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# Insects on the Menu: Evaluating Entomophagy for Future Food Security

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**Abstract:- Entomophagy, the practice of eating insects as food, offers a sustainable alternative to conventional animal protein sources. Insects are potentially rich sources of nutrients like protein, vitamins, healthy fats, and minerals. Globally, insects are already a dietary staple in many cultures and offer a lower environmental footprint compared to traditional livestock, emitting lesser greenhouse gases and requiring less land. With the potential to address malnutrition and enhance food security, entomophagy is increasingly recognized as a viable solution to global food challenges. However, cultural and psychological barriers remain, and broader acceptance could facilitate its integration into mainstream diets.**

## I. INTRODUCTION

As the global population is mushrooming, it is expected to exceed 9 billion by 2050. More specifically, the explosion of the middle class has put more strain on beef and poultry meat, among the traditional protein sources (Suthar *et al*., 2019). To address the needs of an expanding population, we need an alternative protein source that is easily available and easy to produce. In this context, entomophagy enters the food chain from the Greek words entomos (insect) and phagein (to eat). Insects are the oldest terrestrial animals on Earth, having been consumed for food for at least 400 million years (Bernard and Womeni, 2017). Paleontological evidence indicates that early humans consumed insects, demonstrating that people had been consuming insects for around 7,000 years (Arnold *et al*., 2014). Today, 113 nations all over the world engage in entomophagy (MacEvilly, 2000). Over 2,300 bug species from 18 different groups have been recognized as edible, out of an estimated 6 to 10 million insect species worldwide (Tang *et al*., 2019). Many people in parts of the world like Africa, Asia, and Latin America eat edible insects (Banjo *et al*., 2006).

## II. WHY INSECTS ARE TO BE CONSUMED?

Demand for food is expected to almost double, but scarcity of land resources will have serious implications for food production. The FAO is looking at insects also as an alternative source of food. It is estimated that at least 2 billion people around the world have already incorporated insects into their diets. Insects constitute not only a protein supplement but also open up the possibility of eating other animals further down the food web (Arnold *et al*., 2014). The practice of consuming insects would have some negative or at best, negligible effects on the environment, health and livelihoods of humans.

### *A. Environmental Impact:*

Insects, when promoted as a food source, produce significantly fewer greenhouse gases (GHGs) compared to most livestock. For instance, only a few insect species like termites and cockroaches generate methane, a potent greenhouse gas. Insect farming does not require large amounts of land and does not necessitate deforestation for expansion. Ammonia emissions from insect farming are also much lower than those from conventional livestock, such as pigs. Because insects are cold-blooded, they are highly efficient at converting feed into protein. For example, crickets require 12 times less feed than cattle, four times less than sheep, and half as much as pigs and broiler chickens to produce the same amount of protein. Additionally, insects can be fed on organic waste.

### *B. Environmental Impact:*

Insects when promoted as a food source for sale have been reported to produce much lower greenhouse gas emissions than rearing livestock. For instance, only a few insect species like termites and cockroaches generate methane, which is a potent greenhouse gas. Raising insects as livestock does not require massive tracts of land, and thus there is no need to increase deforestation. Insect farming, furthermore, does not produce as much ammonia as pig farming or small-scale pig production does. Because insects have a cold-blooded metabolism, they use feed very effectively as a protein source. For instance, crickets use 12 times more feed than cattle use, 4 times more than sheep and 50 times more than incubated hens to yield an equivalent level of protein. Furthermore, they can also consume organic leftovers.

### *C. Health Benefits:*

Insects are a healthy protein alternative for the mainstream diet of chicken, pork, beef and fish. Many species of insects are also known to be good sources of omega-3 fatty acids and essential trace elements such as calcium, iron and

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zinc. In a majority of places, insects are routinely consumed as part of the local and national foods.

*D. Livelihood Opportunities:*

Insect harvesting or farming is a low-technology and low-capital activity that serves as an entry point for marginalized groups such as women and landless people. This mini-livestock approach creates income-generating potentials for both rural and urban dwellers who practice farming at different levels of intensiveness as may be possible for the investments made in these enterprises.

*E. Addressing Malnutrition:*

Insects are viewed as having high feed conversion efficiency and high reproduction rate and thus pose a potential solution for the problem of protein deficiency and malnutrition across the globe.

## III. PREFERENCE OF INSECTS AS FOOD IN THE WORLD

It is in the Netherlands that the commercial cultivation of insects for human consumption started in 2008 and in the same year, the campaign to promote entomophagy was launched. Entomophagy was the topic of presentation and conversations in one of the sessions of an international conference in May 2014 held by Wageningen University with FAO's support (Arnold *et al*., 2014) (Table 1, Fig.1)

## IV. MARKET

The edible insect market was valued at more than USD 55 million in 2017 and considering the global outlook it is forecasted that the industry's growth will be considerable with a compound annual growth rate of over 43.5 percent by the year 2024. The demand for insect-based animal feeds in the US in 2018 is estimated at USD 688 million and is forecasted to grow to USD 1.4 billion in 2024. Certainly, the aquaculture sector contributed the largest share, estimated to be over 50 % of the total insect feed market in 2018 (Globe Newswire, 2020). The worldwide market of edible insects is anticipated to grow to USD 8 billion by 2030 (Globe Newswire, 2019).

In Assam, Arunachal Pradesh, Manipur and Nagaland India, scooping insects is a norm. In a state, some tribes specialize in certain edible bug species. It is estimated that across all tribes in India, around 255 insect species are used as food (Fig. 2). Coleopteran species were stated to be the most widely used, with approximately 34% of all insect feeding being engaged with this group. (Pradhan and others, 2022)

A study on the familiarity, experience, perception, and willingness of entomophagy was carried out by Tao and Li (2018). In cumulative, 73%, of respondents expressed a probable motivation for adopting edible insects in the future, and 82% of insect consumers surveyed knew about entomophagy. An overwhelming number of people indicated their readiness to consume edible insects in the forthcoming years (Figs. 3, 5 and 6). Only 42% of those polled were able to claim that they had eaten edible insects before participating in the current study, despite 73% responding favourably to this question (Fig. 4). The popular means to consume edible insects are as a snack (22%), as an appetizer (19%) and as a side dish (19%) (Fig. 7). Considering their tiny size, or because snacking is becoming increasingly prevalent overall, edible insects seem to be the most popular snack. These findings seem to imply that humans prefer eating insects.

## V. COMMON EDIBLE INSECTS

The most often consumed insects globally are bees, wasps, and ants (Hymenoptera, 14%), beetles (Coleoptera, 31%), and caterpillars (Lepidoptera, 18%). Termites (Isoptera, 3%), dragonflies (Odonata, 3%), flies (Diptera, 2%), cicadas, leafhoppers, planthoppers, scale insects, and true bugs (Hemiptera, 10%), grasshoppers, locusts, and crickets (Orthoptera, 13%), and insects from other orders (5%) constitute the other insects that are frequently consumed (Van Huis *et al*., 2014) (Fig. 8).

*A. Hymenoptera*

- *Ants*

In eastern India, particularly in Chhattisgarh, Odisha, and Jharkhand, red ants are the primary ingredient of a chutney, which has different names in local tongues, like 'demta' in Chaibasa (Jharkhand) and 'chaprah' or 'chapda' in Basta (Chhattisgarh). The ingredients for making chutney include garlic, ginger, chilies, and salt, and often the chutney is called 'Chaprah' after the leaf houses made by ants from Sal tree leaves. It has a sour taste due to formic acid in the ants and hence a strong, pungent flavour. It has proteins, zinc, cobalamine, copper, potassium, and calcium-rich in red ants, thus developing immunity and strengthening bones. Anemia due to cobalamine deficiency is known as pernicious anemia. In China, India, Indonesia, and Thailand, the larvae, pupae, and eggs of the Asian weaver ant (*Oecophylla smaragdina*) are also eaten (DeFoliart, 2002).

- *Bees*

Hymenoptera order includes bees. It is a common cultural practice to eat honeybee broods in Mexico, Ecuador, China, and Thailand. Because honeybees (*Apis mellifera*) are kept all over the world and are considered a delicacy in many cultures because of their taste and texture, the main food resource is their brood. The nutty, crunchy texture and slightly sour flavor of honeybee broods make them edible, cookable, and even dehydratable (Chen *et al*., 1998). The consumption of bees as part of food is also beneficial because of the high content of amino acids, B vitamins, and other nutrients in bees and their larvae. Bees are a staple dish in Thailand because they have a buttery texture, rather fatty. The Aboriginal people of Australia also use stingless bees to make sugar.

- *Other Wasps and Bees*

Hebo is the local term for the larvae of yellow jacket wasps (*Vespula* and *Dolicho vespula* spp.) that are consumed in Japan.

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### *B. Coleoptera*

➢ *Beetles*

The palm weevil and other beetle species, such as aquatic beetles, wood-boring larvae, and dung beetles, are consumed in enormous quantities. In addition to having a lower fat content, beetles have more proteins than meat, poultry, and egg products.

➢ *Weevils*

The larvae of the palm weevil Rynchophorous spp. were described by Linnaeus in his book Systema Naturae as having "Larvae assate in deliciis habentur" or fried larvae are tasty. Palm weevil larvae are consumed in Asia (Rynchophorous spp.), Africa (*Rynchophorus phoenicis*), and Latin America (*Rynchophorus palmarum*). Some credit their high fat content to their exquisite flavour (Cerda *et al*., 2001, Fasoranti and Ajiboye, 1993). Normally, palm weevil larvae are collected, cleaned, then fried for human consumption. Because the larvae are high in fat and release oil when they are fried, adding oil is unnecessary. Salt, pepper, and onion form a common accompaniment. Another popular practice is to roast the larvae over an open grill (Fasoranti and Ajiboye, 1993).

### *C. Lepidoptera*

➢ *Caterpillars*

Caterpillars are perhaps the most diverse edible insects around the world. Beyond providing crucial sources of protein and other micronutrients, they also enhance many people's lives in various parts of the world. The best-known are probably Australia's witchetty grubs (Meyer-Rochow, 2005). In Thailand and the Lao People's Democratic Republic, the bamboo caterpillar, *Omphisa fuscidentalis*, is a popular attraction (Yhoung-Aree and Viwatpanich, 2005). According to Van Huis (2003), 30 percent of all edible bug species are caterpillars, and thus they are very popular in sub-Saharan Africa. 38 kinds of edible caterpillars are listed by Malaisse (1997).

➢ *Mopani Caterpillar*

Mopane woods are found in Botswana, Namibia, Zimbabwe, and the northern parts of South Africa. Its range is closely related to that of the mopane tree (*Colophospermum mopane*), which is the primary host of Mopani caterpillars (Stack *et al*., 2003; Ghazoul, 2006). Mopane caterpillars, like many other edible insects, are not only "famine foods" that are eaten during periods of food scarcity. Caterpillars are part and parcel of the diet but, on the other hand, an important source of food when famine hits them (Stack *et al*., 2003). Caterpillars are the most consumed, traded, and costly edible insects in the tropics since they are a very good source of proteins and lipids for many natives (Ngute *et al*., 2020). It is part of the local culture to collect, process, trade, and consume mopane caterpillars, but for the marginalized communities, it is a way of subsistence. The mopane caterpillar has 48–61% protein and 16–20% fat, of which 40% constitutes essential fatty acids. Additionally, mopane caterpillars are a significant source of iron, zinc, and calcium. After cleaning the worms, the traditional preservation method of mopane worms involves boiling without adding any extra water and then adding large amounts of salt. After this, they are either smoked or sun-dried for extra flavour. Caterpillars are usually canned in brine industry. Mopane worm tins are available at rural markets and stores in Southern Africa. The highest caterpillar consumers are Congo, the Central African Republic, Cameroon, Uganda, Zambia, Zimbabwe, Nigeria, and South Africa. (Ekesi and Nissay, 2017). Under stress, dried mopane caterpillars are a rich source of nutrition and can be stored for several months. For many rural families, collecting and selling the caterpillars is a huge source of cash, and often the primary reason to harvest. (Stack *et al*., 2003; Illigner and Nel, 2000). Southern Africans eat mopane worms, which are the larval form of the saturniid moth *Gonimbrasia belina*. The bamboo caterpillar, scientifically known as *Omphisa fuscidentalis*, is a popular delicacy in Asia.

➢ *Moths*

The Bogong moth, or cutworm *Agrotis infusa*, is consumed by Australians (Flood, 1980).

### *D. Isoptera*

➢ *Termites*

They have been widely consumed throughout Southeast Asia and the African continent. Termites are rich in protein, fatty acids, and other micronutrients. Fried or dried termites contain 32–38% proteins (Tihon, 1946; Oliveira *et al*., 1976; Nkouka, 1987). *Macrotermes bellicosus* and *M. subhyalinus*, two aboveground hill termite species of Africa, have high contents of essential fatty acids, such as linoleic acid (Oliveira *et al*., 1976). Their respective fatty acid contents are about 34 and 43 percent. This species has an impressive 64% protein content. In Central Africa, it has been reported that soldiers of larger termite species are consumed. Once they are prepared, fried, and sun-dried, they can be eaten as snacks or as a main course or side dish (Kinyuru *et al*., 2009). Although termites are often steamed in banana leaves in Uganda, they may be fried, sun-dried, or smoked. Firstly, to kill the sun dry or smoke, termites must be boiled or roasted for a few minutes (Silow 1983). They are often crushed as a powder with the pestle and mortar and later eaten mixed with honey (Ogutu, 1986) adding that big macro-termite species are commonly consumed. In Africa, people pound the ground around termite hills to mimic heavy rain, encouraging termites to come out.

### *E. Orthoptera*

➢ *Crickets*

The cricket species, *Acheta domesticus* and *Gryllodessi gillatus* are suggested edible species of crickets, and some other commercially sold species can also be in the diet of humans. Crickets are an excellent source of protein, iron, and vitamin B12 for adults. As the powder is added to protein shakes, bars, and flour, they can be incorporated to make different types of products. In America, "cricket flour" is already in one brand of chips. The body's inflammation will self-regulate, and the good gut bacteria will be grown through eating them regularly (Claire Stam, 2018). Cricket

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consumption is highest in South Africa, Congo, the Central African Republic, Zambia, Zimbabwe, Nigeria, Cameroon, and Uganda (Nissay and Ekesi, 2017). In Latin America, Chapuline is probably the most known edible grasshopper. Salt, lemon, and garlic are added to a little oil and toasted to give flavor.

*F. Blattodea*

➢ *Cockroaches*

In general, cockroaches are considered scavengers. Interestingly, many cockroach species differ in size, color, and, above all, taste. After removing the wings and legs, these are used. The immature form is smaller and much more fragile than the adult insect. These can be boiled, sautéed, roasted, or crispy-fried. The species *Blatta lateralis*, also known as the Turkish roach, and *Blaptica dubia*, known as the Dubia roach, are edible due to their high nutrient content (Bessa *et al*., 2020). The way cockroaches are consumed varies between nations depending on the local customs. Some of these include frying, toasting, and boiling. The flavour and texture of cockroaches can be compared to greasy chicken. According to a study, Pacific beetle cockroaches can produce milk to feed their young and can relate to mammals. This milk contains "lactates," which are extremely nutritious substances that are rich in protein (dense crystal), carbohydrates, amino acids, and good fat. Because this milk has more than three times the calorie content of buffalo milk and good nutritional value, some researchers also propose that it can be regarded as a complete food. It is also claimed that because crystals are extremely stable and can make excellent protein supplements, it may be possible to produce them in large quantities (Kendell Wood, 2016).

*G. Others*

➢ *Spider*

*Cyriopagopus altostratus* or *Haplopelma albostriatum* is known as the tasty spider or Thailand Zebra Leg tarantula. This species of spider can be found in Myanmar, Thailand, and Cambodia (Megsy, 2019).

## VI. NUTRIENT VALUE OF INSECTS

The nutritional content of edible insects varies significantly, in part due to the vast number of species; even within the same class of edible insect species, values may differ based on the insect's developmental stage, particularly in species that exhibit a complete metamorphosis, called holometabolous species, like ants, bees, and beetles), habitat, and diet (Table 3 & 4). As with most foods, the nutritional content is also affected by how they are prepared and processed (e.g., drying, boiling, or frying) before they are eaten; for example, insects constitute 5-10 percent of the protein consumed in some African communities.

*A. Carbohydrates*

The calorie value of edible insects is determined by their composition, especially the amount of fat. The energy content of larvae or pupae is often higher than that of adults. In contrast, insect species with lots of protein have less energy (Table 5). Ramos-Elorduy *et al*. examined 78 different species of insects in their 1997 study and concluded that each one had a calorific value between 293 and 762 kcal per 100 g of dry mass.

*B. Proteins*

Protein is an essential constituent of our diet, and it is necessary to consume a daily amount of protein. Edible insects contain more protein than livestock. Xiaoming *et al.* (2010) reported the protein content of 100 insect species belonging to different orders. They reported that the protein content ranged between 13% and 77% of dry matter with considerable variation both at the order and at the level of insect order. Bukkens (1997) reported that the protein content in mopane caterpillars was lower when dry-roasted at 48% than when dried at 57%. In termites, protein content was at 20% in the raw form but increased to 32% and 37% when fried and smoked, respectively, and this was attributed to changes in water content. Given the high protein content in insects, inclusion in the diet can improve the intake of animal-based proteins. Protein content in edible insects varies from 35.3% in termites (Isoptera) to 61.3% in crickets, grasshoppers, and locusts (Orthoptera) on a dry matter basis (Table 6).

In addition, the protein level of insects varies with different metamorphic stages (Ademolu *et al*., 2010). Adults have a higher protein concentration compared to their earlier developmental stages. The variation of protein in the metamorphic stages of variegated grasshopper (*Zonocerus variegates*) is summarized in Table 7 (Ademolu *et al*., 2010).

*C. Fats*

The macronutrient with the highest energy is fat. Fat constitutes ten to sixty percent of the dry substance of the edible insects. It is more than in adults during the larval stage (Xiaoming *et al*., 2010). Among the insects, caterpillars have the most amount of fat. The bug has fat in the form of 80% triacylglycerols and less than 20% phospholipids. The witchetty grub is one of the edible insect species with a high-fat content (38 percent dry weight). These are rich in oleic acid, which is an omega-9 mono-unsaturated fatty acid (Table 8) (Naughton *et al*., 1986). mainly to the *Xyleutes* species cossid moth larvae, which are known to feed on the river red gum roots (*Eucalyptus camaldulensis*) and live 60 cm underground. They are high-protein, high-fat delicacies sought by the Aborigines and can be served raw or lightly fried in hot ashes. When prepared, the exterior of the witchetty grub turns crispy as roast chicken, its inner part turns bright yellow and tastes like almonds.

*D. Amino Acids*

Cereal proteins, which are the staple food in most parts of the world, sometimes have low lysine content and sometimes lack the amino acids tryptophan (maize, for example) and threonine. These amino acids are highly prevalent in some insect species. For example, the lysine amino acid scores of palm weevil larvae and some caterpillars of the Saturniidae family are greater than 100 mg per 100 g

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of pure protein (Bukkens, 2005). The species and orders of edible insects have quite different amino acid compositions. However, the World Health Organization (WHO, 2007) reports that, on average, the amino acid composition of edible insects reported in the literature satisfies the amino acid requirements of human adults (in mg/g protein) for methionine (16 mg/g protein) and methionine + cysteine (22 mg/g protein), with one exception (flies) for cysteine (6 mg/g protein). According to WHO (2007), most edible insects meet the essential amino acids needed for human nutrition except in the order Hemiptera, which is low in isoleucine, lysine, phenylalanine + tyrosine, and valine. The order Diptera is low in leucine and cysteine. For instance, some species contain relatively high levels of tryptophan, lysine, and threonine while others contain relatively high levels of phenylalanine + tyrosine (Rumpold & Schlüter, 2013).

### *E. Vitamins*

According to Balinga *et al.* (2004), insects are rich in riboflavin, pantothenic acid, and biotin. Folic acid is also present in high quantities in locusts (Orthoptera), grasshoppers, crickets, and beetles and their larvae (Coleoptera). Nevertheless, regarding the vitamin consumption standards of FAO, insects are generally not a good source of vitamin A, vitamin C, niacin, and, in most cases, thiamin and vitamin (E. Schlüter and Rumpold, 2013). Edible insects contain riboflavin in concentrations ranging from 0.11 to 8.9 mg/100g. Larvae of the yellow mealworm beetle *T. molitor* contain a high concentration of vitamin B12 (0.4µg per 100g). Certain butterfly caterpillars, including *Imbrasia oyemensis* and *Imbrasia epimethea*, were shown to have retinol and β-carotene, with 32-48 µg of retinol in each. Except for *Dorsophila melanogaster*, most of the insect species analyzed had vitamin E levels in the very low range (6-16 mg/kg DM). Crushed and freeze-dried silkworm powder from *Bombyx mori* also contains a very substantial concentration of vitamin E, amounting to about 9.65 mg per 100 g.

### *F. Minerals*

It is widely accepted that diet influences the micronutrient content of edible insects. 85 edible microcompositions were summarized (Rumpold and Schlüter, 2013). Edible insects can provide substantial amounts of copper, iron, magnesium, manganese, phosphorus, selenium, and zinc. Edible insects can be interesting when it comes to the nutritional value of minerals such as iron, zinc, potassium, salt, calcium, phosphorus, magnesium, manganese, and copper. For example, the palm weevil larvae *Rhynchophorus phoenicis* (26.5 mg per 100 g of dry matter) and *L. migratoria* have a high iron content (8–20 mg per 100 g of dry matter), while *Gonimbrasia belina* has a high iron content (31-77 mg per 100 g of dry matter) and zinc content (14 mg per 100 g of dry matter) (Table 9). (Bukkens, 2005).

## VII. EDIBLE ECONOMIC PRODUCTS FROM INSECTS

- **SOR-Mite** (protein-enriched sorghum porridge). Depending on regional tastes, the fermented combination can be eaten as porridge for breakfast, lunch, or dinner. It is simple to get both raw components locally as well (Institute of Food Technologists, 2011).
- **Termite crackers and muffins:** Crackers, muffins, meatloaf, and sausages from termites and lake flies were found to have a very high marketing potential in Kenya (Ayieko *et al*., 2010).
- **Buqadilla:** A new snack called buqadilla is being developed for the Dutch market. Chickpeas and fewer mealworms (40%) constitute this spicy Mexican leguminous food product.
- **Crikizz:** Another European product that is insect-based is Crikizz.

➢ *Advantages of Entomophagy*

- Insects require less space for farming (FAO, 2011).
- No direct competition between insects and food intended for human consumption.
- High reproduction rates and demand exceed supply.
- Potential for high financial returns and quick cash flow.
- Insects are nutrient-dense, contributing positively to human nutrition.
- Efficient in converting feed into protein.
- Easy to raise and maintain, with minimal training required.
- Portable and adaptable.
- Good source of nutrition.
- Less water is required compared to traditional livestock.
- Generally disease-free and healthy.
- New policies and regulations must be developed to ensure that the nutritional value of insects is preserved.
- Nutrients are digested very fast, and bioavailability is very high.
- Insects have a high feed conversion efficiency, which has a positive impact on the environment. For instance, crickets need 2 kg of feed to gain 1 kg of body weight.
- Helps to reduce environmental contamination, since it can be reared on organic waste and even human and animal wastes.
- Insect farming takes much less space and water than cattle raising.
- Insects release much fewer greenhouse gases and ammonia than pigs or calves.
- Insect farming requires minimal land for its farming hence very sustainable for food production.

➢ *Disadvantages of Entomophagy*

- Insects treated with pesticides can be unsafe for consumption by humans.
- Herbicides can bioaccumulate in insects, posing potential health risks.

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- The California Department of Health Services reported cases of lead poisoning from eating chapulines in November 2003.
- There is a risk of adverse allergic reactions to insect-based foods.

## VIII. REGULATIONS AND FOOD SECURITY

The use of insects as food and feed is governed in part by regulatory norms. The use and trade of insects in food and feed chains can be directly impacted by the absence of particular laws and standards, and the development of the edible insect industry, particularly in industrialized nations, may be severely hampered (Huis *et al*., 2013). The Lao PDR delegation proposed the creation of a regional Codex food standard for edible crickets and cricket products in a project document presented at the 17th FAO/WHO Codex Alimentarius Coordinating Committee for Asia (CCASIA) in 2010. By ensuring fair practices in the exchange of goods (edible insect products) on the international market from the Lao PDR, this standard would assist in safeguarding consumer health.

### *A. Biological Hazards*

Based on phylogenetic differences, entomopathogenic, or microbial pathogens of insects, are innocuous to humans and animals. Nevertheless, insects can become a vector for a range of microorganisms that are harmful to human and animal health, mainly in circumstances where hygienic conditions are not under proper control (Kooh *et al*., 2019). Although there seems to be little chance of zoonotic pathogen transmission to humans through edible insects, more research is needed to fully understand the possible dangers for food and feed (Dicke *et al*., 2020). Insects have a diverse microbiota that is found in many other anatomical regions apart from the stomach. This microbiome consists of microbes that are either naturally occurring in an insect's life cycle or that are added during farming and processing (EFSA Scientific Committee, 2015).

➢ *Bacteria*

According to the EFSA Scientific Committee (2015), several species of bacteria have been associated with farmed edible insects. They are members of the Enterobacteriaceae family and certain species from the genera *Staphylococcus, Streptococcus, Bacillus, Pseudomonas, Micrococcus, Lactobacillus, Erwinia, Clostridium,* and *Acinetobacter*. Another major food safety issue is the endospore-forming bacteria in edible insects. Because these bacteria are heat-resistant, they may survive the most common processing techniques for edible insects, like boiling, deep-frying, and drying (Martinez *et al*., 2007).

➢ *Virus*

Edible insects pose negligible risks regarding the transmission of foodborne viruses like hepatitis A, hepatitis E, or norovirus. Insect breeding facilities, however, can easily expose an insect production system to introducibles through substrates, including all viruses that target vertebrates (Vandeweyer *et al*., 2020). Arthropod-borne arboviruses, transmitted to humans through edible insects, include West Nile disease, Rift Valley fever, chikungunya, and hemorrhagic fever, among others, and their potential incidence and mode of transmission remain to be studied further (EFSA Scientific Committee, 2015).

➢ *Fungi*

The foodborne fungus can result in food spoiling by diminishing the nutritional value of the products and deteriorating the quality of the products. Some fungi are harmful to man and can produce mycotoxins, classified as chemical dangers. Mold species of *Aspergillus, Alternaria, Cladosporium, Fusarium, Penicillium, Phycomycetes*, and *Wallemia* and yeast, including relatives of *Tetrapisispora, Candida, Pichia*, and *Debaryomyces*, are associated with the microbiota on the surface of edible insects or in the gut and have the potential to be dangerous (Rumpold and Schlüter, 2013, Kooh *et al*., 2019).

➢ *Mycotoxins*

Edible insects have been discovered to contain several mycotoxins, though not in levels that raise public health concerns (De Paepe *et al*., 2019). According to Charlton *et al*. (2015), dried housefly (*Musca domestica*) larvae contained beauvericin, enniatin A, and enniatin A1 at levels considered non-toxic. However, aflatoxins have been found in some commercial lots of "ready-to-eat" mopane worms in Botswana, ranging up to 50 µg/kg. This highlights the importance of proper handling, processing, and storage of edible insects in a sanitary manner (Mpuchane *et al*., 2000). According to Camenzuli *et al*. (2018), the larvae of black soldier flies and lesser mealworms did not accumulate any of the four mycotoxins-aflatoxin B1, deoxynivalenol, zearalenone, and ochratoxin A-that were added to the insect substrates at levels significantly higher than the maximum limits set by the European Commission (EC). Concentrations of mycotoxins and metabolites in lesser mealworms were below the corresponding LOQ (Camenzuli *et al*., 2018). The available data indicate that mycotoxin metabolism may vary between species, producing metabolites that have not yet been examined.

### *B. Chemical Hazards*

Agricultural waste-raised insects may be subjected to pesticides, mycotoxins, and other chemical risks such as dioxins and hazardous metals.

➢ *Pesticide*

Yellow mealworms can accumulate, degrade, enantiomerize, and expel a variety of chiral fungicides, including metalaxyl, myclobutanil, diniconazole, epoxiconazole, and benalaxyl, according to research on pesticide feeding (Liu *et al*., 2013). Housefly samples have been shown to contain chlorpyrifos, however at levels that are not dangerous (Charlton *et al*., 2015). At edible insect farms, controlled feeding may reduce the dangers of pesticide residues.

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➢ *Toxic Metals*

Several variables, such as the kind of metal, insect species, growth stage, substrates utilized, and environmental contamination, are linked to the accumulation of hazardous metals by edible insects (EFSA Scientific Committee, 2015). In the Mexican state of Oaxaca, the local term for dried grasshoppers were found to contain high amounts of lead. According to Handley *et al.* (2007), this was one of the causes of high blood lead levels during a lead poisoning outbreak among migrants in Monterey County, California, in the United States.

➢ *Trace metals*

The amounts of traces of minerals (iron, manganese, magnesium, and copper) obtained by taking certain edible insect species have also to be thought well. Yellow mealworms have been known to accumulate significantly high levels of selenium (Hogan and Razniak, 1991).

### C. *Other Substances*

Gaylor *et al.* (2012) documented the bioaccumulation of polybrominated diphenyl ether (PBDE) from household crickets (Acheta domesticus) and polyurethane foams, which are frequently present in consumer goods. Additionally, edible insect samples from Belgium have been shown to contain tributylphosphate (Poma *et al.*, 2017). Hexabromocyclododecane (HBCD) is quickly expelled by mealworms in their frass, according to feeding trials conducted by Brandon *et al.* (2020). Poma *et al.* (2019) discovered that edible insects have modest levels of contamination (within legal limitations) from a variety of chemical compounds, including plasticizers, halogenated flame retardants, persistent organic pollutants, and organophosphorus flame retardants.

- **Dioxins:** The buildup of dioxins (polychlorinated dibenzo dioxins and dibenzofurans, PCDD/PCDF) and dioxin-like polychlorinated biphenyls (PCB) in edible insects is not well understood currently.
- **Mineral oils:** Black soldier flies have been found to contain high concentrations of mineral oil hydrocarbons (MOH) (van der Fels-Klerx et al., 2020).
- **Histamine:** Chomchai and Chomchai (2018) hypothesized that eating fried insects (such as silkworm pupae or grasshoppers) was the cause of histamine toxicity, also known as scombroid poisoning, which has been documented in Thailand.
- **Potential for allergies:** Due to cross-reactivity, customers who are sensitive to crustaceans may be in danger from eating foods based on insects (Srinroch et al., 2015). The double-blind, placebo-controlled food challenge experiments by Broekman et al. (2016) have confirmed that patients with shellfish allergies experience severe allergic reactions to yellow mealworms.

### D. *Physical Risks*

Because dehydrated insects include hard components like stings, wings, rostrums, and spines on shinbones that can cause physical obstructions, eating them whole can present physical risks.

## IX. INTERNATIONAL STANDARDS

➢ *Codex Alimentarius*

The Codex Alimentarius is a set of global standards, regulations, and codes of conduct designed to preserve consumer health and promote ethical behaviour in the global food trade. Since the World Trade Organization's Agreement on Sanitary and Phytosanitary Measures recognizes the Codex as the norm for food safety, Codex standards have a significant impact on how trade disputes are settled. A proposal to create a Codex regional standard for edible house crickets *(A. domesticus*) and cricket-based products was reviewed by the 17th FAO/WHO Codex Alimentarius Coordinating Committee for Asia (2010) (CX/ASIA 10/17).

## X. REGIONAL AND NATIONAL LEGISLATION

➢ *The European Union*

EU 2015/2283, a novel food regulation suggests that before releasing an insect-based product into the market, a particular application must be submitted to the European Commission (EC), followed by a scientific review by EFSA. Among the applications being considered are flours derived from migratory locusts (*L. migratoria*), yellow mealworms (*T. molitor*), and house crickets (*A. domesticus*). EU 2015/2283 is a novel food regulation implying that before releasing an insect-based product into the market, a particular application must be submitted to the European Commission (EC), followed by a scientific review by EFSA. If the edible insects of interest are recognized as traditional foods from third countries with a history of safe use (25 years of continuous use), insect food business owners in the EU may be able to get their goods approved as "novel foods." As long as no safety concerns are brought up by EFSA or other EU member states within four months of the EC submitting a valid and comprehensive notification to the member states and EFSA, such products may be put on EU markets (EFSA NDA Panel, 2016).

➢ *United States of America*

The Food and Drug Administration (FDA) of the United States of America oversees regulating the use of edible insects, insect parts, or insect derivatives in food. Therefore, edible insects and food products made from insects must abide by the Federal Food, Drug, and Cosmetic Act (FD&C Act) and its accompanying laws. For instance, FDA approval is required for the use of insects and insect derivatives as food additives or as colorants.

➢ *Asia*

In several Asian nations, eating insects has a long history. Insect farming is practiced in Cambodia, the Lao People's Democratic Republic, Malaysia, the Republic of Korea, Thailand, and Vietnam, among other nations (Durst and Hanboonsong, 2015; Reverberi, 2020). In the majority of these nations, there are no particular rules governing the use of insects as food; however, in Malaysia and Thailand, for example, laws on food safety and quality also frequently regulate the use of insects. The government of the Republic of Korea has put in place several legislative measures to assist

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the insect sector, which will benefit farmers and the country's economy financially.

## XI. CONCLUSION

Since edible insects are high in proteins, lipids, vitamins, and minerals and offer substantial economic and environmental advantages, entomophagy presents a solution to the growing global demand for nutrition. Many people throughout the world use it as an alternative food source because of its high nutrient, vitamin, and mineral content, which provides many health benefits in addition to being a valuable source of protein.

## PROSPECTS

By becoming an essential component of the daily diet, edible insects help address global issues, especially food instability and hunger. Insect-based products are expected to soon be available in supermarkets as environmental benefits become more widely recognized and technological developments boost the efficiency of insect farming. India may develop into a center for insect bioresources in the future due to its tropical climate. Edible insects might be embraced as a vital dietary component by Indians and people from other countries, addressing urgent global challenges like food scarcity and hunger.

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**TABLES**

Table 1: Consumption of Insects in Different Countries in the World

| Country | Consumption of Insect |
|---|---|
| South America | Butterfly, grasshoppers, crickets, cicadas, ants, flies, bees and wasps |
| Colombia | Giant queen ants, palm grubs and caterpillars |
| Asia | Grasshoppers, crickets, silkworm pupa, dragonflies, termites, and beetles |
| Thailand | Giant water beetle |
| Africa | Caterpillars, mopane worm, termites and locusts |
| Pacific islands | Pupua, Palmgrubs, grasshoppers, crickets, stick insects, mantids and locust. |
| Australia | Honey ants, grubs, moth, bardigrubs and cerambycid beetle |
| China | Ants, Silkworm pupua, fly larvae, cricket, blattaria, termites |
| India | Termite, dragon fly, grasshopper, ants, eri and mulberry silkworm, honey bee, cricket |

Source: Insects Cambridge world history of food, Shantibala, 2012

Table 2: Edible Insects Consumed in Different States of India

| Insect name | State | Edible form |
|---|---|---|
| Diving beetle | Manipur | Roasted fried and curry |
| Water scavenger | North east states | Roast forms of larva and adult |
| Asian long horned beetle | North east states | Roasted and fried forms |
| Dragon flies | North east states | Roasted and fried body |
| Muga, silk worm | Tribals of Assam | With edible herbs and spices |
| Red ant | Bodo tribals in north east | Chutney |
| Crickets | North east states | Fried body |
| grasshopper | North and south tribals | Fried and edible with herbs |
| Termite | South states | Consumed as dried, roasted |

Source: Shantibala *et al.,* 2012

Table 3: General Nutritional Value of Insects g/100g Dry Weight

| S.no | Species (Order) | Protein | Fat | Mineral | Carbohydrate | Energy Kcal |
|---|---|---|---|---|---|---|
| 1 | Caterpillar (Lepidoptera) | 15-60 | 7-77 | 3-8 | 2-29 | 323-450 |
| 2 | Beetles (Coleoptera) | 21-54 | 18-52 | 1-7 | 6-23 | 138-447 |
| 3 | Cricket (Orthoptera) | 8-25 | 34 | 2-17 | 4-11 | 120-323 |
| 4 | Bees (Hymenoptera) | 1-81 | 4-62 | 0-6 | 1-6 | 416-655 |
| 5 | Cockroach (Blattodea) | 20-23 | 6-8 | 1-2 | 5-7 | 200-220 |
| 6 | Spider (Arachnida) | 63 | | 9-10 | 0.5-1 0 | 320-390 |

Source: Verkerk et al. (2007), van Huis et al. (2013), Belluco et al., (2013) and Xiaoming et al., (2010).

Table 4: Nutrients Composition of Different Insects

| Nutrients and energy | Cockro -aches | Beetles | flies | beetles | Bees, wasps, ants | termites | Cater pillars | Dragon flies | Grasshoppers, locusts |
|---|---|---|---|---|---|---|---|---|---|
| Data amount | 3 | 45 | 6 | 27 | 45 | 7 | 50 | 2 | 51 |
| Protein % | 57.30 | 40.69 | 49.48 | 48.33 | 46.47 | 35.34 | 45.38 | 55.23 | 61.32 |
| Fat % | 29.90 | 33.40 | 22.75 | 30.26 | 25.09 | 32.74 | 27.66 | 19.83 | 13.41 |
| Fiber % | 5.31 | 10.74 | 13.56 | 12.40 | 5.71 | 5.06 | 6.60 | 11.79 | 9.55 |
| Nitrogen free extract % | 4.53 | 13.20 | 6.01 | 6.08 | 20.25 | 22.84 | 18.76 | 4.63 | 12.98 |
| Ash % | 2.94 | 5.07 | 10.31 | 5.03 | 3.51 | 5.88 | 4.51 | 8.53 | 3.85 |
| Energy Kcal/100g | | 490.30 | 409.78 | 478.99 | 484.45 | | 508.89 | 431.33 | 426.25 |

Source: Rumpold and Schlüter (2013)

Table 5: Energy Obtained from Different Insects

| Location | Common name | Scientific name | Energy (kcal/100g fresh weight) |
|---|---|---|---|
| Australia | Australian plague locust, raw | *Chortoicetes terminifera* | 499 |
| Australia | Green (weaver) ant, raw | *Oecophylla smaragdina* | 1272 |
| Canada, Quebec | Red-legged grasshopper, whole, raw | *Melanoplus femurrubrum* | 160 |
| US, Illinois | Yellow mealworm, larva, raw | *Tenebrio molitor* | 206 |
| US, Illinois | Yellow mealworm, larva, raw | *Tenebrio molitor* | 138 |
| Ivory coast | Termite, adult, dewinged, dried, flour | *Macrotermes subhyalinus* | 535 |
| Mexico, Veracruz state | Leaf-cutter ant, adult, raw | *Atta mexicana* | 404 |
| Mexico Hidalgo state | Honey ant, adult, raw | *Myrmecocystus melliger* | 116 |
| Thailand | Field cricket, raw | *Gryllus bimaculatus* | 120 |
| Thailand | Giant water bug, raw | *Lethocerus indicus* | 165 |
| Thailand | Rice grasshopper, raw | *Oxya japonica* | 149 |
| Thailand | Grasshopper, raw | *Cyrtacanthacris tatarica* | 89 |
| Thailand | Domesticated silkworm, pupa, raw | *Bombyx mori* | 94 |
| The Netherlands | Migratory locust, adult, raw | *Locusta migratoria* | 179 |

Source: FAO, 2012

Table 6: Range of Proteins Obtained from Different Insects

| Insect order | Stage | Protein range(%) |
|---|---|---|
| Coleoptera | Adults and Larvae | 23-66 |
| Lepidoptera | Pupae and Larvae | 14-68 |
| Hemiptera | Adults and Larvae | 42-74 |
| Homoptera | Adults, larvae and eggs | 45-57 |
| Hymenoptera | Adults, pupae, larvae and eggs | 13-77 |
| Odonata | Adults and Naiad | 46-65 |
| Orthoptera | Adults and Nymph | 23-65 |

Source: Xiaoming *et al*., 2010

Table 7: Total Proteins Presents in Different Instar of Variegated Grasshopper, *Zonocerus variegatus*

| Instar: | Gram protein/100 g fresh weight |
|---|---|
| 1$^{st}$ | 18.3 |
| 2$^{nd}$ | 14.4 |
| 3$^{rd}$ | 16.8 |
| 4$^{th}$ | 15.5 |
| 5$^{th}$ | 14.6 |
| 6$^{th}$ | 16.1 |
| Adult | 21.4 |

Table 8: Fat Content and Randomly Selected Fatty Acids of Several Edible Insect Species Consumed in Cameroon

| Edible Insect species | Fat content (% of dry matter) | Composition of main fatty acids (% of oil content) | SFA, MUFA or PUFA |
|---|---|---|---|
| African palm weevil (Rhynchophorus phoenicis) | 54% | Palmitoleic acid (38%)<br>Linoleic acid (45%) | MUFA<br>PUFA |
| Edible grasshopper (Ruspolia differens) | 67% | Palmitoleic acid (28%) Linoleic acid (46%)<br>α-Linolenic acid (16%) | MUFA<br>PUFA<br>PUFA |
| Variegated grasshopper (Zonocerus variegates) | 9% | Palmitoleic acid (24%)<br>Oleic acid (11%)<br>Linoleic acid (21%)<br>α-Linolenic acid (15%)<br>γ-Linolenic acid (23%) | MUFA<br>MUFA<br>PUFA<br>PUFA<br>PUFA |
| Termites (Macrotermes sp.) | 49% | Palmitic acid (30%)<br>Oleic acid (48%)<br>Stearic acid (9%) | SFA<br>MUFA<br>SFA |
| Saturniid caterpillar (Imbrasia sp.) | 24% | Palmitic acid (8%)<br>Oleic acid (9%)<br>Linoleic acid (7%) | SFA<br>MUFA<br>PUFA |

| | | | |
|---|---|---|---|
| | | α-Linolenic acid (38%) | PUFA |
| Note: SFA – saturated fatty acids; MUFA and PUFA – mono and poly unsaturated fatty acids. | | | |

Source: Womeni et al., 2009.

Table 9: Recommended Intake of Essential Minerals Per Day Compared with the Mopane Caterpillar (*Imbrasia belina*)

| Mineral | Intake Recommendation for 25-year-old Males (mg per day)* | Mopane Caterpillar (mg per 100 g dry weight) |
|---|---|---|
| Potassium | 4700 | 1032 |
| Chloride | 2300 | – |
| Sodium | 1500 | 1024 |
| Calcium | 1000 | 174 |
| Phosphorus | 700 | 543 |
| Magnesium | 400 | 160 |
| Zinc | 11 | 14 |
| Iron | 8 | 31 |
| Manganese | 2.3 | 3.95 |
| Copper | 0.9 | 0.91 |
| Iodine | 0.15 | – |
| Selenium | 0.055 | – |
| Molybdenum | 0.045 | – |
| Note: * Dietary reference intakes (DRIs): recommended dietary allowances and adequate intakes, minerals, Food and Nutrition Board, Institute of Medicine, National Academies. | | |

Source: Bukkens, 2005.

**FIGURES**


Fig 1: Recorded Number of Edible Insect Species, by Country
Source: Centre for Geo Information, Wageningen University, based on data compiled by Jongema, 2012.

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Fig 2: Map of India Showing where the Entomophagy has been in Practice

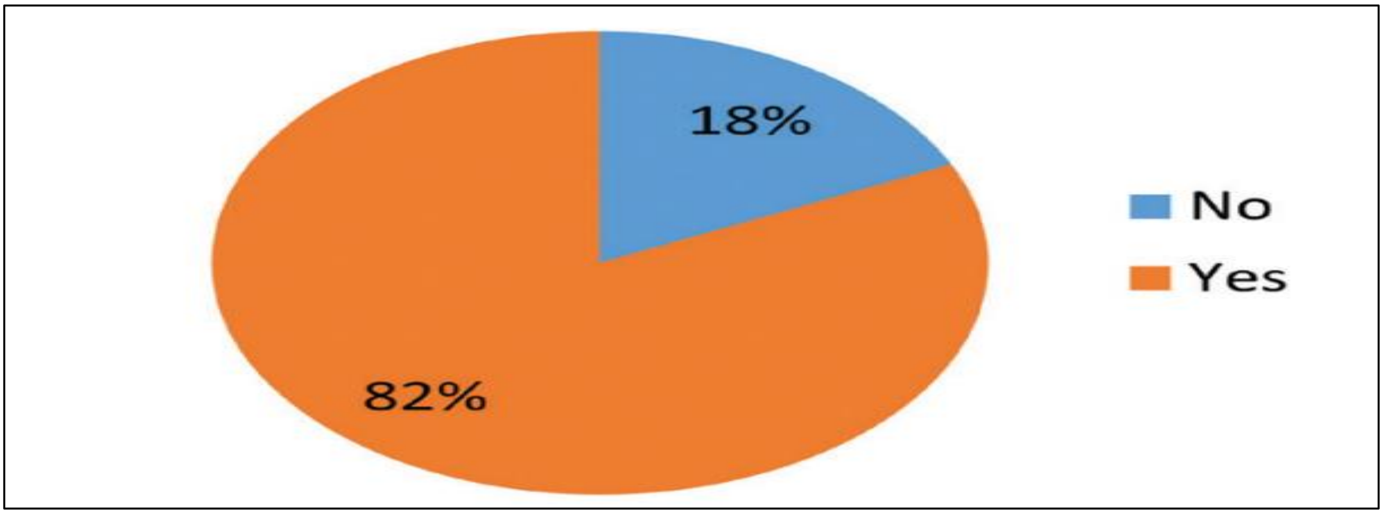


Fig 3: Familiarity with Entomophagy

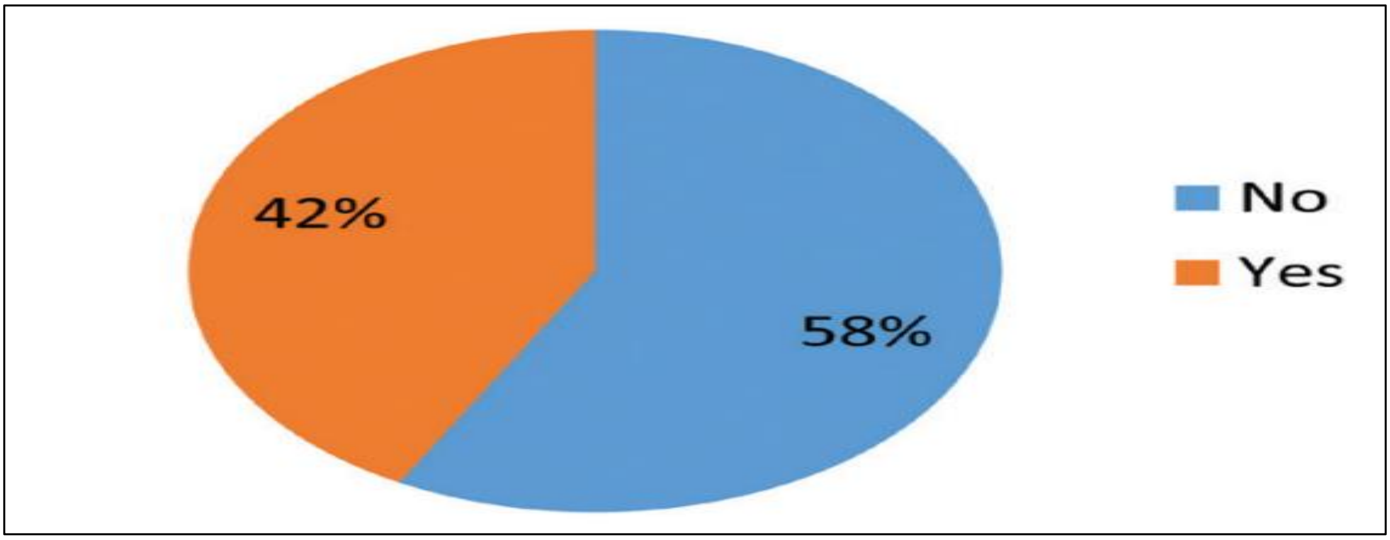


Fig 4: Experience with Entomophagy

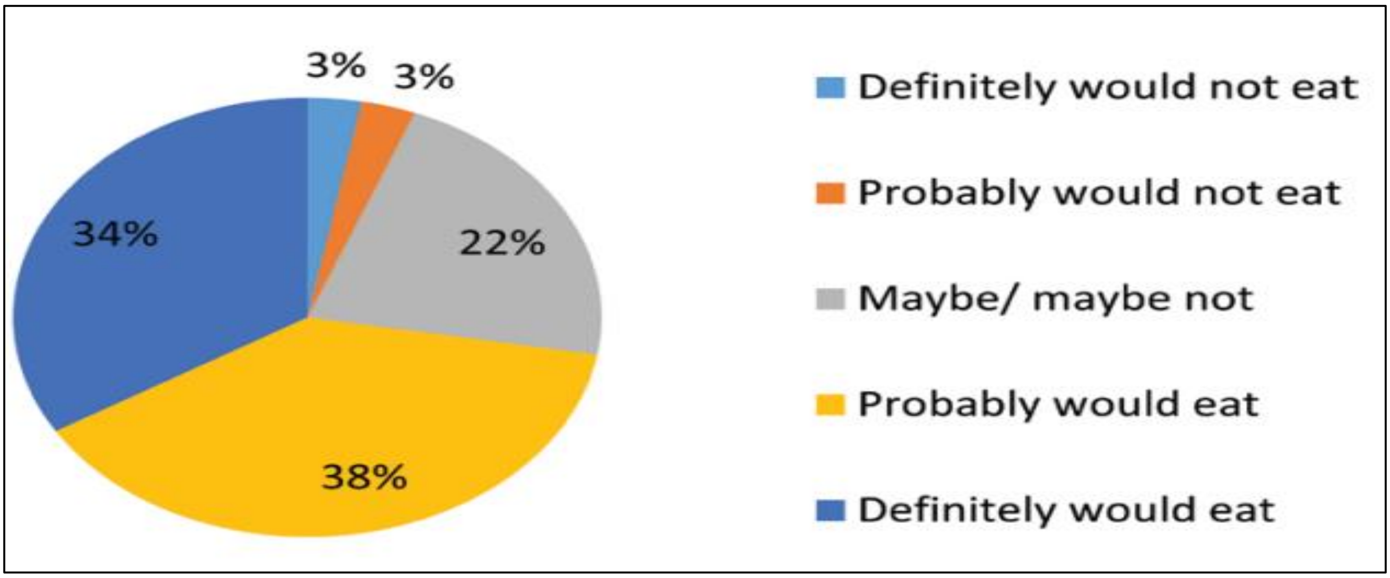


Fig 5: Future Willingness to Consume Edible Insects

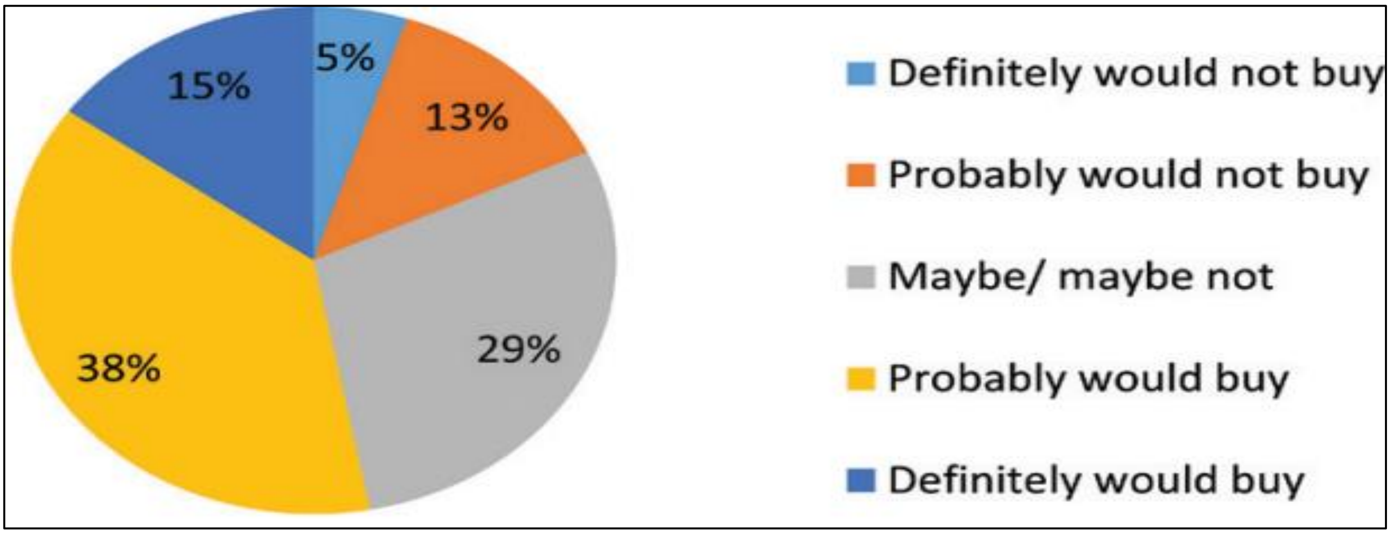


Fig 6: Future Willingness to Purchase Edible Insect Products

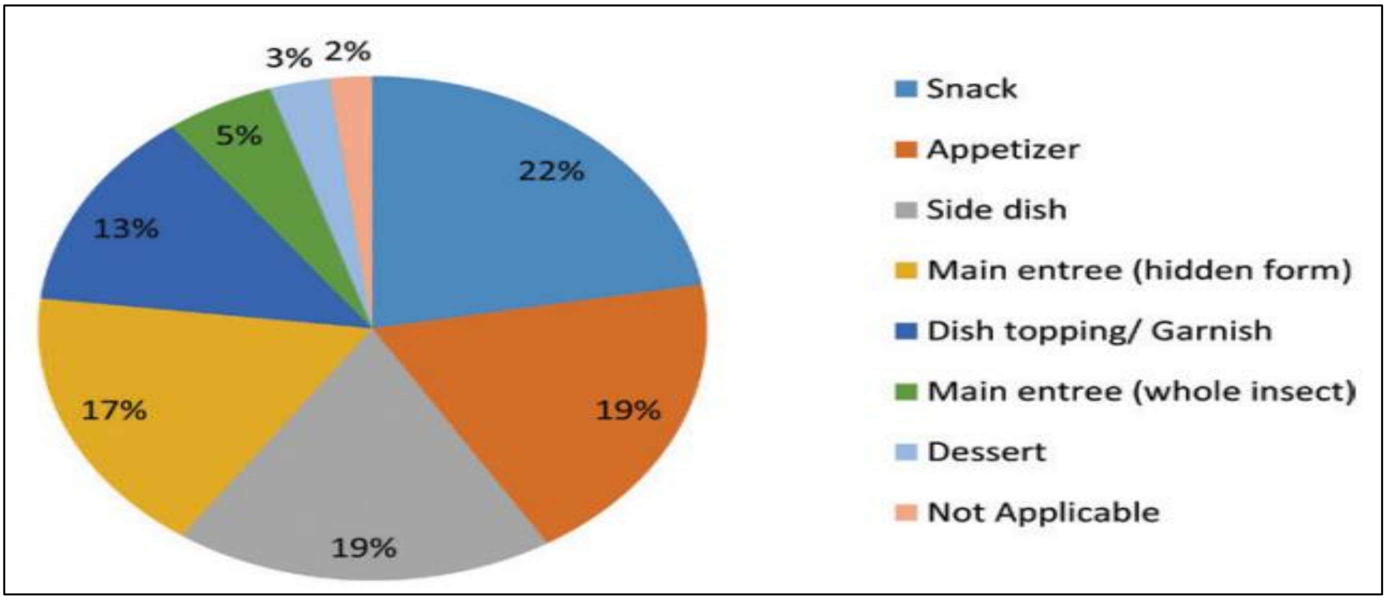


Fig 7: Perception of Edible Insects in the Diet

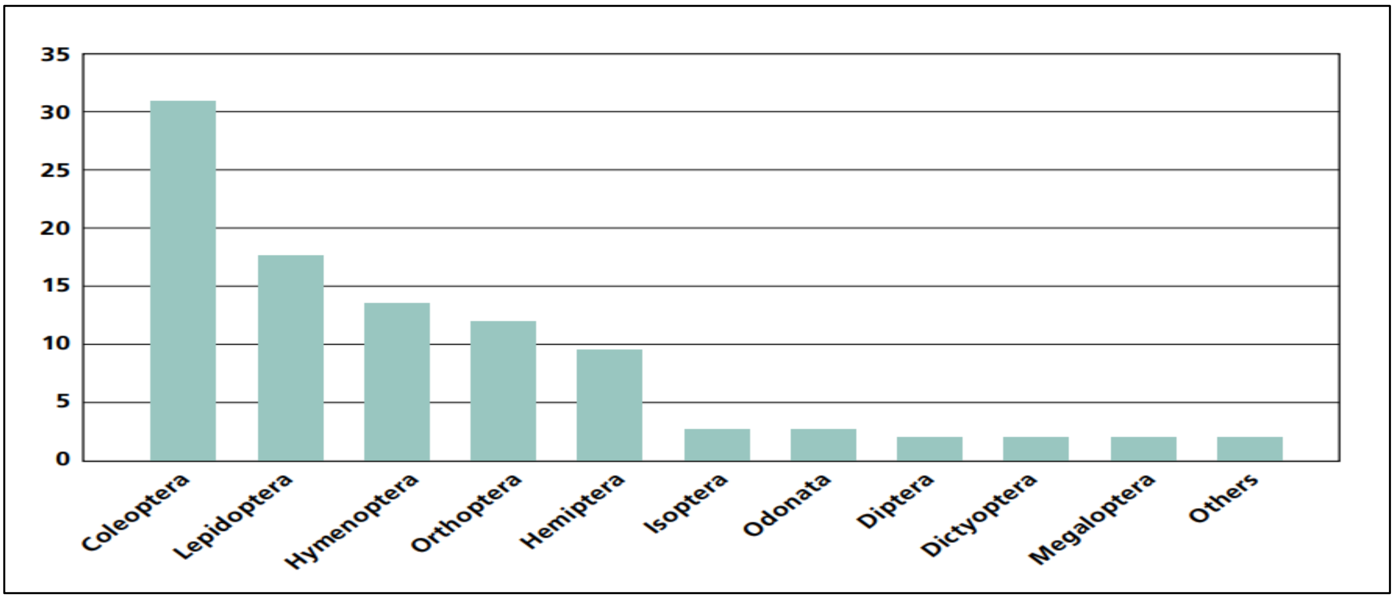


Fig 8: Number of Insect Species, by Order, Consumed Worldwide
Source: Jongema, 2012