, 2020; Sabri et al., 2023).

There are some publications that suggest that protein-rich insects, especially grasshoppers, can be used in the treatment of obesity. Therefore, different versions of the grasshopper will not cause obesity in the future. It is predicted that its use in foods will become widespread in various forms. There is no doubt that the locust was studied by Muslim researchers for food. Someone has reported that they need to take it and examine it. Researchers have not found any Islamic evidence approving the consumption of insects. Grasshoppers are the only exception (Kurt, 2010; Ole, 2013; Karaman, 2019; Baysal, 2003; Berger et al., 2018; Çaycı, 2019; Hacıoğlu, 2019; Boran, 2020).

The World Halal Summit in Istanbul in 2018 did not allow insects as food. Pork is also not allowed. Muslims cannot eat pork. Likewise, it has been stated that Muslims do not eat insects. According to Jewish religious rules, grasshoppers are the only insects that can be eaten. It is written in the Torah that four types of locusts can be eaten. These are red, yellow, mottled gray and white locusts. The prohibition of eating insects is repeated in the Torah much more often than the prohibition of eating pork. Some Hindus do not eat. Insects are prohibited from eating. There is no similar nutritional code in Christianity. It is known that insect consumption is not welcomed in places with a large Christian population, such as Europe (Kurt, 2010; Ole, 2013; Karaman, 2019;

Baysal, 2003; Berger et al., 2018; Çaycı, 2019; Hacıoğlu, 2019; Boran, 2020; Sabri et al., 2023).

SECTION 12

THE FUTURE OF ENTOMOPHAGY

12.1. Latest Developments in Insect Consumption Worldwide

The human population is expected to reach 10 billion in 2050, and it is evident that there will be significant challenges in meeting the future's food requirements. It is reported that due to population growth, traditional protein sources will not be sufficient, and alternative protein sources are needed to address this global problem (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Chung et al., 2022; Sabri et al., 2023).

Insect, microalgae and bacterial proteins are being explored as alternative protein sources due to their environmentally friendly breeding conditions and high nutritional values. According to literature reviews, insects have the potential to be used as a new ingredient due to their high protein content. In addition, if bars, crackers or baked goods are formulated with insect flours and consumers are assured that these familiar foods still contain insects and maintain the taste they are accustomed to, a positive impression can be formed about these products. Research on this subject is currently limited, but significant strides are being made in the food industry through increased studies, research and development in this area and the transition to industrial applications. According to 2023 estimates, insect consumption rates seem to be approaching today rations (Figure 38) (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; Gorbunova and Zakharov, 2021; Chung et al., 2022; Sabri et al., 2023).

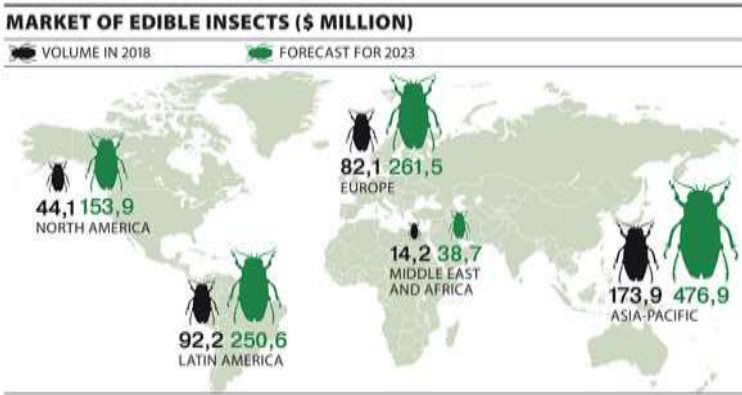


Figure 38. According to Bloomberg source, edible insect market in the World (by Gorbunova and Zakharov, 2021).

In the recent list of edible insects published by Wageningen University and compiled by Jongema (2014), there are 2403 species. However, other literature suggests that there are 1611 species of edible insects and 81 species of medicinal insects. Striking examples have also been provided from certain arthropods, such as non-insect spiders. It has been observed that certain edible species, which are significant plant pests, can also be utilized in biological control through entomophagy. Information on 81 insect species of medicinal importance and 1611 insect species on the edible list is provided in the table 4 (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; Gorbunova and Zakharov, 2021; Chung et al., 2022; Sabri et al., 2023).

In addition to insects, certain spiders and ticks also provide edible sources. From the family Nephilidae of the order Araneae, *Araneus edulis* (Labil.), *Epeira nigra* Vinson, *Haplopelma albostriatum* (Simon) are examples of tarantulas from the family Theraphosidae, while *Heteropoda venatoria* Latreille family Sparassidae. Moreover, the family Theraphosidae includes the bird-eating spider *Holotele waikoshiemi*, as described by Bertani and Araújo and the *Melopoaeus* sp. *Nephila antipodiana* (Walck) belongs to the family Nephilidae., *N. clavata* Koch, *N. edulis* (Labil.), *N. inaurata* (Walckenaer), *N. madagascariensis* Vinson, *N. pilipes* (F.). ticks. It has been reported that some members of the Ixodidae family are edible (Ramos-Elorduy, 1997; Ramos-

Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Mistuhashi, 2016; Chung et al., 2022; Sabri et al., 2023).

The list of edible insects includes several important and noteworthy families and species, such as follows: from some species (*Forficula* sp. earwig) of Dermaptera; from the family Belostomatidae (Hemiptera, Giant water bug) *Abedus* sp., *Lethorcerus americanus* (Leidy), *L. deyrollei* (Vuillefroy), *L. indicus* (L. & S.) and *L. indicus* Lep. & Serv species; *Corisella edulis* (Champion), *Graptocorixa abdominalis* (Say), *Graptocorixa bimaculata* (Guérin), *Corisella mercenaria* (Say), *Krizousacorixa azteca* (Jacz.), *Krizousacorixa femorata* Guér Corixiidae family (Hemiptera, water boatman); *Cylindrostethus scrutator* (Kirkaldy) and *Gerris spinole* (Leth.) belonging to Gerridae family (Hemiptera), the water strider is represented by *Nepa* sp., *Laccotrephes griseus* (Guer.), *L. japonensis* (Scott), *L. maculatus* (F.), *L. robustus* Stal, *L. ruber* (L.) form Nepidae (Hemiptera, water scorpion), *Ranatra chinensis* Mayr, *R. longipes* Lansbury, *R. unicolor* Scott, *R. varipes* Stal from the subfamily Ranatrinae (Hemiptera, water stick insect) (Jongema, 2014; Mistuhashi, 2016). In the order Diptera, the species include Tephritidae *Anastrepha ludens* (Loew), known as the Mexican fruit fly, used for biological control, as well as *Drosophila melanogaster* and *Musca domestica* (L.), the common fruit fly, used for genetic biomaterial (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Mistuhashi, 2016; Chung et al., 2022; Sabri et al., 2023).

In the order Coleoptera, primarily from terrestrial habitats, *Algarobius* sp. from the family Buprestidae. Seed beetles for biological control, *Eugnoristus monachus* (Oliv.) Species from the Dryophthoridae family, known for their biological struggle, are listed. In aquatic Coleoptera, from the family Dytiscidae (diving beetles), the species include *Acilius* sp., *Agabus fulvipennis* Régimbart, *Copelatus* sp., *Cybister* sp., *Dytiscus* sp., *D. habilis* Say, *D. marginalis* L., *D. marginicollis* LeConte, *D. validus* Régimbart, *Eretes sticticus* (L.), *Hydaticus rhantoides* Sharp, *Laccophilus apicalis* Sharp, *L. fasciatus* Aubé, *L. pulicarius* Sharp diving beetle, *Megadytus* sp., *Platambus guttulus* (Régimbart), *Rhantaticus congestus* (Klug), *Rhantus atricolor* (Aubé), *R. consimilis* Motsch., *R. latus* (Fairm.), *Rhantus pulverosus* (Stephens), *Thermonectus basilaris* (Harris), *T. marmoratus* (Gray) and other

Thermonectus sp. types can be provided as examples. From the Hydrophilidae family, specifically the water scavenger beetles, are *Helephorus olivaceus* F., *H. picicornis* Chev., *H. senegalensis* (Percheron), *H. pallidipalpes* (MacLeay), *Sternolophus rufipes* (F.), *Tropisternus mexicanus* Lap., *T. sublaevis* (LeC.), *Tropisternus tinctus* Sharp and *T. collaris* (F.). Additionally, the list of edible insects includes *Haliplus punctatus* Aubé from the Haliplidae family, *Suphisellus* sp. from the Noteridae family; *Austrelmis chilensis* (Germain), *A. condimentarius* (Philippi) from the family Elmidae and *Berosus* from the family Hydrophilidae. It also includes *Aulonogyrus strigosus* F. and *Dineutes marginatus* Sharp species from the Gyrinidae family (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Mistuhashi, 2016; Chung et al., 2022; Aydoğan, 2023; Sabri et al., 2023).

Finally, *Atractomorpha psittacina* (de Haan) (spotted grasshopper for control struggle) from the family and *Schizodactylus monstrosus* (Drury) (sand cricket) and *S. tuberculatus* Ander species from the Schizodactylidae family can cited given as examples in the Orthoptera (Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Jongema, 2014; Chung et al., 2022; Sabri et al., 2023).

12.2. Biological Control And Insectageddon

Biological control involves using living organisms to decrease pest populations instead of relying on chemicals. In order to reduce the population of harmful insects, organisms such as viruses, rickettsia, bacteria, fungi and protozoa are used because they cause the death of infested species. Even though entomopathogens are effective in the biological control of many invertebrates, arthropods, especially insects, have developed various and effective defense mechanisms against these pathogens. It is understood that the body is protected by defense mechanisms such as cuticle thickness, melanin content in the skin and resistance mechanisms in the intestinal structure (Van Den Bosch, 1971; Masahiro et al., 1992; Hawkins et al., 1999; Atay and Oğur, 2011; Costa-Neto and Dunkel, 2016; Bektaş, 2018; Bektaş et al., 2019; Bektaş, 2020; Reynoso-Velasco and Arce-Pérez, 2020; Wang et al., 2005; Gorbunova and Zakharov,

2021; Bektaş, 2021; Lange and Nakamura, 2021; Parra and Coelho, 2022; Van Itterbeeck and Pelozuelo, 2022; Chung et al., 2022).

In addition, the hemolymph fluid and specialized cells in insects contribute to their immunological resistance. Of course, these protection methods provide the opportunity for new ideas to be generated in the field of entomophagy, as well as the development of medical drugs (Table 3). Microorganisms are utilized to decrease the population of harmful insects in specific regions. With the microbial control method and entomophagic approaches for animal feeds that do not cause technical irritation, the use of insecticides can be minimized. For example, stink bugs (*Bathycoelia disticta*) (Hemiptera: Pentatomidae) are a hazardous pest in South African orchid gardens. This pest is primarily managed using insecticides, making alternative control methods important. A PCR-based metabarcoding test was developed to identify plant material in the gut of stink bugs (Masahiro et al., 1992; Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Van Huis, 2003; Atay and Oğur, 2011; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; Bektaş, 2018; Bektaş et al., 2019; Bektaş, 2020; Reynoso-Velasco and Arce-Pérez, 2020; Wang et al., 2005; Wang and Yao, 2011; Gorbunova and Zakharov, 2021; Bektaş, 2021; Lange and Nakamura, 2021; Parra and Coelho, 2022; Van Itterbeeck and Pelozuelo, 2022; Chung et al., 2022; Sabri et al., 2023).

Climate change triggers stressors that influence ecosystems, making it a prominent and concerning issue for ecosystems worldwide. The long-term monitoring of the impact of global warming on aquatic insects in ecosystems offers the advantage of providing important insights into the prediction of changes in insect populations, including invasive or endangered species, and potential ecosystem mechanisms. In addition to impacting climate change, which also affects edible insects, the use of agricultural chemicals such as pesticides accelerates insect losses. For this reason, the use of pesticides is unavoidable in modern agriculture (Masahiro et al., 1992; Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Van Huis, 2003; Atay and Oğur, 2011; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; Bektaş, 2018; Bektaş et al., 2019; Bektaş, 2020; Reynoso-Velasco and Arce-Pérez, 2020; Wang et al., 2005; Gorbunova and Zakharov,

2021; Bektaş, 2021; Lange and Nakamura, 2021; Parra and Coelho, 2022; Van Itterbeeck and Pelozuelo, 2022; Chung et al., 2022; Sabri et al., 2023; Bektaş, 2023).

When using pesticides, it is important to evaluate both the protection of the product against diseases, pests and weeds, as well as the potential negative effects on humans and the environment. In this system, also known as Integrated Pest Management, agricultural yields can be improved in terms of both quality and quantity, while ensuring food safety and the sustainability of the agricultural ecosystem. In this approach, it is important to take care not to harm insects outside the agricultural area (Masahiro et al., 1992; Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Van Huis, 2003; Atay and Oğur, 2011; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; FAO, 2018; Bektaş, 2018; Bektaş et al., 2019; Bektaş, 2020; Reynoso-Velasco and Arce-Pérez, 2020; Wang et al., 2005; Gorbunova and Zakharov, 2021; Bektaş, 2021; Lange and Nakamura, 2021; Parra and Coelho, 2022; Van Itterbeeck and Pelozuelo, 2022; Chung et al., 2022; Sabri et al., 2023; FAO, 2024).

Today, most insect species are considered edible, including ants, grasshoppers, bees, wasps, crickets, and more. It has been listed that more than 1,900 insect species in the world are edible. These edible hexapods are used as human food, and approximately 2 billion people worldwide consume insects. Therefore, when comparing plant and animal proteins with insect proteins, edible insects are valuable sources in terms of essential amino acid profile, total protein level and other nutritional values. The design was intended to incorporate natural plants that have the ability to attract pollinator insects, with a focus on the sustainability of insect species. In addition, populations of edible insects will also be preserved (Masahiro et al., 1992; Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1998; Ramos-Elorduy et al., 1998; Van Huis, 2003; Atay and Oğur, 2011; Jongema, 2014; Mistuhashi, 2016; Costa-Neto and Dunkel, 2016; Bektaş, 2018; Bektaş et al., 2019; Bektaş, 2020; Reynoso-Velasco and Arce-Pérez, 2020; Wang et al., 2005; Gorbunova and Zakharov, 2021; Bektaş, 2021; Lange and Nakamura, 2021; Parra and Coelho, 2022; Van Itterbeeck and Pelozuelo, 2022; Chung et al., 2022; Sabri et al., 2023; Bektaş, 2023).

Table 3: Specimens of Insects Used For Medicinal and Product Purpose (by Jongema, 2014; Wang and Yao, 2011).

Ordo	Family	Species	Benefits	Terrestrial / Aquatic
Hymenoptera	Apidae	<i>Apis</i> sp.	Insect product	Terrestrial
Hemiptera	Coreidae	<i>Acanthocephala</i> sp.	Medical	Terrestrial
	Apidae	<i>Bombus rufocinctus</i> Cresson, <i>Nannotrigona testaceicornis</i> (Lep.), <i>Melipona beecheii</i> Bennett, <i>Lestrimelitta limao</i> (Smith), <i>Tetragona clavipes</i> (F.), <i>Tetragonisca fiebrigi</i> (Schwarz)		
	Pentatomidae	<i>Chlorocoris</i> sp.		
Blattodea	Blattellidae	<i>Blattella germanica</i> (L.)	Medical	Terrestrial
Hymenoptera	Formicidae	<i>Eciton</i> sp.	Medical	Terrestrial
	Vespidae	<i>Mischocyttarus basimacula</i> (Cameron), <i>M. pallidipectus</i> (Smith), <i>Polistes canadensis</i> (L.), <i>P. instabilis</i> Sauss., <i>P. major</i> Beauv., <i>Vespula squamosa</i>		
Lepidoptera	Hepialidae	<i>Hepialus cingulatus</i> Yang & Zhang, <i>H. davidi</i> Poujade, <i>H. dongyuensis</i> Liang, <i>H. ganna</i> Hübner, <i>H. jinshaensis</i> Yang, <i>H. litangensis</i> Liang, <i>H. luquensis</i> Yang & Yang, <i>H. luquensis</i> Yang & Yang, <i>H. macilentus</i> Eversmann. <i>H. markamensis</i> Yang, Li & Shen. <i>H. nebulosus</i> Alphéraky, <i>H. pratensis</i> Yang, <i>H. varians</i> Staudinger, <i>H. xunhuaensis</i> Yang, <i>H. yeriensis</i> Liang, <i>H. yunnanensis</i> Yang & Li, <i>H. zhongzhiensis</i> Liang, <i>H. albipictus</i> Yang and <i>H. yulongensis</i> Liang.	Medical	Terrestrial
	Nymphalidae	<i>Morpho</i> sp.		
Coleoptera	Meloidae	<i>Meloe dugesi</i> Champ., <i>M. laevis</i> Leach, <i>M. nebulosus</i> Champ., <i>Mylabris cichorii</i> (L.)	Medical	Terrestrial
	Zopheridae,	<i>Zopherus jordani</i> Sallé	Medical	Terrestrial

Table 4: Edible terrestrial and aquatic insects (by Jongema, 2014).

Ordo	Family	Benefits	Terrestrial / Aquatic
Ephemeroptera	Baetidae, Caenidae, Ephemeridae and Palingeniidae	Edible	Aquatic Semiaquatic
Megaloptera	Corydalidae	Edible	Terrestrial
Isoptera	Hodotermitidae, Kalotermitidae, Rhinotermitidae and Termitidae	Edible	Terrestrial
Odonata	Aeschnidae, Coenagrionidae, Corduliidae, Gomphidae, Lestidae, Libellulidae and Macromiidae	Edible	Terrestrial
Phasmida	Diapheromeridae and Heteropterygidae	Edible	Terrestrial
Phthiraptera	Pediculidae	Edible	Terrestrial
Dictyoptera	Blattidae, Blaberidae, Cryptocercidae, Ectobiidae, Empusidae, Mantidae and Tarachodidae	Edible	Terrestrial
Dermoptera	Forficulidae	Edible	Terrestrial
Plecoptera	Nemouridae, Perlidae, Perlodidae and Pteronarcydae	Edible	Terrestrial
Tricoptera,	Hydropsychidae, Leptoceridae, Stenopsychidae	Edible	Terrestrial
Hymenoptera	Cynipidae, Formicidae, Sphecidae, Tenthredinidae and Vespidae	Edible	Terrestrial
Hemiptera	Belostomatidae and Nepidae	Edible	Aquatic Semiaquatic
Diptera	Drosophilidae, Muscidae, Bibionidae, Calliphoridae, Culicidae, Ephyridae, Rhagionidae, Sarcophagidae, Syrphidae Stratiomyidae, Oestridae, Tephritidae and Tipulidae	Edible	Terrestrial
Heteroptera	Aetalionidae, Aphididae, Alydidae, Cercopidae, Cicadidae, Coccidae, Dactylopiidae, Dinidoridae, Eriococcidae, Erotylidae, Flatidae, Kerriidae, Largidae, Membracidae, Monophlebidae, Naucoridae, Psyllidae, Pyrrhocoridae, Scutelleridae, Tibicinidae and Tessaratomidae	Edible	Terrestrial
Lepidoptera	Arctiidae, <i>Bombycidae</i> Brahmaeidae Castniidae, Cossidae, Crambidae, Erebiidae, Eupterotidae, Gelechiidae, Geometridae, Hepialidae, Hesperidae, Lasiocampidae, Limacodidae, Lycaenidae, Lymantriidae, Mimalionidae, Noctuidae, Notodontidae, Nymphalidae, Oecophoridae, Papilionidae, Pieridae, Pyralidae, Psychidae, Saturniidae, Sesiidae, Sphingidae, Tortricidae, Uranidae and Zygaenidae	Edible	Terrestrial
Coleoptera	Bostriichidae, Bruchidae, Buprestidae, Carabidae, Cerambycidae, Curculionidae, Dryophthoridae Elateridae, Lucanidae, Meloidae, Nitidulidae, Passalidae, Scarabaeidae, Tenebrionidae, Zopheridae	Edible	Terrestrial
	Dytiscidae, Hydrophilidae, Haliplidae, Noteridae, Elmidae and Gyrimidae	Edible	Aquatic Semiaquatic
Ortoptera	Acrididae, Anostomatidae, Catantopidae, Gryllidae, Gryllotalpidae, Gryllacridae, Gomphidae, Pyrgomorphidae, Rhaphidophoridae, Romaleidae, Schizodactylidae, Tettigoniidae	Edible	Terrestrial

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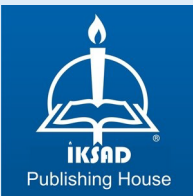
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