Czech University of Life Sciences Prague

Faculty of Agrobiology, Food and Natural Resources

Department of Microbiology, Nutrition and Dietetics (FAFNR)

Insect as human food and the consumers' health risk

Bachelor thesis

Bsc. Agriculture and Food

Supervisor: Sarvenaz Khalili Tilami, Ph.D.

Author: Temwani Kaoma

DECLARATION

I declare that the bachelor thesis ''Insect consumption and the health risks'' is my own work and all the sources citied are listed in the Bibliography. This thesis has not been submitted or accepted for any degree qualification at this or any university.

In Prague on date of submission………………………………………………………………

. Temwani Kaoma………………………..

ABSTRACT

Entomophagy, the consumption of insects, is promoted as a healthy, sustainable source of protein for humans and animals. This study was aimed at exploring the consumption of insect as an attractive alternative source to meet the nutritional and food demand for the growing population. In contrast to the several advantages of entomophagy, there is little known on its risk assessment, level of consumption and safety of edible insects to support the marketing and protect consumers therefore, the study focused on the possible health risks associated with their consumption. The following were the study objectives: To assess the availability and accessibility of insects as human food, to explore the nutritional value of insects as human food and to investigate the possible health risks of edible insects to the consumers.

Literature reviewed show that insect consumption can present a nutritional opportunity, possessing a high content of protein and vital micronutrients. It was also established that insects have an insignificant negative environmental impact than most traditional Western forms of animal protein. Insects could make valuable economic and nutritional contributions to numerous foods or feed systems. Various literature support the consumption of edible insects as a valuable source of protein.

The study also concluded that edible insects are readily available with over 1, 900 species of edible insects identified and have high nutrient content that surpasses traditional sources of protein like pork, poultry and beef and contain valuable nutritional components such as protein and fiber. Despite the availability and nutritional value of edible insects they may pose a health risk to consumers. The health risks range from allergy to endogenous factors, presence of anti-nutrients, allergens in insects and toxic interference from the feed that these insects may be feeding or are fed on among others. Liabilities of entomophagy include the possible content of allergenic and toxic substances as well as antinutrients and the presence of pathogens. The study therefore recommends that further studies needs to be conducted to assure the safety of insect consumption, more studies needs to be conducted in a natural and real environment with real participants that consume insects in order to better inform the study in addition to, evaluating the nutritional and sensorial attributes Relevant bodies such as the Food and Agriculture Organisation (FAO) need to initiative deliberate studies on the topic so as to assure food safety and also to assure that the alternative protein source is developed further. There is also need for more studies on the nutritional potential of edible insects and proper processing and decontamination methods to ensure food safety.

ACKNOWLEGDEMENTS

I am highly indebted to my supervisor Dr. Sarvenaz Khalili Tilami from the Czech University of life sciences for the kindness, encouragement and academic guidance. The insights and corrections would not have been more valuable. For this is am grateful and will remain indebted.

I would like to thank my course coordinator, Ms. Jitka Klouchkova for helping me and instructing me during my journey in this course. I would also like to thank the University for all the knowledge and experiences that I have gained during my study period.

SUMMARY

Entomophagy (insect consumption) has been found to be a growing trend among communities. Increasing world population resulting in the increase for demanding food globally coupled with the rising cost of animal protein coupled with the environmental safety of livestock farming are some of the drivers of the increasing demand of edible insects as an alternative food source. The role of edible insects as novel protein source is increasingly becoming more noticeable thus consuming the raw and processed forms of insect has recently gained increasing attention.

This study investigated the consumption of insects and the safety of this practice to humans. It was found that entomophagy contributes positively to the environment and to the human health and livelihoods. However, there is little known about the risk assessment and safety of edible insects. Therefore, the thesis aimed to assess the health risks associated with their consumption in addition to their potential as food source. In order to extend the existing knowledge, different aspects of entomophagy have been discussed. These include the traditional insect consumption methods and the Western society preference of insect products rather than the whole insects.

Numerous literature support the consumption of edible insects as valuable source of protein. Edible insects are readily available with over 1, 900 species of insects being identified worldwide and edible insects have high nutrient content that surpasses traditional sources of protein. Despite the availability and nutritional value of edible insects, they may pose a health risk to consumers. Further studies needs be conducted to assure food safety in addition to the nutritional potential and proper processing of edible insects.

Key Words:

Entomophagy, consumption, edible insects, health risks, protein source

DEDICATION

This thesis is dedicated to my father and mother who have supported me throughout my education, and to my family for always being there for me and supporting through all times.

Table of Contents

LIST OF FIGURES

CHAPTER 1

1.1 INTRODUCTION

The practice of insect consumption as a type food, often referred as "entomophagy" has gained a lot of interest in both developed and developing countries in recent times (Evans et al., 2015). However, the eggs, larvae, pupae and adults of insects were used in old times as food ingredients by humans (human insectivory), and this culture has continued into modern error. Man was proven to be omnivorous in early development years and ate insects quite extensively. Before people made tools for hunting or farming, insect played a vital role in the human diet. Moreover, people lived mainly in warm areas, where different kinds of insects were available throughout the year. Insects were often a welcome source of protein in the absence of meat (Sponheimer et al., 2005). As mentioned above, entomophagy is not a new habit as it has been practiced for years by many cultures worldwide as a means of providing unique, delicious and nutritious food to the consuming populations.

Today, Entomophagy is traditionally practiced in 130 countries around the world with the African and American continents being the most entomophagous until now. Over 2000 insect species are known to be edible. Worldwide, the most commonly consumed species are beetles, caterpillars, bees, wasps and ants (Ramos-Elorduy et al., 2002). They are followed by grasshoppers, locusts and crickets, cicadas, leafhoppers and bugs, termites, dragonflies, flies and other species. This type of food is considered a popular delicacy a fascinating arrangement of food enrichment. A good example is, in Mexico, chapulines (grasshoppers of the genus Sphenarium) are a most common national meal eaten with beans and beef (Cerritos and Cano-Santana, 2008). In Europe, few countries are practicing entomophagy and often consider it culturally inappropriate or even taboo. The nutritional content of insects is comparable to commonly eaten meats. Due to the drastic growth in the worldwide population and increasing food demands for production of traditional beef, pork and chicken meat, edible insects must be seriously considered as a novel protein sources (Dreon and Paoletti, 2009). In terms of farming conditions, the following insect species could be bred and consumed in the west: house cricket (*Acheta domestica*), Jamaican field cricket (*Gryllus assimilis*), African migratory locust (*Locusta migratoria*), desert locust (*Schistocerca gregaria*), yellow meal worm beetle (*Tenebrio molitor*), super worm (*Zophobas morio*), lesser mealworm (*Alphitobius diaperinus*) western honey bee (*Apis mellifera*) and wax moth (*Galleria mellonella*) (Ramos-Elorduy et al., 2002).

The increase of population growth in the world increases our demand for protein sources, but our available farm space is limited. The United Nations (2020), projected world population to reach 9.8 billion in 2050, and 11.2 billion by 2100, resulting in an additional need for food of half the current needs. Conventional protein sources may be insufficient, which means motivates the need to consider novel sources of proteins which in this case are edible insects (Godfray et al., 2010). In comparison with livestock, insect breeding is more environmentally friendly due its lower greenhouse gas emissions, water pollution and land use (Van Huis et al., 2013). Insects show higher feed conversion efficiency in comparison with mammalian livestock. For instance, the feed conversion of house crickets (A domestica) to be 2 times that of chickens, 4 times higher in pigs and 12 times higher than in cows (Van Huis et al, 013). A fascinating positive aspect of entomophagy is its help towards reducing the use of pesticides. Collection of edible insects that are considered as pests, can contribute to reduced use of insecticides. Moreover, the economic benefits of gathering insects in comparison to the cultivation of plants should also be taken seriously. In Mexico, the gathering of insects for human consumption resulted in a reduction in the quantity of pesticides in agricultural crop production and a decreased financial burden on farmers (Sponheimer et al., 2005; Van Huis, 2015).

1.2 Objectives of the Study

In view of the increased need for alternative sources of protein which edible insects offer and the increase of entomophagy, it is important that studies be conducted to assess insects as human food and the health risks that this possess. This study focused on the edible insects in relation to humans although they are also an alternative source of proteins for livestock.

The objectives of this study were as below:

- To assess the availability and accessibility of insects as human food
- To explore the nutritional value of insects as human food
- To investigate the health risks of edible insects to the consumer

CHAPTER 2

2.2 LITERATURE REVIEW

The literature review provides a review of various literature on the topic. It looks at the entomology in relation to its geography, history and culture. It also highlights the types, characteristics and orders of edible insects. It further looks at how these insects are collected or harvested by the consumers.

2.2.1 Edible Insects: Species and Characteristics

The number of insect species consumed would be an interesting factor to note despite the low acceptability of Western populations to entomophagy. Some argue that there are more than 1900 edible insect species. The following are the species according to their ranking in order of percentage of consumption: *Coleoptera* (beetles), *Lepidoptera* (butterfly and moths), *Hymenoptera* (bees, wasps and ants), *Orthoptera* (grasshoppers and crickets), *Isoptera* (termites), *Hemiptera* (true bugs), and *Homoptera* (cicadas). Of these, 250 insect species are consumed in Africa, 549 in Mexico, 180 in China, and 160 in the Mekong area (Jongema, 2017).

Wasps are one of the most popular insect species in Japan, despite the country not being considered as a tropical country (FAO, 2013). With this said, it can be deduced that the number of insects and insects species consumed as food globally which is quite significant despite Western populations not really embracing insects as part of their diet. The recorded edible insect species by order of consumption worldwide is presented in Figure 2.1.

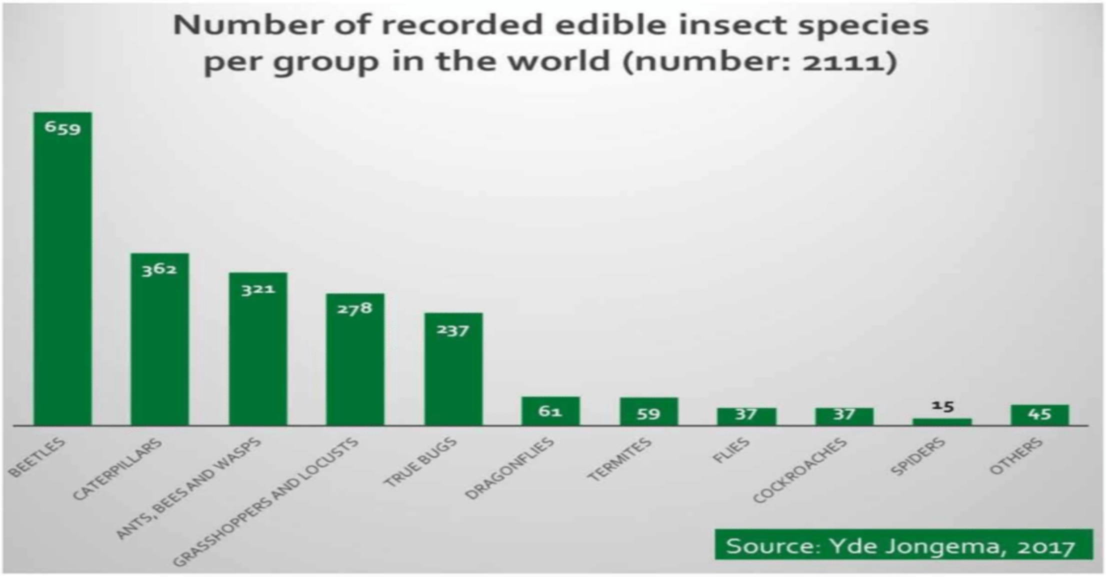

Figure 2.1. Number of insect species, by order consumed worldwide (Jongema, 2017)

2.2.3 Classification

Insects have been classified into Animalia kingdoms. Each of the kingdoms is then further divided into more specific and smaller groups based on similarities. The various levels of groups are named by the convention of taxonomists (scientists that study classifications). The standard groups in a typical complete classification of species would for example honey bee, *Apis mellifera Linnaeus* which is further divided and classified as below:

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Hymenoptera

Family: Apidae

Genus: Apis

Species: *Apis mellifera Linnaeus* (Moore, 2013).

2.2.4 Insect Orders

Insect orders are studied from those which are considered to be the most primitive, progressing through to those which are more advanced (flies, moths, bees, and beetles).

The Class Hexapoda is usually studied under a classification system with about 30 orders. (Moore, 2013). Here are some of the more important orders which are likely to be encountered:

List of Insect Orders

Kingdom: Animalia

Phylum: Arthropoda

Subphylum: Hexapoda

Class: Entognatha

Order: Collembola, Order: Diplura, Order: Protura, Class: Insecta, Subclass: Archaeognatha, Order: Archaeognatha, Subclass: Dicondylia, Order: Zygentoma Subclass: Pterygota Infraclass: Neoptera, Order: Coleoptera, Order: Dermaptera, Order: Dictyoptera, Order: Diptera, Order: Embiidina, Order: Grylloblattodea, Order: Hemiptera Order: Hymenoptera, Order: Isoptera, Order: Lepidoptera, Order: Mantophasmatodea, Order: Mecoptera, Order: Orthoptera, Order: Phasmatodea, Order: Phthiraptera, Order: Plecoptera, Order: Psocoptera.

2.2.5 Coleoptera (Beetles)

Characteristics

The biggest order by number of species is Coleoptera. One in five living animal species is a beetle. It includes about 1/4 of all known insects with about 280,000 different species worldwide. Their feeding habits are varied. Some feed on living plants; some are predaceous; some are scavengers; and others bore in wood. This order includes some of the best known and most important of insect enemies. While many are terrestrial, some are aquatic. The most famous members of this group are lady beetles, June beetles and the cotton boll weevil.

2.2.6 Lepidoptera (Moths, butterflies)

Characteristics

This is a large order of insects and one of the most popularly known. It contains some of our most notorious pests; such as the bollworm, cutworms, codling moth and cabbageworm. Lepidoptera generally have four well developed sets of wings covered with overlapping scales in adults. Some adult lepidoptera have reduced wings or none at all. The Mouth parts of the adults are formed for sucking but some insects here have reduced or non-functional mouth parts. Butterflies usually fly during the day and can be spotted by the clubbed antennae. Moths also usually fly at night but there are some exceptions. Moths have antennae that are feathery but not clubbed. Lepidoptera undergo complete metamorphosis (egg, larva, pupa, adult). The larvae are called caterpillars. Most caterpillars feed on plants and many can be said to be agricultural pests. The 'naked' pupa of a lepidopteran insect is called a chrysalis. Certain groups, such as the silk moths, pupate within a protective layer of silk, which is known as a cacoon. Immature stages (larvae) are called caterpillars (Moore, 2013).

Familiar names like cutworms, horn-worms and so on apply to groups of caterpillars that may be related taxonomically or through similar biology. Their mouth parts are formed and developed for chewing. The well-developed head has short antennae. Almost all have crochets (they are small hooks) on the prolegs even if the prolegs are reduced. The function of these hooks is to help the caterpillar hold onto the substrate. A Caterpillars diet is composed of foliage, stored products, linens. Some are leaf-miners and a few are borers in herbaceous and woody plants. Many lepidoptera feed on leaves of plants in the larval stage. A few caterpillars bore in plant stems, others may be leaf-miners and a few are ever predators. All lepidoptera undergo complete metamorphosis. Microlepidoptera are often under 1/4 inch, the biggest moths and butterflies' range about 3 inches (Godfray et al., 2010).

2.2.7 Diptera (Flies)

Characteristics

Diptera are generally winged but have only one set of wings with a few veins. Their hind wings are represented by a set of slender, club-shaped structures known as halteres. A few adults may be wingless, primarily parasites. The Mouth parts are formed and developed for sucking or piercing. Fly larvae may be completely different from the adults and are generally found in different habitats. Immatures, are usually called maggots. Immature Diptera also have mouth parts, which are modified for sucking or for piercing. Primitive flies, which includes midges and mosquitoes have head capsules but most immature flies have poorly formed heads. Many fly larvae are known to be associated with aquatic habitats or very wet areas with organic matter. A few are internal parasites of mammals. Larvae may either thin, elongate or thin and wide. Some may be elaborately ornamented. True flies or diptera come in many forms and sizes and are an interesting and important group (University of Nebraska, 2023).

This order includes insects that come in forms that are parasitic, predaceous and others that live on living or dead plants or animal material. A few members in this order cause a great amount of harm to crops. Many harmful flies spread infections and diseases, such as mosquitoes that are known to carry yellow fever and malaria and are responsible for millions of human deaths (University of Nebraska, 2023). This is one of the most important insect orders from the standpoint/view of human health because of the species that cause several diseases. Flies also undergo complete metamorphosis.

2.2.8 Orthoptera (grasshoppers, crickets, katydids, mantids, stick insects, cockroaches)

Characteristics

- Undergoes incomplete metamorphosis
- Adults and immatures possess chewing mouth parts
- A few may be very important agricultural pests
- Several of their hind legs have been modified for hopping
- Several communicate acoustically

Common and Interesting Orthoptera

- Grasshopper
- Large katydid
- Large endemic katydid - *Salomona guamensis*
- Stick insect - *Acanthograeffea denticulate*

2.2.9 Isoptera (termites)

Characteristics

- They are social insects that live in a nest which they build
- Each species has 3 or more roles/duties: worker, soldier, king, queen

Some modern taxonomist considers termites to be in the same order as roaches, blattodea (Moore, 2013).

2.2.10 Odonata (dragonflies, damselflies)

Characteristics

- They are all are predators
- Immatures are known as naiads, and they are aquatic. Naiads diet are composed of aquatic insects, small fish, tadpoles, etc.
- The adults will feed on flying insects

Odonata is divided into 2 sub-orders: Anisoptera, the dragonflies and zygoptera, the damselflies (Moore, 2013)

2.2.11 Hymenoptera (Ants, Bees, Wasps, Parasitic wasps)

Hymeno means God of marriage (refers to the union of the front and hind wings by means of hamuli).

Characteristics

Looking at this from a human standpoint, this order would be most likely the most beneficial in the entire insect class. It contains an outstanding number of great species that are of value as parasites or predators of insect pests, and they also contain the most important pollinators of plants- these insects are bees. Hymenoptera are an extremely fascinating group, in terms of their biology, for they exhibit a massive diversity of habits and complexity of social behavior patterns culminating in the social organization of bees, wasps, and ants. The winged members in this order possess four membranous wings. The front wings are larger than the hind wings and have a row of tiny hooks known as hamuli on their anterior margin by which the (back wings) hind wing attaches to a fold on the posterior edge of the front wing. A mature colony containing a single mated queen produces up to six virgin queens and hundreds to thousands of males. This depends on the species. Each male insect can mate only once, but *Eciton burchellii* queens are known to mate with a dozen males on average. This mating frequency is considered to be among the highest in eusocial *Hymenoptera* (Borowiec, 2016; Kronauer, 2006; Moore, 2003).

The wings may possess relatively a few veins, and in some other forms, there are no veins at all. The mouth parts are mandibulate, but in several, especially bees, the labium and maxillae tend to form a tongue-like structure by which liquid is extracted. The antennae generally contain ten or more segments and are usually fairly long. The tarsi (small bones by hind limb) are usually five-segmented. The ovipositor is usually well developed. In some instances, it is modified into a sting, and its role is as an organ of offense and defense. Due to the stinging organ evolving from an egg-laying organ, only females have the ability to sting.

Sexes in most hymenoptera are controlled by fertilization of the egg. The fertilized eggs will develop into females, and the unfertilized eggs usually develop into males. Hymenoptera undergo complete metamorphosis (all the stages: egg, larva, pupa and adult). Larvae are known as grubs. Several hymenoptera are parasitoids of other insects. Eggs are laid inside the body of the host insect and the grub will feed internally, eventually killing its host. They are called parasitoids in order to differentiate them from parasites which generally do not kill their hosts. Many hymenopterous parasites have been used for biological control of insect pests (Moore, 2013).

2.3 Collection of Edible Insects (Harvesting)

Insect collection methods have evolved with time. Some studies reveal that early hominids, either homo or Australopithecus robustus in southern Africa, used bones as tools to harvest termites from their nests in termite hills for close to a million years (Blackwell and d'Errico, 2001). This information from visible ware patterns on the suspected bone tools. The gatherers are presumed to have collected the insects by driving the bones down into the termite hills, forcing the termites to come out, before collecting them. Another method was by destroying the termite hills although more sophisticated techniques were also used by the Gbaya in the Central African Republic (Joulian and Roulon-Doko, 1994) in Tanzania.

As time is evolving, insect collection in some parts of Africa has been a preserve of women. Women who are the ones that often collect insects use methods that are dictated by insect behaviours such as resting places, hibernation and response to light and temperature. For example, inactivity at low temperatures aids easy catching of locusts and grasshoppers in the early hours of the morning. Those that are trapped at night include Night flyers such as termites and some types of grasshoppers. They are collected by luring them into traps by light and some insects like palm weevils can be attracted to artificially modeled breeding sites. Some species such as crickets, cicadas can be located by the sound they make. Some special tools are also used to facilitate capturing such as glue, sticks, nets and baskets (Van Huis, 2003). According to some studies, the Mofu-Gudur in northern Cameroun use the sap from some specila trees as glue to trap insects. The Gbaya in the Central African Republic use a stick from *Lantana rhodesianus* or grass stems of

Andropogon gayanus with glue at the end, to collect edible flower beetles (Cetoniinae), cicadas and grasshoppers (Roulon- Doko, 1998).

In southern Africa children trap cicadas by climbing trees or by using long poles, the ends of which have been dipped in glue. The San women in the Central Kalahari use small brooms, and beetles are trapped using nets attached to the ends of millet stems to catch insects on soil. Here, grasshoppers *Cyrtacanthacris tatarica* and *Lamarckiana cucullata* are collected by hand in the morning and the evening from trees and huts (Nonaka, 1996).

To collect some cerambycids, the Gbaya in the Central African Republic cut several *Burkea africana* trees around the village. A few days later the cerambycids arrive to attack the tree, and a waiting person near the trunk is then able to collect them (Roulon-Doko, 1998).

According to a study, In Thailand and the Lao People's Democratic Republic, it was found that ants were harvested from the early morning when the ants were least active and until midday. Collectors use a long (6-10 m) bamboo stick with a net mounted close to the pointed tip to pierce the *Oecophylla* leaf nests after which the bamboo stick is shaken and brood drops and is poured into buckets of water with enabling the collectors to separate the different ant castes and developmental stages. The ant harvest here was found to be January and May and no ants are collected outside this period (Sribandit et al., 2008).

In view of the foregoing, it can be seen that collection of insects employs various methods some of which are primitive. It is also worth noting that that harvesting depends on various reasons ranging from behavior to type of insects. Insect collection has also evolved with time and more conventional and advanced methods are now used. The collection methods which are deemed primitive may contribute to the scarcity of edible insects on the market.

CHAPTER 3

3.1 INSECTS AS HUMAN FOOD

3.1.1 Consumption of Insects: History and Geography

Entomophagy is considered the norm in many parts of Africa, Asia, Latina America and Australia while it is not as pronounced in other developing countries (Ramos-Elorduy et al., 2002). It is mistakenly believed that entomophagy is solely practiced in tropical regions, but in countries which are partially or fully in temperate zones, such as the Netherlands, China, Japan and Mexico, with this information, we know that insect species are consumed as a source of nutrition and nourishment (FAO, 2013).

Between 150 and 200 species of edible insects are eaten in Southeast Asia. The indigenous people of Mexico have a deep knowledge of plant and animal species while insects form a part of their diet (FAO, 2013; Ramos- Elorduy et al., 2002). However, in Western culture eating edible insects is considered a primitive habit and is normally looked upon with disgust, Bodenheimer (1951) strongly thinks that this horror and repulsion is solely based on customs and prejudice.

He explains: "it is rather doubtful whether primitive man ever felt an instinctive aversion against the eating of insects. Scores of writers have explained at great length how most of the vegetarian insects in themselves, by their environment and by their food habits, belong to the cleanest of animals, actually being much cleaner than most other animals which are served at our tables (De Gier and Verhoeckx, 2018).

It is still a long way until insects become accepted by Western population as a proper protein and food source. Education and providing better information, in addition to proper marketing would lead to have a better approval of entomophagy which can help to reduce prejudices, fear and negative perceptions that the general public hold towards edible insects (Sogari, et al., 2017).

It is however important to acknowledge that the percentage of the edible insects that are consumed globally differs and the Beetles are the most consumed. Insects have different consumption demand which is not associated with the issue of the safety of the insects, but shows less acceptability of certain insects (Figure 3.2).

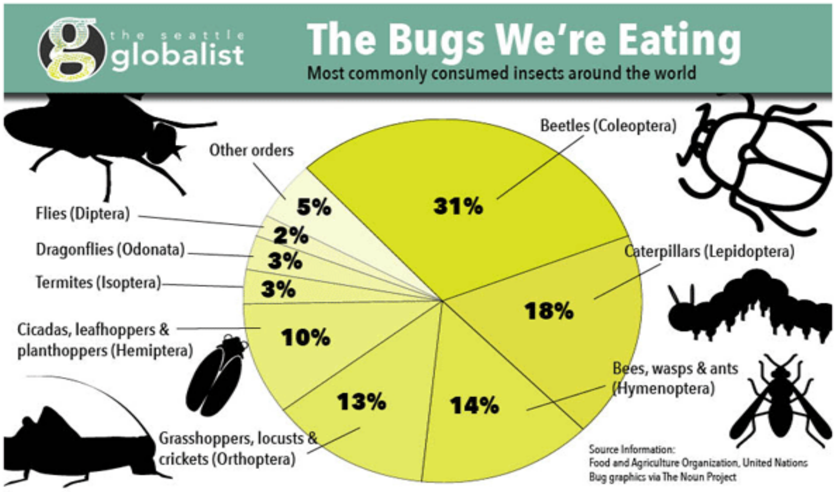

Figure 3.1 Insects for Food and Feed (FAO, 2013)

3.1.2 Nutritional value of edible insects

Insects are good source of proteins. They are considered as promising valuable contributor to novel foods and feed proteins. This places insects as a significant source of nutrients to meet the food demands of the growing world population. Moreover, the alternative food must be considered even by populations in the western world where it is not widely accepted. It is worth noting that the western population can be attracted if this novel food is packaged in a way that can be accepted by its population. The nutritional value of edible insects is very diverse mainly because of the large number and variability of species (Kourmiska and Adamcova, 2016). The nutritional value also changes according to the preparation and processing (Liguori et al., 2022). Insects are great sources of amino acid, monounsaturated and polyunsaturated fatty acids. Insects are also rich in several micronutrients; vitamins such as B group vitamins, vitamin A, D, E, K, and C as well as minerals such as zinc, copper, iron, magnesium, calcium, manganese, phosphorous, selenium (FAO, 2013; Rumpold and Schluter, 2013; Payne et al., 2015).

Insects are known to possess these nutrients and hence are a valuable replacement that can reduce human demand for animal protein and enhance the usage of natural resources (Sosa and Fogliano, 2017). Protein is the main component of the nutrient composition of insects and varies from 20 to 76% of dry matter depending on the type and development stage of the insect (Kourimska and Adamkova, 2016; Liguori et al., 2022) and the other component in the nutrient composition of edible insect is fat. Variability in fat content is large (2-50% of dry matter) (Kourimska and Adamkova, 2016). Total polyunsaturated fatty acids' content may be up to 70% of total fatty acids. Considering the average protein content, Orthoptera (grasshoppers, locusts and crickets) provide the most protein, as high as 61.32%, and second are Blattodea (cockroaches) standing at around 57.3%.

The highest fat content goes to Coleoptera (beetles) with 33.4%, followed by Isoptera (termites) standing at 32.74%. (Rumpold and Schlüter, 2013). As mentioned-above, insects are made up of different components, but the levels of components such as protein and lipid varies across species of insects and also varies within the same species. The variations are attributed to what they feed on, the stage of development at which they are, their sex and their environment of habitation (Ramos-Elorduy et al. 2002). Carbohydrates ranged between 2.7 mg and 49.8 mg per kg of fresh matter which represented mainly by chitin (Kourimska and Adamkova, 2016). The figure below shows the general range of these components and their energy content:

Nutrients and energy*	Cockroaches (*Blattodea*)	Beetles (*Coleoptera*)	Flies (*Diptera*)	Beetles (*Hemiptera*)	Bees, wasps, ants (*Hymenoptera*)	Termites (*Isoptera*)	Caterpillars (*Lepidoptera*)	Dragonflies (*Odonata*)	Grashoppers, locusts, crickets (*Orthoptera*)
Data amount n	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
min	43.90	8.85	35.87	27.00	4.90	20.40	13.17	54.24	6.25
max	65.60	71.10	63.99	72.00	66.00	65.62	74.35	56.22	77.13
SD	11.71	15.61	13.12	15.09	15.19	15.91	15.56	1.40	14.65
Fat, %	29.90	33.40	22.75	30.26	25.09	32.74	27.66	19.83	13.41
min	27.30	0.66	11.89	4.00	5.80	21.35	5.25	16.72	2.49
max	34.20	69.78	35.87	57.30	62.00	46.10	77.17	22.93	53.05
SD	3.75	18.91	9.35	18.74	11.96	9.05	17.89	4.39	10.90
Fiber, %	5.31	10.74	13.56	12.40	5.71	5.06	6.60	11.79	9.55
min	3.00	1.40	9.75	2.00	0.86	2.20	0.12	9.96	1.01
max	8.44	25.14	16.20	23.00	29.13	7.85	29.00	13.62	22.08
SD	2.81	6.50	2.81	5.74	6.32	2.47	5.15	2.59	4.23
NFE, %	4.53	13.20	6.01	6.08	20.25	22.84	18.76	4.63	12.98
min	0.78	0.01	1.25	0.01	0.00	1.13	1.00	3.02	0.00
max	10.09	48.60	8.21	18.07	77.73	43.30	66.60	6.23	85.30
SD	4.91	12.33	3.25	5.93	20.56	17.16	19.81	2.27	17.22
Ash, %	2.94	5.07	10.31	5.03	3.51	5.88	4.51	8.53	3.85
min	2.48	0.62	5.16	1.00	0.71	1.90	0.63	4.21	0.34
max	3.33	24.10	25.95	21.00	9.31	11.26	11.51	12.85	9.36
SD	0.43	4.83	8.14	5.44	1.56	3.98	2.65	6.11	1.65
Energy, Kcal/100g		490.30	409.78	478.99	484.45		508.89	431.33	426.25
min		282.32	216.94	328.99	391.00		293.00	431.33	361.46
max		652.30	552.40	622.00	655.00		776.85	431.33	566.00
n (Energy)	0	17	3	18	28	0	30	1	16
> 400 kcal/100g		13	2	13	27		25	1	9
> 500 kcal/100g		10	1	8	7		16	0	2
SD		111.42	173.28	98.53	58.88		114.10	0.00	63.70

*n = amount of data, min = lowest value, max = highest value, SD = standard deviation, and NFE = nitrogen-free extract.

Table 3.2 Main nutrient components of edible insect orders and their energy content (on a dry matter basis (Rumpold and Schluter, 2013)

The protein content of insects is more satisfying compared to the casein and soy which need thorough processing before consumption (Berardy et al., 2015. It is also highly digestible (between 77% and 98%) (Rumpold and Schluter, 2013). In addition, removal of the content of chitin and some other food processes can even improve the protein content (Belluco, et al., 2013). A particular study of entomophagy among the Luo of Kenya, showed consumption of insects can provide minerals such as iron, zinc and calcium (Christensen, 2006).

In third world or developing countries, where certain sources of animal protein are not easily accessible or affordable, deficiency of minerals such as iron and zinc can thus be resolved through the practice of entomophagy. Entomophagy can also help calcium deficiency (although to a lesser degree) in developing countries where other animal sources are either not accessible or unaffordable (Christensen, et al., 2006). In addition to minerals, insects are a sufficient source of vitamins. For example, Angolan caterpillar, Usta terpsichore (Saturnidae) is rich not only in iron, copper and zinc, but also in thiamine (vitamin B1), and riboflavin (B2) (Belluco, et al., 2013).

The energy value of edible insects varies mostly on their fat content (Koumiska and Adamkova, 2016) for instance, larvae or pupae showed higher energy level in comparison to the adults. Conversely high protein insect species shown lower energy content (Rumpold and Schluter, 2013). In one particular study, it was found that insects have significant protein content which varies from 20 to 76% of dry matter depending on the type and development stage of the insect. Fat content variability is large (2–50% of dry matter) and depends on many factors. Total polyunsaturated fatty acids' content may be up to 70% of total fatty acids. Carbohydrates are represented mainly by chitin, whose content ranges between 2.7 mg and 49.8 mg per kg of fresh matter. Some species of edible insects contain a reasonable amount of minerals (K, Na, Ca, Cu, Fe, Zn, Mn and P) as well as vitamins such as B group vitamins, vitamins A, D, E, K, and C (Kourimska and Adamkova, 2016).

The percentage of other species was around 50.7% for yellow mealworm (T. molitor) to 62.2% for the African migratory locust (L. migratoria). Insect protein digestibility, which is around 76 to 96% was also examined. These values are only slightly smaller on average compared to the values for egg protein (95%) or beef (98%) and even higher than in the case of many plant proteins (Finke, 2004; Capinera, 2008). The Measured amounts of nitrogenous substances that are in insects may be more than their actual protein content, this is because some nitrogen is also bound in the exoskeleton (Klunder et al., 2012). Insects possess a number of nutritionally valuable amino acids including high levels of phenylalanine and tyrosine. Some insects contain large amounts of lysine, tryptophan and threonine, which is absent in some cereal proteins. An example would be in Africa, Angola in particular where the intake of these nutrients may be supplemented by eating termites of the genus Macrotermes subhyalinus (Ugwumba, 2008).

The native people of Papua New Guinea, usually eat tubers, this is where content of lysine and leucine is low. The resulting nutritional gap is later possibly compensated by the eating of larvae of the Rhynchophorus family beetle that have high content of lysine. On the contrary, tubers contain a high proportion of tryptophan, and aromatic amino acids which are present in limited quantities in these larvae. Nutritional intake of such a diet is therefore balanced. Analysis of almost a hundred edible insect species showed that the content of essential amino acids represents 46–96% of the total amount of amino acids (Xiaoming et al., 2010).

It is also important to note that these insects are consumed at their different stages of their development. For example, the caterpillar is consumed only at larva stage and not at adult stage because it changes into adult stage (Latham, 2015).

Scientific Name	Stage of Consumption	Protein (%)	Crude Fibre (%)	Moisture (%)	Ash (%)	Carb (%)	Vitamin A (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Fe (mg/100 g)	Ca (mg/100 g)	Zn (mg/100 g)	P (mg/100 g)	Mg (mg/100 g)	Fats (mg/100 g)	Reference
Blattodea (termites and cockroaches)		**33.2 ± 14.5**	**4.7 ± 3.9**	**2.9 ± 0.1**	**5.2 ± 2.5**	**23.2 ± 0**	**2.7 ± 0.2**	**1.8 ± 0.2**	**3.2 ± 0.2**	**86 ± 96.8**	**54.1 ± 42.6**	**13.8 ± 3.5**	**125 ± 11**	**0.2 ± 0.1**	**22.2 ± 9.8**	
Periplaneta Americana	Adult	39.6	13.1		6.2											[35]
Macrotermes nigeriensis	Adult	35.9	5.5		5.8											[35]
Macrotermes bellicosus	Adult	20.4	2.7	2.8	11.3	23.2	2.9	2.0	3.4	27.0	21.0		136.0	0.2	36.1	[36]
Macrotermes natalensis	Adult	22.1	2.2	3.0	4.1		2.6	1.5	3.0	29.0	18.0		114.0	0.3	21.4	[36]
Pseudacathotermes spinige	Adult				6.8					332.0	84.7	11.9				[37]
Macrotermes spp.	Adult				2.4					93.9	83.7	8.1				[37]
Macrotermes herus	Adult				6.8					161.0	132.0	14.3				[37]
Macrotermes bellicosus	Adult	40.7			5.7					42.7		16.9			8.4	[38]
Macrotermes bellicosus	Adult	20.4	2.7	2.8	2.9		2.9	2.0	3.4	27.0	21.0		136.0	0.2		[36]
Syntermes soldiers	Adult	64.7			4.2					32.5		17.6			23.0	[38]
Macrotermes natalensis	Adult	22.1	2.2	3.0	1.9		2.6	1.5	3.0	29.0	18.0		114.0	0.3		[36]
Coleoptera (beetles)		**32.8 ± 11.5**	**6.2 ± 7.8**	**7.6 ± 15.7**	**4.7 ± 2.7**	**22.6 ± 13.2**	**11.2 ± 1.4**	**1.9 ± 0.9**	**5.4 ± 1.2**	**14.1 ± 8.9**	**43.6 ± 14.3**	**14.4 ± 12.1**	**109.6 ± 48.5**	**10.1 ± 4.2**	**29.1 ± 16.6**	
Analeptes trifasciata	Larvae	20.1	2.0	2.2	5.1		12.5	2.6	5.4	18.2	61.2		136.4	18.2		[36]
Oryctes boas	Larvae	26.0	1.5	1.9	1.5							2.3				[6,36]
Oryctes monoceros	Larvae	26.4		4.7	7.8	51.6										[39]
Aphodius rufipes	Larvae	22.4	28.1	3.3	2.7	13.1				30.9	42.2			11.7	30.5	[36]
Rhynchophorus phoenicis	Larvae	28.4	2.8	2.7	2.7		11.3	2.2	4.3	12.2	39.6	26.5	126.4	7.5	66.6	[6]
Oryctes rhinoceros	Larvae	50.5								4.5					38.1	[6]
Oryctes owariensis	Larvae	50.6		8.4	7.7	14.3									18.9	[40]

Table 3.3 Nutritional composition and energy content of edible insects (Hlongwane et al., 2020)

Insect	Developmental Stage	Protein	Fat	Fibre	NFE*	Ash	Reference
Blattodea (including infra order Isoptera)							
Edible cockroaches and termites		46.3	31.3	5.2	13.7	4.4	[22]
Macrotermes bellicosus	A	40.7	44.8	5.3	2.2	5.0	[36]
Macrotermes nigeriensis	A	37.5	48.0	5.0	2.1	3.2	[37]
Odototermes sp.	A	33.7	50.9	6.3	6.1	3.0	[38]
Syntermes sp. soldier	A	64.7	3.1	23.0	2.5	4.2	[36]
Coleoptera							
Edible beetles		40.7	33.4	10.7	13.2	5.1	[22]
Allomyrina dichotoma	L	54.2	20.2	4.0	17.7	3.9	[39]
Oryctes rhinoceros	L	52.0	10.8	17.9	2.0	11.8	[37]
Protaetia brevitarsis	L	44.2	15.4	11.1	22.5	6.9	[39]
Tenebrio molitor	L	53.2	34.5	6.3	1.9	4.0	
Tenebrio molitor	P	51.0	32.0	12.0	--	--	[40]
Tenebrio molitor	L	52.0	31.0	13.0	--	--	
Zophobas morio	L	46.0	35.0	6.0	--	--	
Diptera							
Edible flies		49.5	22.8	13.6	6.0	10.3	[22]

Table 3.4 Proximate Nutrient Composition (g/100g dry matter basis) of edible insects (Meyer-Rochow et al., 2021)

Table 3.3 and 3.4 show that the composition of edible insects has a variation e.g., Coleoptera (Grubs, Beetles) possess an average content of proteins 47% which is a huge difference with protein contents of the species within this order ranging between 8.85 to 71.1 %. It is said that this variation comes from the many differences between species in developmental stages, feed, origins and measuring methods. In addition to the protein and fat, fibre, nitrogen- free extract (NFE) and ash are the other components of insects.

3.1.2.1 Insect orders

Blattodea (cockroaches), Coleoptera (beetles, grubs), Diptera (flies), Hemiptera (true bugs), Hymenoptera (ants, bees, wasps), Isoptera (termites), Lepidoptera (butterflies, moths), Odonata (dragonflies, damselflies), Orthoptera (grasshoppers, crickets, locusts).

According to Rumpold and Schluter, (2013) the average fibre contents of Isoptera (termites) ranges from 5.06% to 13.56%, with the maximum yields being black ants (polyrhachis vicina) from the regions of China e.g., Guizhou. The species with the lowest amount of fibre content are larvae (Aegiale hesperiaris k (maguey worm; Lepidoptera) with 0.12% and larvae of honeybee (Subhachai et al., 2010).

NFE content is a commonly calculated value which represents carbohydrates other than fibre is between 4.63% for dragonflies, damselflies (odonata), 22.4% for isoptera (termites, ants). The insects that possess the richest carbohydrates content are crickets (subspecies Brachytrupes). Insects with the lowest carbohydrate content are the ant (Atta Mexicana, Hymenoptera) ranges 0.00-4.92%, the beetle (Tenebrio molitor, Coleoptera) ranges 0.01-3.86% (Subhachai et al., 2010).

Average ash content of the edible insects ranges between 2.94% for Blattadea (Cockroaches) and 10.31% for Diptera (flies) with maximum yields 25.95% for eristalis spices (Diptera). The lowest ash contents were found in sphenarium mexicanum S (Orthoptera) with 0.34%. The mean energy contents of edible insects range from about 409.78 – 508.89 kcal/100g based on dry matter with maximum energy contents being 762.00- 776.85 kcal/100g e.g., Phasus triangularis (Lepidoptera) - 655.00 kcal/100 g. Minimum energy contents range from e.g., 216.94 kcal/100 g for Ephydra hi ans (Diptera). Again, the margin of deviation becomes clearly visible, even within the same order as in this case Lepidoptera (butterflies and moths) the energy content fluctuates considerably.

However, the maximum and minimum energy contents found can be said to be overall outliers, 79.65% of all 113 energy contents of edible insects obtained from literature range above 400 kcal/100 g, 40.94% above 500 kcal/100 g. Consequently, the energy contents of most edible insects are substantial even in comparison to meat which is due to the two major components of insects: protein and fat.

3.1.2.2 Protein and amino acid content of insects

According to a study performed by Rumpold and Schluter, (2013) on nutritional composition and safety aspects of edible insects, it was concluded that many edible insects provide satisfactorily with energy and protein and meet amino acid requirements for humans (Rumpold and Schluter, 2013). Considering the average protein content of the insect orders, the order Orthoptera including grasshoppers, crickets, locusts are rich in protein (61.32%) and the order Isoptera (termites) have around 35.34% protein content (Rumpold and Schluter, 2013). The species *Melanoplus femurrubrum*, *sphenarium histirio* (from the order Orthoptera) possessed the highest protein contents with 77.00, 71.15-77.00 respectively (Rumpold and Schluter, 2013). Within all nine insects orders (Table 3.6), maximum protein content range from 56.22% (order Odanata) to 77.13% (order Orthoptera) have been obtained with maximum protein contents which are above 70% (for 4 of the nine insect orders) (based on dry matter). Insects, especially grasshoppers potentially represent an excellent alternative protein source.

In a study to compare insect protein to that of animals and plants it was found that insect protein showed equal or higher to soy protein as an amino acid source (Rumpold and Schluter, 2013). Thus insects have a significant protein content as seen from this study.

According to feeding trials on rats, by-product of the silk industry for instance spent silk worm pupae, was shown a significantly lower protein quality than casein despite of having higher food intake, protein digestibility, weight gain, protein efficiency ratio (PER), and net protein utilization (NPU) (Altomare et al 2020). This was the reason for a bad odour of the silkworm pupae meal and a growth depressing pupal hormone ecdysone. The chemical score of the spent silk worm pupae protein was 60 compared to 100 for whole egg protein and 55.3 for casein.

Feeding trials with broiler chicks performed by Al-qazzaz and Ishmail (2016) showed an improved growing performance and carcass quality. It also showed that insect meal contains a greater amount of essential amino acids compared to conventional animal feeds.

3.1.2.3 Lipid contents and fatty acid of insects

Fats comprise of the second biggest portion of the nutrient composition of edible insects, (Table 3.4). Average fat content in order Orthoptera for instance grasshoppers species is about 13.41%.. Orthoptera (grasshoppers, locusts and crickets), Lepidoptera (caterpillars), Blattodea (cockroaches), Isoptera (termites), and Coleoptera (beetles, grubs) have average fat contents of 13.41%, 27.66%, 29.90%, 32.74%, and 33.40% dry weight, respectively4. In general, larvae and pupae have more fat than adult insect (Mlcek, 2014; Rumpold and Schluter, 2013; Schlüter and Rumpold, 2017). According to Xiaoming et al., (2010), caterpillars has the highest fat content. Daylan et al. (2014) determined the total fat content in caterpillars (Lepidoptera) from 8.6 to 15.2 g per 100 g of insects where as in grasshoppers and related Orthopetra species, lower amount were found which ranged from 3.8 g to 5.3 g per 100 g of insects.

It is worth noting that lipids are the main and most concentrated source of energy in human food. The nutritional value of lipids is determined by the quantitative and qualitative composition of fatty acids (Orkusz, 2021). Just like the fatty acid composition, the cholesterol content in insects varies with their diet. According to the study performed by Rumpold and Schluter (2013), the cholesterol content was high in house crickets (105 mg/100 g fresh weight), Bombay locusts (66 mg/100 g fresh weight) and bamboo caterpillars (8.6 to 15.2 g per 100 g). In contrast, large fresh caterpillar eggs (raw) contain 372 mg cholesterol per 100 g fresh weight which has more than three times cholesterol content compared to the house cricket. Omotoso and Adedire (2007) indicated much lower cholesterol content ranged between 7.31 to 22.91 mg/100 g dry weight for the edible insects in Southern Nigeria e.g., *Imbrasis belina* and *Rhynchophorus Phoenicis* respectively. According to the findings of Jing and Behmer (2020), insects cannot synthesize cholesterol. Some insect species e.g., the honey bee (A. mellifera) is not able to convert the plant sterols to cholesterol. In addition, it was discovered that it is possible to circumvent the making of cholesterol in insects by replacing 5-sterols with 7- sterols in their diet. This has been achieved successfully for the Lepidopteran *Heliothis zea*.

It is possible to utilize insects as food constituent for human diet being nutritious but low in cholesterol level. The presence and contents of micronutrients has to be considered.

3.1.1.4 Vitamin and mineral content of insects

Insects contains lipophilic vitamins (Xiaoming et al., 2010, Kourmiska and Adamkova, 2016). According to Bukkens (2005), variety of insects contain thiamin (vitamin B1) which ranges from 0.1 to 4 mg per 100 g of dry matter whereas riboflavin (vitamin B2) ranged from 0.11 to 8.9 mg per 100 g dry matter. Cobalamin (vitamin B12) presented in the larvae of meal worm beetle (*Tenebrio molitor*) is around 0.47 µg per 100 g whereas house cricket (*Acheta domesticus*) has 5.4 µg per 100 g (in adults), 8.7 µg per 100 g (in nymphs). Most insects show very high amounts of phosphorous. Not many but enough insects supply sufficient amounts of magnesium. It is noted that true bugs (Hemiptera) and some species of the order Orthoptera (crickets, locusts) are especially rich in magnesium. It must also be noted that insects are low in sodium. Only some caterpillars (larvae of the order Lepidoptera) have high-sodium contents per 100 g (Kourimska and Admakova, 2016). The required amount of iron depends greatly on its bioavailability, and the consumer's age and sex etc. There are no exact numbers of iron's bioavailability in insects, hence required amount of 58.5 mg/day is assumed. It can noted that, insects partially contain much more iron and calcium than beef, pork, and chicken. It was also suggested, that eating insects could decrease iron and zinc deficiency in 3rd world countries. Although this could not be confirmed for iron supply, most edible insects show high zinc contents (Rumpold and Schluter, 2013). This is most common in species of the order Orthoptera (grasshoppers, crickets, locusts) which can be consider as zinc supplementing food (Rumpold and Schluter, 2013; Morgane et al., 2015). Although a 100 g of edible insects generally lack sufficient content of calcium and potassium, edible insects possess the potential to provide micronutrients namely, copper, iron, magnesium, manganese, phosphorous, selenium, and zinc (Rumpold and Schluter, 2013). Only beetles and termites have low content of manganese. The content of micronutrients in edible insects in the case of farm bred species can be controlled through feed and in wild edible insects their content is seasonal (Kourmiska and Adamkova, 2016). In addition, edible insects can be utilized in low-sodium diets. Further research has proven that 100g of insects based on dry matter is rich in riboflavin, pantothenic acid, and biotin. Orthoptera and Coleoptera (beetles) insect orders, are rich in folic acid. However, 100g of insects are sufficient for vitamin A, C, niacin and in most scenarios Thiamine. It also contains low content of Vitamin E. The solution to this could be to increase intake either as a fluid or in solid form.

3.1.2 Edible Insects versus Meat- The Nutritional Perspective

Entomophagy, is increasingly being acknowledged and has gained attention for its nutritional benefits and environmentally friendly production amid climate change. However, the nutrition factor does play a critical role in the growing preference, especially among the population that has accepted the phenomenon (Liguori et al., 2016).

According to Orkusz, (2021) argues that some edible insect species have a higher energy value, higher content of protein, fat, polyunsaturated fatty acids, and cholesterol than meat from slaughter animals. This is notwithstanding the fact that the content of saturated fatty acids, monounsaturated fatty acids, thiamine, niacin, cobalamin, and iron is lower.

Regardless of the species and form of development, insects have higher content of tocopherol, riboflavin, calcium, zinc, copper, and manganese than meat. Insects have also been found to be a valuable source of vitamin C and dietary fiber as compared to meat (Orkusz, 2021). This just goes to show that edible insects are indeed a valuable source of proteins and must be explored further to ascertain the viability and safety issues that may hamper its acceptance. However in another study by Payne et al., (2016) it was found that nutritional composition showed high diversity among insect species. For example, crickets, palm weevil larvae and mealworm on a value score was significantly healthier than beef and chicken and none of six tested insects were statistically less healthy than meat.

It has also been argued that most edible insects can meet the protein and energy requirements of human diet. They have also been found to have a high content of mono and polyunsaturated fatty acids, are rich in trace elements such as copper, iron, magnesium, manganese, phosphorus, selenium and zinc, as well as vitamins like riboflavin, pantothenic acid, biotin, and folic acid in some cases (Rumpold and Schluter, 2013). Having said this, it is worth noting that the nutritional value of insects compares well with meat and fish. Moreover insects are said to have a superior amount of crude protein. For example, caterpillars contain 50 to 60, palm weevil larvae 23 to 36, Orthoptera 41 to 91, ants 7 to 25 and termites 35 to 65 in g/100g dry weight. One hundred grams of caterpillars provide of an individual's daily protein requirement, and more than 100% of the daily requirements for many of the vitamins and minerals (Morgane, et al., 2015). Insect protein is also said to be healthier compared to other forms of protein (Rumpold and Schluter, 2013). For example some studies show that the consumption of red meat is linked to the high risk of stroke, diabetes, colorectal and lung cancer (Spencer et al, 2010). On the other hand there is insufficient evidence to link white meat of poultry with the above-mentioned disease (Spencer et al, 2010; Orkusz, 2021).

Nutritional values can differ considerably even within a small group of insects depending on an insect's stage in metamorphosis, origin of that particular insect and its diet (Ramos-Elorduy et al. 2002). Similarly, the nutritional value can change according to its preparation and processing before it is eaten (drying, cooking, frying etc.) (Van Huis et al., 2013). Insect nutritional composition shows a high diversity between species. For example, crickets, palm weevil larvae and mealworm were significantly healthier than beef and chicken and none of the named tested insects were statistically less healthy than meat (Payne et al., 2016).

According to a nutritional comparative study on edible insect and meat performed by Orkusz (2021), insects are a better dietary component for supplementing daily rations deficient in riboflavin compared to meat. The comparative analysis carried out on the composition of the meat of slaughtered animals and insects cannot conclude unequivocally that insects have a higher nutritional value, because the content of individual nutrients varies significantly in both meat and insects **(**Orkusz, 2021).

Insects also have a high food conversion ratio. Their bodies adapt to the temperature of the environment they are inhabiting so that they don't need to use a large part of their food to maintain their body temperatures, this simple fact is the reason for their higher feed-conversion ratio (Oonincx et al., 2010). Another factor for consideration is the energy efficiency of insects from an edible weight perspective. Thus, humans can consume a great amount of insect bodies compared to that of the cattle, birds or fish where there are wasted parts like bones, claws, skins and shell (Ramos-Elorduy, 2002). Insects reproduce faster and grow faster. An individual insect can reproduce up to thousands of offspring while livestock reproduce only few and it takes months (and sometimes years) for them to reach adulthood. All that contributes to achievement of a greater rate of protein production out of insects compared to livestock (Abbasi et al., 2016).

Howard and Stanley-Samuelson (1990) analysed the phospholipid fatty acid composition of the adult *Tenebrio molitor* and found that over 80 percent of these fatty acids consisted of palmitic, stearic, oleic and linoleic acids. Finke (2002) found the same fatty acids in high amounts in T. molitor larvae. Polyunsaturated fatty acids are mostly found as phospholipids (Howard and Stanley-Samuelson, 1990). The study further found that in terms of minerals, Mealworms contain comparable values of copper, sodium, potassium, iron, zinc and selenium while in terms of Vitamins, Mealworms have generally higher vitamin content than beef, with the exception of vitamin B12 (Van Huis et al., 2013).

3.2 Farming of Edible Insects: Methods and Merits

Owing to the growing demand for edible insects and the need to meet the demand for alternative sources of protein amid a declining food source, insect rearing is being pursued in various regions on the globe. Although the practice is new it is steadily gaining ground with the Western world being the one that is lagging behind due to the negative perception about Insect consumption. However, insect farming has resulted into some regions stepping up from basic techniques to using advanced methods of insect rearing.

3.2.1 Insect Farming Methods

Apart from collecting edible insects from their natural habitat, there is a growing innovative and technologies involving large scale of insects in some developed countries such as Holland, Denmark and Belgium and in developing countries such as Kenya, Thailand and Vietnam. Thus the number of potential consumers is likely to grow due to rising rearing and acceptance of insect consumption and its utilization in food diets such as pasta (Huis et al, 2013; Sogari et al., 2019).Two contrasting farming systems are principally considered. One is the Thai cricket farming model, based on micro-farms, in which the small farmers do not make the flour; this task instead being handled by specialised businesses. The other is the western farming model, in which farms are large, and the flour is produced by the very same factory-farm. Examples of this model are found in the Netherlands (Protifarm) and Canada (Entomofarm). Since insect powders (flour) in packaged foods represent a new category of food product, little market data and/or surveys a (Reverberi, 2020).

Insect farming is in its infancy, but is rapidly growing agribusiness in the world and is providing access to alternative protein source that can be reared in a way that does not adversely interfere with the climate and provides income to insect farmers in places like East Africa (Huis et al., 2013). With the continental drive to transform existing food systems that are becoming continuously unsustainable due to scarcity of arable land and water, and high ecological imprint, insect farming for food and feed with circular economy potential has gained remarkable interest (Tanga et al., 2021). The authors further note that the industry has grown in the region with a number of companies emerging in Kenya, Tanzania and Uganda with most farms rearing Crickets and Black Soldier Fly. As part of their conclusion, they point out that only about 95% of the insect farms in the region were operating as microenterprises, but have a potential to grow and become more automated. According to the study some of these companies utilize mechanization and automation to lower the cost of insect farming. These insect farming enterprises recycle organic waste recipes into nutrient-rich biomass that can be incorporated into various feed formulations providing opportunities for income generation.

Owing to the demand for safe, certified insect powder, there is are growing activities such as insect farming and processing and the transformation of a traditional unprocessed food into a modern, packaged product. This can be seen in the increase of insect farming and packaging in some countries on the globe (Reverberi, 2020). Thailand is one country that has seized the opportunity of this growing market in insect farming. In the last 20 years, the country has positioned gained itself the reputation and status of being one of the few countries with a high number of insect farms which are estimated to be 22,000 (Hanboonsong et al., 2013.) According to recent findings, the main insect type reared in Thailand are crickets with the two main species being *Acheta Domesticus* and *Gryllus Bimaculatus*. The findings further show that Thai farmers used to farm crickets in concrete cylinders, plastic boxes, wood and other types of containers, but more recently large pens with a concrete perimeter are becoming the rearing standard. These rearing areas are easy to clean, cheap to build and very resistant. Inside the pen, the living space for the crickets is provided by dozens of egg trays. The rearing pens and the farm are protected with mosquito nets to prevent other insects from entering (Reverberi, 2020).

Insect farming is also gaining ground in other parts of the world such as Cambodia where cricket farming is also common, but not as developed as in Thailand. However Non-Governmental Organisation (NGO) support through entities such as the Cambodian Cricket Framing Association is helping to improve the sector in terms of knowledge on modern and safe insect farming methods (Miech, 2016).

Insect farming in China, a country with a good population of consumers is not as pronounced as the wild harvesting. However, it is practiced in half of the regions despite it being less common than wild harvesting. Silkworms, which have been farmed for over 4,000 years, have a production capacity of about 500,000 tons per year of fresh pupae, representing 75% of the global production. Significant quantities of mealworms are also grown for pet food, with very competitive prices of up to US$8 per kg for defatted mealworm powder (Reverberi, 2020). The larvae of the beetle have been mentioned as a promising option for mass rearing in Western countries because the species is endemic in temperate climates and easy to farm on a large scale, it has a short life cycle, and farming expertise is already available, particularly in the pet food industry (van Huis et al., 2013). This would offer a boost to the acceptance of the consumption insects in the Western societies.

3.2.2 Merits and Benefits of Insect Farming

Edible Insect farming has a number of advantages. Firstly, they can be reared on organic side streams, reducing environmental contamination, while adding value to waste. Secondly, they emit relatively few Green Houses Gases (GHGs) and relatively little ammonia. Thirdly, they require significantly less water than cattle rearing. Fourthly, they have few animal welfare issues, although the extent to which insects experience pain is largely unknown (Glover and Sexton, 2015).

One thing is certain that feeding a growing world population with more demanding consumers has created a need for an increase in food production. This has placed a huge burden on already limited resources such as land, oceans, fertilizers, water and energy. Thus, there is need for adopting food production methods that may not lead to adverse practices such as increases in GHG emissions, as well as deforestation and environmental degradation. These environmental problems, particularly those associated with raising livestock, need urgent attention as meeting this demand will require innovative solutions. The scenario has created an opportunity for insects to help meet rising demand in meat products and replace fishmeal and fish oil.

In view of the forgoing, insect production is becoming an option that can help mitigate some of these challenges. For example, insects need much smaller spaces in comparison to other types of food production methods such as livestock rearing or fish farming. Thus, people are already rearing their own insects in the corners of their kitchens. Industrial application of insect production demands less complicated machinery and user-friendly control systems although the practice may be expensive. However, it worth noting that insects are still expensive because of the scarcity of the edible insects and a farming industry which is still growing.

It has been estimated that for each hectare of land used in mealworm protein production, 2.5 hectares is needed for milk, 2-3.5 hectares are needed for pork and chicken production and 10 hectares is needed for beef protein (Abbasi et al., 2016; FAO, 2013). Most insect species feed on organic matter in nature and easily exploit organics sources such as plants and animals. Insects raised on organic waste proved to be more efficient in producing biomass and weight. From an environmental point of view, insects are more beneficial as they can be reared on organic waste adding more value to them. Insects can also be used in feeding of poultry and fishes producing equal or better results than soya or fish flour (FAO, 2013; Ramos- Elorduy et al., 2002).

Another merit of insect production over other forms of farming is water use. Less water is needed for producing insects compared to the estimated numbers for animal protein. 2,300 liters of water is needed for producing 1 kg chicken. That number arises to 3,500 liters for 1 kg of pork and even more, the necessary water stands at 22,000 liters for producing 1 kg of beef while that number has been estimated up to 43,000 liters (FAO, 2013). Livestock production is to blame for around 35-40% of worldwide methane and 9% of CO_2 emissions, speeding the impact of global warming. Add to that the effects of deforestation in order to produce more land for livestock pasture and their nurture (Abbasi, et al., 2016).

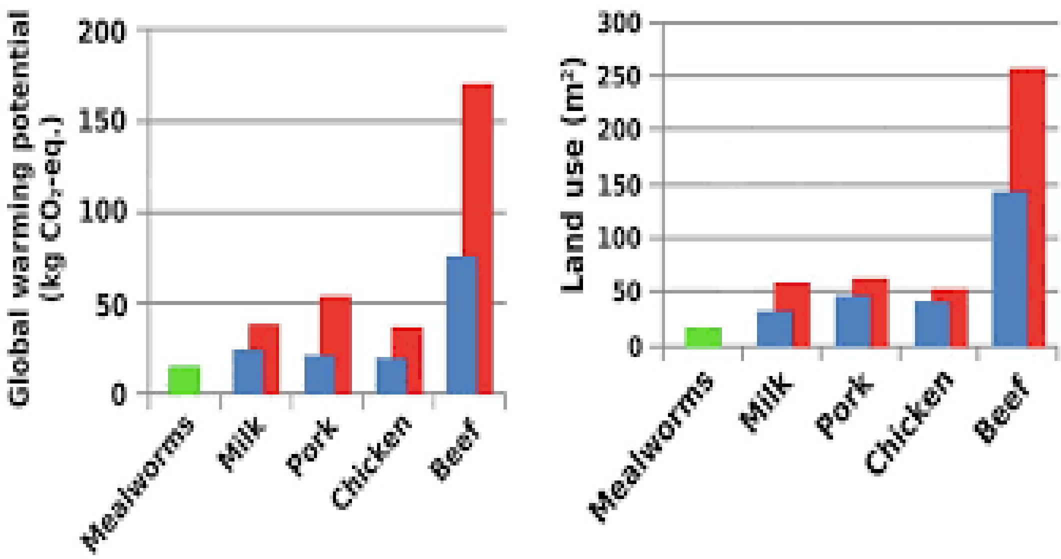

Figure 3.7 Environmental Impact of Mealworms Compared to other Animal Products (Valerie and Patz, 2020)

In view of the increasing relevance of the sector and the management peculiarities, some studies have been conducted to ascertain the impact of insect rearing on the environment. As seen, most studies agree that insect rearing is safer to the environment and its impact is less adverse as compared to livestock rearing (Egonyu et al., 2021).

3.3 Edible insect as food products and novel food ingredients

Insect consumption has not been widely welcomed in western societies owing to various factors such as culture, perceptions and general dislike (Gmuer et al, 2016; Batat and Peter, 2020). For example, the low willingness to accept edible insects as a meat substitute were observed among Australian consumers. The main reason was due to the strong psychological barriers such as neophobia and disgust, combined with a perception about threats to masculinity (Sogari et el., 2019). In a study conducted by Kulma et al (2020), 37.8% of the 1,340 respondents had experienced eating insects. Although more than half of the respondents reported their experience as being positive, only 11.8% consumed insects regularly. Of those who had no experience with edible insects, 14% stated their willingness to taste insects. Regarding their preferences, ground insects or insect meal were the favourite forms of consumption, regardless of the species. From a sociodemographic point of view, age and gender significantly influenced the responses; younger people and men reported more positive attitudes towards entomophagy than older people and women. Regarding eating whole insects, processed crickets, katydids and locusts were the top-rated insects (Kulma et al. 2020). Cockroaches were the least popular choice. The majority of the respondents (around 77.7%) also claimed that they would not mind consuming meat products originating from livestock that were fed insects.

It is worth noting that in the near future, as young people become more aware of sustainability and climate change issues related to food production, the impact of the potential benefits of insects might grow. Furthermore, a positive sensory experience might improve the acceptability of insects as food. Introducing new processed, insect-based products may help establish familiarity with such novel food options and open up new business opportunities (Sogari et el., 2019).

It has been found that products with visible insects are met with more disgust and apprehension by Western consumers than those where insects are processed and disguised in the product. The degree of processing also has an effect on consumer acceptance, and products where insects are completely disguised, such as insect flour, are more readily accepted than products where insects are still visible (Gmuer et al., 2016). Kulma et al. (2020) indicated greater preferences of western society to consume products containing insect protein meal than the whole insects. Therefore, products such as pasta or bakery products enriched by insect flour might help break the neophobia barrier and increase the interest in entomophagy (Wilkinson et al. 2018; Barton et al. 2020). Bakery products are more promising food products to enrich with powder forms of edible insects that could develop not only their nutritional value but also influence both the technological and sensory properties of the end-products (Biró et al., 2020).

It can be mentioned that insect consumption in developed countries is slowly gaining acceptance due to a number of factors such as the nutritional benefits and environmental awareness on the effects of livestock rearing in accelerating climate change (Ho et al., 2022). The authors further found that formulation and serving methods may increase the overall acceptability of food products in Western Society. The study which was conducted among consumers in USA cricket powder sausage showed lower liking scores than the control meal which had no crickets ($p < 0.05$). The cricket powder pasta was found to be higher in overall liking attribute than the control meal ($p < 0.05$). The cricket powder Brownies were rated highly across the physical attributes, except for texture and aftertaste ($p < 0.05$). Though the cricket powder products were found to be acceptable. The use of cricket powder may have affected the texture and flavour profile of both cricket powder sausage and brownies. The participants selected more positive emotions terms for both the cricket powder and control products than negative emotions. Negative terms selected, such as worried, decreased once the products were consumed ($p < 0.05$). Plate waste and subjective satiety may also be indicators of consumer acceptability. Significant correlations were found between appearance liking and satiety as well as taste liking and plate waste for both the control and cricket powder products ($p < 0.05$) (Ho et al., 2022). The study therefore recommended that future acceptance of insect-based products may be encouraged by evaluating the products throughout an eating experience.

Western societies are embracing insect consumption and adapting novel methods such as processing insects and adding it to other products such as bakery as pasta. This tends to improve acceptability as the likelihood of positive emotions is enhanced.

3.4 Insect as food: The regulatory framework

Foods that are contaminated by biological or chemical hazards can cause outbreaks or sporadic cases in consumers. Hence, in several countries, foodstuffs are subject to various regulations and monitoring of their production conditions (Kooh et al., 2019). As such, it is very important to be able to quantify the relative contributions of different sources to the human disease burden. In fact, several studies performed all over the world which shown food of animal origin was responsible for more than 50% of reported food-borne infectious diseases outbreaks (Kooh et al., 2019).

In view of the foregoing, it has been recommended that the same health and sanitation regulations that are employed in the processing and storage of other traditional foods of feed items must be applied in regards the processing and storage of edible insects and their products (Van Huis et al., 2013). Owing to the biological makeup of insects several issues should be considered, such as microbial safety, toxicity, palatability and the presence of inorganic compounds (Van Huis et al., 2013). Specific health implications should also be considered when insects for feed are reared on waste products such as manure or slaughterhouse waste.

It has been observed that insects have traditionally been harvested and consumed in many food cultures including Mexico, China and Australia, without a specific regulatory framework (Van der Spiegel, 2016). Due to the momentum of insect farming in both developing and developed nations, there is need for a regulatory framework that aligns with international standards. This is a fact that many agree on if safety will be guaranteed.

According to Liguori et al., (2022) the current European food legislation on novel food (EU Reg. 2015/2283) of 2018 which requires applications for the authorization of novel foods in the European market stipulates that applicants need to fulfil the requirements for the application and authorisation to bring a novel food into the European market and ensures a high level of food safety for the European consumers. The European market thus has regulation on the novel insect food as a way of striking a balance between novel foods and safety and has so far seen the authourisation of dried *Tenebrio molitor* larva, 'frozen, dried and powder form of *Tenebrio molitor* larva', frozen, dried and powder forms of *Locusta migratoria*, and frozen, dried and powder forms of *Acheta domesticus* under the novel food regulation (European Commission, 2023). This seeks to assess and identify gaps in the current strategies for predicting allergenicity of novel foods and new alternative protein sources and familiarise, understand and perform an allergenicity assessment of a novel food protein (Liguori, 2022)

Further, the European food legislation on novel food (EU Reg. 2015/2283) requires that a comprehensive assessment of nutritional, microbial and toxicological risks and evidence that the novel food is unlikely to trigger allergic reactions is conducted before authorising the introduction of the novel food/protein source on the European market. However, the risk assessment of allergenic potential of novel proteins is still challenging despite the availability of methods and standards for the assessment the risks (European Food safety Authourity (EFSA) NDA Panel, 2014; Verhoeckx et al., 2020). The EU regulation has however impacted the regulation in Thailand which is one of the major growers of cricket for the European market. The Thai farmers are required to adhere to set regulation that meet the EU standards (Preteseille *et al.*, 2018). Thus this is a positive impact which may help to enhance insect food safety for human consumption.

Francesca (2019) notes that in the European Union, the regulatory status of insects was an issue of much debate the new novel food regulation was adopted. In the old novel food regulation no mention was expressly made to insects as novel food and this resulted in different approaches of the European Member States. The study points out that the adoption of the new novel food regulation, the legal status of edible insects has been clarified: insects and their part now fall in the definition of novel food and they need to be authorized before being placed on the market. However, the study contends that the authorization process, the classification of insects as food poses new challenges when it comes to the legislation applicable to insects farming, slaughtering and processing.

In other jurisdictions such as the United States of America (USA) the approach was not different: the Food and Drug Administration (FDA) has devoted significant attention to insects in human food as defects, but has given little public attention to insects as human food or as an intentional component of human food. Their regulatory classification is therefore still unclear since they shall either be approved as food additive or their use shall be generally recognized as safe (GRAS) to be legally placed on the US market. The US requires that in order to determine safety the manufacturer making the GRAS determination would have to demonstrate that the substance is generally recognized as safe under the condition of its intended use through the experience based on common use in food (Francesca, 2019; Hutt et al., 2014). Having said this, it is clear that the lack of congruent regulation is raising complications in the industry.

A study conducted by Lahteenmaki-Uutela et al., (2021) contends that the growth of this industry is restricted due to outdated food and feed regulations covering insect use. It also argues that each country has its own substantive and procedural rules which complicates international marketing strategies for insect products.

It can be argued world food regulatory bodies such as the Food and Agriculture Organization (FAO Van der Spiegel) and the World Food Program (WFP) among others must come up with international standards on insect farming, collection and marketing. Regional bodies may also consider this especially in regions such as central and Southern Africa where insect consumption is widely practiced despite limited or blurred regulation. For example South Africa does not have a clear legal framework despite having a general food and safety framework which does not directly address insect food regulation (Niassy et al., 2018).

CHAPTER 4

4.1 CONSUMERS HEALTH RISKS

In addition to the nutritional and environmental benefits of introducing edible insects into the human diet and due to the growing acceptance of entomophagy, the potential food safety hazards and health risks to the consumers must be addressed. Thus, caution should be exercised regarding the risk factors of eating edible insects. Just as animal and plant products, some insects are not safe for consumption due to their endogenous and exogenous risk factors.

Insects are consumed in two main ways: as whole insects or as part of other food products as ingredients. However, the consumption of these insects has motivated interest among scholars and other stakeholders who continue to investigate the safety of edible insects to humans. Thus research has been undertaken in the area of farming, processing and finally consumption in order to mitigate or curb the possible food insecurities prevalent in many developing countries and thus boost nutrition. However, it is worth noting that insects are also known to have a less likelihood of transmitting zoonotic infections when compared with other nutritional sources such as animal protein (Imathiu 2020). This is not to say that the consumption of edible insects has no potential to harm consumers. On the contrary, insects are known to be poisonous and can transmit various diseases (Liguori et al., 2022).

There is clearly a need to balance the food safety concerns and the nutritional benefits of edible insects. There is a necessity to promote food safety and hygiene practices in the entire edible insect value chain including during wild harvesting in order to ensure that this affordable and highly nutritious food does not pose any health risks to consumers (Imathiu, 2019). One of the possible risk factors is the obscurity of regulation along value chain which lacks in many countries, especially developing countries. Thus, the urgency of solutions that will boost consumer confidence and ease trade of this commodity between countries is critical.

Further, edible insect rearing also possess a health risk to consumers. In the quest to meet the needs of the growing population and the need to adapt novel food insect rearing is gaining ground, but may pose health risks. Producing insects on a large scale for food and feed will likely lead to many novel challenges. Animals brought into domestication and separated from their natural habitats are susceptible to infectious diseases and insects are no exception. Insect diseases (caused by insect pathogens) can initiate dramatic epidemics in host insect populations in nature, leading to massive mortality and significant population decline. Insect pathogens can also inflict sub-lethal effects which may reduce fitness. For example, infections may result in reduced fertility, reduced ability to move, and higher vulnerability to predators (Vega and Kaya, 2012). In large scale production systems both lethal and sub-lethal insect disease effects may cause serious damage; thus monitoring, prevention and control of diseases are essential. When insects are mass-reared for food and feed they can come into contact with pathogens, which might not be typical of their natural habitat. Also, workers in rearing facilities may carry various kinds of microorganisms, including insect pathogens or vertebrate pathogens, on themselves or their clothing (Cohen, 2004). In a broader, ecological context, development of insect diseases in production systems may spread out from the facilities and into non-target insect populations, which then suffer. Finally, there is also a potential risk for human health, if the insect based food or feed is contaminated with harmful microorganisms (for example from insects fed on manure).

4.1.1 Liabilities of Entomophagy

According to the published report by EFSA (2015), on the risk profile related to the consumption of insects, a large collection of insects in the wild could pose serious interference to the landscape ecosystem. Therefore, it is recommended to consume insects reared at farms in controlled and defined conditions. The health safety of edible insects is hence assured by appropriate and safe feed. The studies carried out in the years 2003- 2010 has shown the possible risks of eating insects fed by bran containing a higher concentration of heavy metals (Bednarova et al., 2010). Thus, it is not advised to eat insects fed by an inappropriate diet, such as organic wastes which may contain toxic elements. This is despite the argument that farm reared insects may be less hazardous. On the other hand farm reared insects would be less hazardous as they would be fed n controlled feed and the environment would be controlled, but the argument that farming may also psoe a threat cannot be ignored. Some argue that

Despite several benefits of edible insects to humans, the likelihood of food safety hazards are singled out and are classified into three categories. These are biological, allergens and chemical hazards. Some sources argue that specific types of insects have certain protein types that are potentially allergen sources. Some insects may produce or contain toxic bioactive compounds. They may also contain residues of pesticides and heavy metals from the ecosystem. Adverse human allergic reactions to edible insects could be also a possible hazard. (Kourmiska and Adamcova, 2016). These proteins types include: arginine kinase, amylase and tropomyosine. However, limited literature exists on the food safety of edible insects (Van Huis et al., 2013; De Gier and Verhoeckx, 2018; Imathiu, 2020). Therefore, edible insects have a potential of being harmful and thus care must be taken in consumption.

From a hygienic point of view some insects may produce or contain toxic bioactive compounds and may also have residues of pesticides and heavy metals from the ecosystem.

Moreover allergic reactions to edible insects could be also a possible hazards to human consumers (Kourimska and Adamcova, 2016).

Some insects may also contain naturally present toxic substances such as cyanogenic glycosides (Zagrobelny et al., 2009). The consumption of grasshoppers and locusts without removing their feet can be fatal as it may cause intestinal blocking, which could have fatal consequences (Bouvier, 1945). Insect consumption can also cause allergies like stated above. Rigid external covering of the body of some insects comprised of chitin, is difficult to be digested for humans. Some people have such a small amount of chitinase enzyme that consuming insects can cause an allergic reaction to them (EFSA, 2015). People with the highest risk are those who are allergic to seafood, such as shrimp (Bednarova et al., 2010).

It is also very important to note that there is the risk of transmission of infectious diseases from some insect species (Kourmiska and Adamkova, 2016). Intestinal microbiota of insects could be a suitable medium for the growth of undesirable microorganisms. Klunder et al., (2012), evaluated the microbial content of fresh, processed and stored edible insects (T. molitor), (A. domesticus and Brachytrupes). The results showed that various types of Enterobacteriaceae and sporulating bacteria can be identified and subsequently isolated from raw insects entering them most likely during contact with the soil (Reineke et al., 2012).

If insects are to become widely and equivocally accepted as part of human diet, it is vital to identify and analyze biological hazards (e.g., bacteria, parasites, viruses, prions, yeasts, molds, mycotoxins, histamine, antibiotic resistance genes) likely to be transmitted.

Thus, there is a need to ensure food safety even as insect consumption is being promoted. Some of the preventive practices would include soaking to decontaminate, boiling the insects and removing unwanted parts that may cause indigestion like legs of a grasshopper and the thorns on the skin of some types of caterpillars.

4.1.1.2 Parasite

It is widely known that insects can carry specific internal and external parasites, which can cause diseases to insects. For example, it has been reported that nematodes belonging to the genera Steinernema and Heterorhabditis, can harm *Acheta domesticus*, while *Spinochordodes tellinni* causes high mortality in crickets and grasshoppers (Libersat et al., 2009). Amongst the parasite species \with the potential to harm and infect humans, around 10% of the species is a host larvae or nymphs of aquatic odonates insects (e.g., dragonfly, damselfly). In some Diptera, various protozoa which are dangerous to human health have been very rarely isolated (*Toxoplasma gondii*, Sarcocystis sp., Isospora sp., Giardia sp., and Cryptosporidium sp.) (Graczyk et al., 2005).

4.1.1.2 Viruses

Like parasites, there are several entomopathogenic viruses specific for invertebrates that cause animal health problems. The most well-known are the densoviruses (AdDV) and the cricket paralysis virus (CrPV), with the latest to cause particularly high mortality rates for A. domesticus populations (Fernandez-Cassi et al., 2019).

Virus-related epizootics have been reported in natural insect populations and also in a vast list of host-insects cultures (Etzel and Legner, 1999; Cory and Myers, 2003). The world-wide increase in mass rearing systems of insects for food and feed is paralleled by an increase in problems associated with insect pathogens, including viruses, potentially leading to huge economic losses (Maciel-Vergara and Ros, 2017).

Insects can also transmit vertebrate viruses. For example, the transmission of H5N1 influenza virus to chickens through infected flies, under experimental conditions (Wanaratana et al., 2013). However, in the case of foodborne viruses of main concern, such as norovirus, rotavirus and hepatitis virus, there is a lack of information on their possible transmission via consumption of insects. In addition, cooking practices and processing methods like drying, boiling and frying can greatly reduce the risk of transmission (EFSA and ECD, 2018; Kooh et al., 2019).

4.1.1.3 Prions

So far, the presence of prion or prion-related protein encoding genes in insects has not been discovered, meaning also that insects lack the potential to act as biological vectors and amplifiers of animal/human prions which is a transmissible and progressive neurodegenerative disorder (Imamura et al., 2022). Nevertheless, it has been shown that some insect species can act as mechanical vectors of prions that are present in the rearing substrate, e.g., for scrapie in sheep (EFSA, 2015). Fernandez-Cassi et al., (2019) summarized studies that report the high stability of prions in the environment, and the prions' ability to maintain their infectivity for long periods of time in soil and water.

4.1.1.4 Biological hazards

Pathogenic microbes of insects (entomopathogenic) are considered harmless to humans and animals due to phylogenetic differences, insects can be vectors for various micro-organisms that are detrimental to human and animal health, especially under poorly controlled hygienic situations/conditions.

The microbiota of insects is quite complex; rather than it being localized in the gut, it occurs on various anatomical parts (Chapman et al., 2013). This microbiota comprises microbes that are either intrinsically part of the insect's life cycle or are introduced at a later stage like farming and processing. With some exceptions, insects are usually consumed in their entirety, as removal of the gut is not always possible.

4.1.1.5 Bacteria

Many bacterial species are associated with both farm-reared and wild-caught edible insects. These include bacterial species from the genera Staphylococcus, Streptococcus, Bacillus, Pseudomonas, Micrococcus, Lactobacillus, Erwinia, Clostridium and Acinetobacter, also including some members of the family Enterobacteriaceae. Some of these bacteria are not only pathogenic and opportunistic, but will also reduce the shelf life of edible insects. To reduce the transmission of foodborne pathogens to humans through entomophagy, it is important for insect farms to have strong biosecurity measures in place and prevent contact with livestock animals.
Feeding experiments with houseflies (*Musca domestica*) using Escherichia coli O157:H7 show that the ingested bacteria can be found in the intestine, crop and mouthparts of the insects. These results show that frequent excretion potentially enhances the dissemination of Enterohemorrhagic Escherichia Coli (EHEC) to foods, particularly during the first 24 hours after ingestion of the bacteria (Sasaki et al., 2000). EHEC is a strain of Enterohemorrhagic coli that produces a toxin called Shiga toxin (Fatima, 2022). This shows how the chances of contamination by houseflies is. Rearing materials can also tell us if there are any potential microbiological risks for us to consider. A good example, if materials such as paper egg cartons are used for rearing insects, there are risks of contamination with bacteria Salmonella and Campylobacter (farmersweekly, 2021).

Air-drying of insects, where they may be in contact with soil, also poses potential food safety issues. ‘Ready-to-eat’ insects sold to consumers in many parts of the world are usually roasted or fried, steps which are very effective in eliminating foodborne pathogens. However, re-contamination or cross-contamination risks may come about if such insects are not hygienically handled or stored before consumption.

The presence of endospore-forming bacteria in edible insects is another major food safety concern, as the heat-resistant spores may withstand the common processing methods adopted for edible insects, such as boiling and deep-frying. Spore-forming bacteria such as Bacillus cereus sensu stricto, B. cytotoxicus, B. weihenstephanensis and Clostridium thermopalmarium have been found in processed edible yellow mealworms, locusts and house crickets (Sasaki et al., 2000).

It can be noted that the safety of insect consumption is threatened by contamination and bacterial infection from the insects. Handling is also another risk factor. Thus, it is important to ensure that these factors are taken into consideration even as the consumption of insects is advanced.

4.1.1.6 The possibility of allergens

It is widely known that food allergies are becoming an increasing problem. Eggs, shellfish, nuts, and milk, once considered so benign, have become common triggers for allergic reactions. A study found that insects can have the same capacity to trigger allergic reactions as do crustaceans (like shrimp and lobster) (Ribeiro et al., 2017). This makes a lot sense when you consider that insects and crustaceans are both classified as arthropods, meaning they have an exoskeleton and segmented bodies. So, if you have a shellfish allergy, you may be affected by cricket flour or roasted grasshoppers. Some risk factors include endogenous factors such as anti-nutrient substances and allergens. It was discovered that some insects just like anthropods (e.g., shellfish) can cause allergic reactions, these are caused by injectant allergens namely (bees, wasps), contactant allergens, inhalant allergens (e.g., cast skins, excreta) and/or ingestant allergens (Rumpold and Schluter, 2013). Inhalant and contactant allergens predominate in insect species, the health effects from insect allergens prevail for personnel of the insect rearing industry (Phillips and Burkholder, 1995), but caution is always advised in relation to allergic reactions at first consumption of edible insects (EFSA, 2015).

Some studies also show that people who are allergic to crustacean or house dust mite have shown cross-reactivity against the grasshopper *Sphenarium mexicanum*, the desert locust, the field cricket, the house cricket, the yellow mealworm. The major cross-reactive proteins are tropomyosin and arginine kinase, well known allergens in arthropods. However, safe food processing can reduce the risk of cross-reactivity and allergenicity of edible insects (Pali-Schöll et al., 2019; Verhoeckx et al., 2014).

4.1.1.7 Anti-nutrients

Anti-nutrients are compounds that reduce the ability of the human body to absorb essential nutrients (Hassan et al., 2014). They can therefore affect and compromise the nutritional value of many foods. Some of the anti-nutrients recorded in insects are tannin, oxalate and phytate (Adesina 2012; Ifie and Emeruwa 2011). According to a study by Shantibala et al., (2014) the nutritive contents of five potentially-edible aquatic insects, *Lethocerus indicus* (Lepeletier and Serville) (Hemiptera: Belostomatidae), *Laccotrephes maculatus* (F.) (Nepidae), *Hydrophilus olivaceous* (F.) (Coleoptera: Dytiscidae), *Cybister tripunctatus* (Olivier), and *Crocothemis servilia* (Drury) (Odonata: Libellulidae)… are a good source of minerals. Anti-nutritional properties of these insects were below 0.52%, which is a non-toxic level.

It may be argued that anti-nutrients are present in insects, but some levels may not be toxic.

4.1.1.8 Pesticides

There is so little research that has been done on the use of pesticides in the raising of insects. A study found that low levels of certain harmful chemicals (Poma et al., 2016). These were no larger than what would be find in most animal-based foods. However, it should not be ignored the fact that the use of pesticides in producing edible insects is largely unregulated, and so using insects as a food source does carry a small amount of risk. The risk is greater when insects are harvested in the wild as opposed to being farmed or raised by an insect farmer. In both Thailand and Kuwait, widespread health problems have come about in cases where dead insects were used for food after there had been attempts to "disinfest" agricultural areas through the use of pesticides (Belluco et al., 2013).

4.1.1.9 Toxins

Adequate knowledge is necessary in order to know which type of insects are good and which ones might be killing. Bees and certain kinds of ants carry harmful substances (toxins) inside of them in order to ward off predators. Those same toxins are still dangerous. Some kinds of beetles carry a metabolic steroid which can result in growth retardation, infertility, or the masculinization of females if it is consumed too frequently (Belluco et al., 2013).

It has been argued that care be taken although, the risks are quite minimal as compared to other food sources such as livestock (Tang et al., 2021).

CHAPTER 5

5.1 CONCLUSION

Various literatures support the consumption of edible insects as valuable source of protein. It can be concluded that the consumption of edible insects provides a novel source of protein and meet the amino acid requirements for humans. In addition, they are rich in MUFA and/or PUFA, as well as several micronutrients but the consumption of the insects must be done with caution as it may be hazardous. In order to be able to fully address the insects as food for human, more investigation needs to be conducted. However, the hygienic and toxicological risks reported by the EFSA, must be considered.

In laying the conclusion, this was done in line with the objectives as below:

To assess the availability and accessibility of insects as human food

The study concludes that edible insects are readily available with over 2, 000 species of insects being identified worldwide. In order to meet the growing demand, efforts have been made to increase accessibility and the existing strategies of rearing insects will further assure availability. This is backed by supporting literature.

To explore the nutritional value of insects as human food

The study concludes that edible insects have high nutrient content that surpasses traditional sources of protein like pork, poultry and beef. The study found that edible insects contain valuable nutritional components such as protein and fiber.

To investigate the health risks of edible insects to the consumer

The study concludes that despite the availability and nutritional value of edible insects they may pose a health risk to consumers. The health risks range from allergy to toxic interference from the feed that these insects may be feeding or are fed on. Liabilities of entomophagy include the possible content of allergenic and toxic substances as well as antinutrients and the presence of pathogens. Thus, there is need for more studies on the nutritional potential of edible insects and proper processing and decontamination methods developed to ensure food safety. There is also need to enhance the regulatory framework of not only rearing and wild harvesting of insects, but also their export and import.

BIBLIOGRAPHY

1. Abbasi T, Abbasi T and Abbasi S. A (2016). Reducing the Global Environmental Impact of Livestock Production: The Mini-Livestock Option. Journal of Cleaner Production, Volume 112:1754–1766. https://doi.org/10.1016/j.jclepro.2015.02.094
2. Al-qazzaz M. F and Ismail D. B. (2016). Insect meal as a source of protein in animal diet. *Animal Nutrition Feed Technnology,* 16:527–547. doi: 10.5958/0974 181X.2016.00038.X.
3. Altomare A. A, Baron G, Aldini G, Carini M and D'Amato A (2020). Silkworm pupae as source of high-value edible proteins and of bioactive peptides. Food Science Nutrition FSN), Volume 8 (6). 10.1002/fsn3.1546
4. Barton A, Richardson CD, McSweeney MB. 2020. Consumer attitudes toward entomophagy before and after evaluating cricket (Acheta domesticus)-based protein powders. Journal of Food Science 85:781–788. Blackwell Publishing Inc.
5. Batat, W and Peter, P (2020). The healthy and sustainable bugs appetite: factors affecting entomophagy acceptance and adoption in Western food cultures. Journal of Consumer Marketing, 37, 291-303, https://doi.org/10.1108/JCM-10-2018-2906.
6. Bednářová M, Borkovcová M, Zorníková G, and Zeman L (2010). Insect as food in Czech Republic, Proceedings MendelNet, 24 November, 2010, Mendel University, Brno 2010, pp. 674–682.
7. Belluco S. B, Losasso C, Maggioletti M, Alonzi C. C, Paoletti M. G and Ricci A (2013). Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review. Comprehensive Reviews in Food Science and Food Safety, Volume 12, Issue 3. https://doi.org/10.1111/1541-4337.12014
8. Berardy A., Costello C and Seager T (2015). Life cycle assessment of soy protein isolate. Proceedings of the International Symposium on Sustainable Systems and Technologies 3; Dearborn, MI, USA, 18–20 May 2015. https://scholar.google.com/scholar_lookup?journal=Proceedings+of+the+International+Symposium+on+Sustainable+Systems+and+Technologies+3&title=Life+cycle+assessment+of+soy+protein+isolate&author=A.+Berardy&author=C.+Costello&author=T.+Seager&
9. Biró, B.; Sipos, M.A.; Kovács, A.; Badak-Kerti, K.; Pásztor-Huszár, K. and Gere, A. (2020). Cricket-enriched oat biscuit: Technological analysis and sensory evaluation. Foods, 9, 1561.
10. Blackwell L. R. and d’Errico F. (2001). Evidence of termite foraging by Swartkrans early hominids. Proc. natn. Acad. Sci. USA 98, 1358–1363.

11. Borowiec M. L (2016). Generic revision of the ant subfamily Dorylinae (Hymenoptera, Formicidae). ZooKeys 608: 1–280. doi: 10.3897/zookeys.608.9427
12. Bouvier, G. (1945). Quelques questions d'entomologie vétérinaire et lutte contre certains arthropodes en Afrique tropicale. *Acta Tropica*, *2*, 42–59.
13. Bukkens S. G. F (2005). Insects in the Human Diet: Nutritional Aspects, in: M.G. Paoletti (Ed.), Ecological Implications of Minilivestock; Role of Rodents, Frogs, Snails, and Insects for Sustainable Development. Science Publishers, New Hampshire 2005, pp. 545–577.
14. Cerritos, R., and Cano-Santana, Z (2008). Harvesting grasshoppers Sphenarium purpurascens in Mexico for human consumption: A comparison with insecticidal control for managing pest outbreaks, Crop. Prot. 27 (2008) 47 3–480.
15. Chapman R. F and Simpson, S. J and Douglas A. E (2013). The Insects: Structure and Function, 5th edition. Cambridge: Cambridge University Press.
16. Christensen D. L, Orech F. O, Mungai M. N, Larsen T, Friis H and Aagaard-Hansen J (2006). Entomophagy among the Luo of Kenya: A potential mineral source. International Journal of Food Sciences and Nutrition 57(3/4):198-203. DOI:10.1080/09637480600738252
17. Daylan T. S, Liya Y, Hein J.F, Valenberg V, Martinus.A.J.S, Boekel V and Lakemond C. M. M (2014). Insect lipid profile: aqueous versus organic solvent-based extraction methods. Food Research International, 62, 1087–1094.
18. De Gier, S and Verhoeckx, K (2018). Insect (food) allergy and allergens. *Mol. Immunol. 2018, 100, 82–106.*
19. Dreon A.L and Paoletti M.G (2009). The wild food (plants and insects) in Western Friuli local knowledge (Friuli-Venezia Giulia, North Eastern Italy), Contrib. Nat. Hist. 12 (2009) 461–488.
20. EFSA (2015). Risk Profile Related to Production and Consumption of Insects as Food and Feed. EFSA Journal, 13, e4257. https://doi.org/10.2903/j.efsa.2015.4257
21. EFSA NDA Panel (Nutrition, Novel Foods and Food Allergens) (2014). Scientific Opinion on the evaluation of allergenic foods and food ingredients for labelling purposes. EFSA Journal 2014; 12(11):3894, 286 pp. https:// doi.org/10.2903/j.efsa.2014.3894
22. EFSA, S. C. (2015). Risk profile related to production and consumption of insects as food and feed. *EFSA Journal, 13*(10), 4257.
23. Egonyu J. P, Kinyuru J, Fombong F, Ng'ang'a J, Ahmed Y. A and Niassy S (2021). Advances in insects for food and feed. International Journal of Tropical Insect Science, 41:1903–1911. https://doi.org/10.1007/s42690-021-00610-8

24. Eur. J. Clin. Nutr., 70 (2016), pp. 285-291
25. Evans J, Alemu M.H, Flore R, Frøst M.B, Halloran A, Jensen A.B, Maciel-Vergara G, Meyer-Rochow V.B, Münke-Svendsen C, Olsen S.B, Payne C, Roos N, Rozin P, Tan H.S.G, Van Huis A, Vantomme P, and Eilenberg J (2015). Entomophagy: An Evolving Terminology in Need of Review, J. Insects Food Feed 1 (2015) 293–305.
26. FAO (2013). Insects for Food and Feed. https://www.fao.org/edible-insects/84627/en/
27. Farmersweekly (2021). The Possible Dangers of Eating Insects. https://www.farmersweekly.co.za/opinion/by-invitation/the-possible-dangers-of-eating-insects/
28. Fernandez-Cassi, X., Supeanu, A., Vaga, M., Jansson, A., Boqvist, S. and Vagsholm, I. (2019) The House Cricket (Acheta domesticus) as a Novel Food: A Risk Profile. Journal of Insects for Food and Feed, 5, 137-157. https://doi.org/10.3920/JIFF2018.0021
29. Finke M.D (2004). Nutrient content of insects, in: Capinera J. L (Ed.) (2008). Encyclopedia of Entomology. Kluwer Academic, Dordrecht, London, pp. 1562–1575.
30. Finke, M.D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biology, 21(3): 269–285.
31. Francesca L (2019). Insects as Food: The Legal Framework. 10.1007/978-3-030-22522-3_8.
32. European Commission (2023). Approval of fourth insect as a Novel Food. https://food.ec.europa.eu/safety/novel-food/authorisations/approval-insect-novel-food_en
33. Gabriella P, Marco C, Mara V, Barbara Sand Antonella D. Z (2022). Potentiality of protein fractions from the house cricket (Acheta domesticus) and yellow mealworm (Tenebrio molitor) for pasta formulation. Lebensmittel-Wissenschaft und-Technologie. 164. 10.1016/j.lwt.2022.113638.
34. Glover D and Sexton A (2010). Edible Insects and the Future of Food: A Foresight Scenario Exercise on Entomophagy and Global Food Security. Evidence Report Number 139, Policy Anticipation, Response and Evaluation. Institute of Development Studies.
35. Gmuer A., Guth, J. N, Hartmann C and Siegrist M (2016). Effects of the degree of processing of insect ingredients in snacks on expected emotional experiences and willingness to eat. Food Qual. Prefer. 54:117–127. doi:10.1016/j.foodqual.2016.07.003
36. Godfray H.C.J, Crute I.R, Haddad L, Lawrence D, Muir J.F, Nisbett N, Pretty J, Robinson S, Toulmin C, Whiteley R, (2010). The future of the global food system. Philos. Trans. R. Soc. B-Biol. Sci. 365 (2010) 2769–2777.

37. Graczyk, T.K., Knight, R. and Tamang, L. (2005) Mechanical Transmission of Human Protozoan Parasites by Insects. Clinical Microbiology Review, 18, 128-132. https://doi.org/10.1128/CMR.18.1.128-132.2005
38. Hassan N. M. E, Hamed S. Y, Hassan A. B, Eltayab M. M and Babiker E. E (2008). Nutritional evaluation and physiochemical properties of boiled and fried tree locust. Pakistan Journal of Nutrition 7: 325-329.
39. Hlongwane Z. T, Slotow R and Munyai T. C (2020). Nutritional Composition of Edible Insects Consumed in Africa: A Systematic Review. Multidisciplinary Digital Publishing Institute (MDPI) Nutrients Journal 2020, 12, 2786; doi:10.3390/nu12092786
40. Ho, I, Peterson, A, Madden, J, Wai, K.; Lesniauskas, R, Garza, J, Gere, A, Amin, S and Lammert, A (2020). The Crick-Eatery: A Novel Approach to Evaluate Cricket (Acheta domesticus) Powder
41. Howard, R.W. and Stanley-Samuelson, D.W. (1990). Phospholipid fatty acid composition and arachidonic acid metabolism in selected tissues of adult Tenebrio molitor (Coleoptera: Tenebrionidae). Annals of the Entomological Society of America, 83(5): 975–981.
42. Hutt P. B, Merrill R. A and Grossman L. A (2014). Food and drug law: cases and materials, University casebook series, 4th edition. Sunderland: Foundation Press.
43. Imamura, M., Tabeta, N., Iwamaru Y., Takatsuki, H., Mori, T and Atarashi, R (2022). Spontaneous generation of distinct prion variants with recombinant prion protein from a baculovirus-insect cell expression system. Biochemical and biophysical research communications
44. Imathiu S (2019). Benefits and food safety concerns associated with consumption of edible Insects. NFS Journal 18, 2019. DOI:10.1016/j.nfs.2019.11.002
45. Imathiu, S (2020). . Benefits and food safety concerns associated with consumption of edible insects. Benefits and food safety concerns associated with consumption of edible insects. NFS J. 2020, 18, 1–11.
46. Jing X and Behmer S. T (2020). Insect Sterol Nutrition: Physiological Mechanisms, Ecology, and Applications. Annual Review Entomology, 7; 65:251-271. DOI: 10.1146/annurev-ento-011019-025017
47. Jongema Y (2017). Number of Recorded Edible Insect Speies per group in the world. https://www.researchgate.net/figure/Number-of-recorded-edible-insect-species-per-group-in-the-world-n2-111-Source_fig2_330797542.

48. Joulian F. and Roulon-Doko P. (1994). Comparaison d'une activité technique chez les hommes et chez les chimpanzés: La collecte des termites. Technique et culture 23–24, 29–62.
49. Klunder H.C, Wolkers-Rooijackers J, Korpela J.M, and Nout M.J.R (2012). Microbiological aspects of processing and storage of edible insects. Food Control 26 (2012) 628–631.
50. Kooh, P. , Ververis, E. , Tesson, V. , Boué, G. and Federighi, M. (2019). Entomophagy and Public Health: A Review of Microbiological Hazards. Health, 11, 1272-1290. doi: 10.4236/health.2019.1110098
51. Kourimska L and Adamkova A (2016). Nutritional and sensory quality of edible insects. ScienceDirect. https://doi.org/10.1016/j.nfs.2016.07.001Get rights and content
52. Kronauer DJC, Berghoff SM, Powell S, Denny AJ, Edwards KJ, Franks NR, Boomsma JJ. (2006) A reassessment of the mating system characteristics of the army ant *Eciton burchellii*. *Naturwissenschaften* 93: 402–406. doi: 10.1007/s00114-006-0121-2
53. Kuehn A, Roggen E, O'Mahony L, Remington B and Crevel R (2020). COST Action 'ImpARAS': what have we learnt to improve food allergy risk assessment. A summary of a 4 year networking consortium. Clinical and Translational. Allergy, 10, 13. https://doi.org/10.1186/s13601-020-00318-x
54. Kulma M, Tumova V, Fialova A and Kourimska L (2020). Insect consumption in the Czech Republic: what the eye does not see, the heart does not grieve over. Journal of Insects as Food and Feed https://www.wageningenacademic.com/doi/epdf/10.3920/JIFF2020.0020
55. Kulma M, Tumova V, Fialova A, Kourimska L. 2020. Insect consumption in the Czech Republic: what the eye does not see, the heart does not grieve over. Journal of Insects as Food and Feed 6:525–535.
56. Latham P (2015). Edible caterpillars and their food plants in Bas-Congo province, Democratic Republic of Congo. https://www.researchgate.net/publication/275518494_Edible_caterpillars_and_their_food_plants_in_Bas-Congo_province_Democratic_Republic_of_Congo_2015
57. Libersat, O. F., Delago, A. and Gal, R. (2009). Manipulation of Host Behaviour by Parasitic Insects and Insect Parasites. Annual Review of Entomology, 54, 189-207. https://doi.org/10.1146/annurev.ento.54.110807.090556
58. Liguori B, Sancho A. I, Poulsen M and Bøgh K L (2022). Novel foods: Allergenicity Assessment of Insect Proteins. National Food Institute, Technical University of Denmark, Lyngby, Denmark. EFSA Journal, doi: 10.2903/j.efsa.2022.e200910

59. Maciel-Vergara G and Ros V. I. D (2017). Viruses of insects reared for food and feed. Journal of Invertebrate Pathology, Volume 147, July 2017, Pages 60-75. https://doi.org/10.1016/j.jip.2017.01.013

60. Meyer-Rochow, V.B, Gahukar, R.T, Ghosh, S and Jung, C (2021). Chemical Composition, Nutrient Quality and Acceptability of Edible Insects Are Affected by Species: Developmental Stage, Gender, Diet, and Processing Method. Foods 2021, 10, 1036. https://doi.org/10.3390/foods10051036

61. Miech P, Lindberg J.E, Berggren A, Chhay T, Khieu B. and Jansson A. (2016). Growth and survival of reared Cambodian field crickets (*Teleogryllus testaceus*) fed weeds and agricultural and food industry by-products, Journal of Insects as Food and Feed, https://www.wageningenacademic.com/doi/abs/10.3920/JIFF2016.0028

62. Mlcek, J. O, Rop, Borkovcova M and Bednarova M (2014). A comprehensive look at the possibilities of edible insects as food in Europe–a review. Polish J Food Nutr Sci, 64, pp. 147-157.

63. Moore, O (2013). Insects Orders. AG/BIO 345 - General Entomology, Fall 2013, University of Guam. https://guaminsects.myspecies.info/sites/guaminsects.myspecies.info/files/Insect%20Orders.pdf

64. Morgane, H., Laura, G., Giovanni, P., and Eleni, F (2015). Review on the use of insects in the diet of farmed fish: Past and future. Animal Feed Science and Technology. 203. 1-22. 10.1016/j.anifeedsci.2015.03.001.

65. Nadeau, L., Nadeau, I., Franklin, F., Dunkel, F (2014). The potential for entomophagy to address undernutrition. Ecol. Food Nutr. 54, 200–208. http://dx.doi.org/10.1080/03670244.2014.930032.

66. Niassy, S., Ekesi, S., Hendriks, S.L. and Haller-Barker, A (2018). Legislation for the use of insects as food and feed in the South African Context. In: Halloran, A., Flore, R., Vantomme, P. and Roos, N. (eds.) Edible insects in sustainable food systems. Springer, Berlin, Germany, pp. 457-470.

67. Omotoso O. T and Adedire C. O (2007). Nutrient composition, mineral content and the solubility of the proteins of palm weevil, *Rhynchophorus phoenicis* f. (Coleoptera: Curculionidae). J Zhejiang Univ Sci B. 2007, 8 (5): 318–322. doi: 10.1631/jzus.2007.B0318

68. Oonincx, D.G.A.B., van Itterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. and van Huis, A (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. Plos One, 5(12): e14445.
69. Orkusz, A (2021). *Edible Insects versus Meat- Nutritional Comparison: Knowledge of Their Composition Is the Key to Good Health Nutrients.* https://doi.org/10.3390/nu13041207
70. OSchlüter, B. Rumpold, T. Holzhauser, A. Roth, R.F. Vogel, W. Quasigroch, (2017). Safety aspects of the production of foods and food ingredients from insects. Mol Nutr Food Res, 61 (2017), Article 1600520
71. Payne C. L R, Scarborough P, Rayner M and Nonaka K (2016). Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition
72. Payne C.L.R, Scarborough P, Rayner M, and Nonaka K (2016). Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over and undernutrition. Eur. J. Clin. Nutr. 70 (2016) 285–291.
73. Payne C.L.R., Scarborough P., Rayner M., and Nonaka K. A (2015). A Systematic review of nutrient composition data available for twelve commercially available edible insects, and comparison with reference value. *Trends Food Sci. Technol.* 2016;47:69–77. doi: 10.1016/j.tifs.2015.10.012.
74. Phillips, J., Burkholder, W (1995). Allergies related to food insect production and consumption. *Food Insects Newsl.* 1995, *8*, 1–2, 4.
75. Poma G, Elvio G. A, Calaprice C, Cuykx M, Focant J. F and Covaci A (2016). Evaluation of hazardous chemicals in edible insects and insect-based food intended for human consumption. An international journal published for the British Industrial Biological Research Association. DOI:10.1016/j.fct.2016.12.006
76. Preteseille, N., Deguerry, An., Reverberi, M. and Weigel, T (2018). Insects in Thailand: national leadership and regional development, from standards to regulations through association. In: Halloran, A., Flore, R., Vantomme, P. and Roos, N. (eds.) Edible insects in sustainable food systems. Springer, Berlin, Germany, pp. 435-441.
77. Ramos-Elorduy J, Pino J.M, Prado E.E, Perez M.A, Otero J.L, and De Guevara O.L (2002). Nutritional value of edible insects from the state of Oaxaca, Mexico. J. Food Compos. Anal.

78. Ramos-Elorduy J, González E and Hernández A (2002). Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. *Journal of Economic Entomology* 95: 214– 20.

79. Raubenheimer, D., and Rothman, J. M. (2013). Nutritional ecology of entomophagy in humans and other primates. *Annual Review of Entomology, 58*, 141e160.

80. Reineke K, Doehner I, Schlumbach K, Baier D, Mathys A and Knorr D (2012). The different pathways of spore germination and inactivation in dependence of pressure and temperature, Innovative Food Sci. Emerg. Technol. 13 (2012) 31–41.

81. Replacement in Food Products through Product Eating Experience and Emotional Response. Foods 2022, 11, 4115. https://doi.org/10.3390/ foods11244115

82. Reverberi M. (2020). Edible Insects: cricket farming and processing as an emerging market. Journal of Insects as Food and Feed 6(2):211-220. DOI:10.3920/JIFF2019.0052

83. Ribeiro J. C, Cunha L. M, Sousa-Pinto B and Fonseca J (2017). Allergic risks of consuming edible insects: A systematic review. Molecular Nutrition and Food Research, July 31, 2017, 62(1) DOI: 10.1002/mnfr.201700030

84. Rumpold B.A, Schlüter O.K, (2013). Nutritional Composition and Safety Aspects of Edible Insects. Mol. Nutr. Food Res. 57 (2013) 802–823. https://www.researchgate.net/profile/Birgit-Rumpold/publication/275016949/figure/download/tbl1/AS:613925716492291@1523382705614/Average-nutrient-composition-and-energy-contents-of-edible-insect-orders-on-a-dry-matter.png

85. Sasaki, T., Kobayashi, M. and Agu, N (2000). Epidemiological Potential of Excretion and Regurgitation by Musca domestica (Diptera: Muscidae) in the Dissemination of Escherichia coli O157: H7 to Food. *Journal of Medical Entomology*, Volume 37, Issue 6, 1 November 2000, Pages 945–949, https://doi.org/10.1603/0022-2585-37.6.945

86. Shantibala T, Lokeshwari R. K and Debaraj H (2014). Nutritional and antinutritional composition of the five species of aquatic edible insects consumed in Manipur, India. Journal of Insect Science, 14: 14. doi: 10.1093/jis/14.1.14

87. Shelomi., M (2015). Why We Still Don't Eat Insects: Assessing Entomophagy Promotion through a Diffusion of Innovations Framework. DOI: 10.1016/j.tifs.2015.06.008

88. Sogari G, Bogueva D and Marinova M (2019). Australian Consumers' Response to Insects as Food. https://doi.org/10.3390/agriculture9050108

89. Sosa D.A.T and Fogliano V. (2017). Insect Physiology and Ecology: Potential of Insect-Derived Ingredients for Food Applications.

https://scholar.google.com/scholar_lookup?title=Insect+Pysiology+and+Ecology&author=D.A.T.+Sosa&author=V.+Fogliano&publication_year=2017&

90. Spencer E.A., Key T.J., Appleby P.N., Dahm C.C., Keogh R.H., Fentiman I.S., Akbaraly T., Brunner E.J., Burley V., Cade J.E., et al., Meat, poultry and fish and risk of colorectal cancer: Pooled analysis of data from the UK dietary cohort consortium. *Cancer Causes Control.* 2010; 21:1417–1425. doi: 10.1007/s10552-010-9569-7.
91. Sponheimer M, De Ruiter D, Lee-Thorp and J, Späth A (2005). Sr/Ca and early hominin diets revisited: New data from modern and fossil tooth enamel, J. Hum. Evol. 48 (2005) 147–156.
92. Subhachai B, Oranut S and Lirong S (2010). Nutritional and fatty acid profiles of sun-dried edible black ants (Polyrhachis vicina Roger). Maejo International Journal of Science and Technology. Food Sci Nutr. 8 (6): 2652–2661. doi: 10.1002/fsn3.1546
93. Tanga M. C, Egonyu J. P, Beesigamukama D, Niassy S, Emily K, Magra M. J, Omuse E, Subramanian S and Ekesi S (2021). Edible Insect Farming as an Emerging and Profitable Enterprise in East Africa. Current Opinion in Insect Science 2021, 48:64–71. DOI: 10.1016/j.cois.2021.09.007
94. texasinsects.tamu.edu/coleoptera (nd). Field Guide to Common Texas Insects: Coleoptera. Available:https://texasinsects.tamu.edu/coleoptera/
95. texasinsects.tamu.edu/Lepidoptera (nd). Field Guide to Common Texas Insects: Lepidoptera. Available: https://texasinsects.tamu.edu/lepidoptera/
96. Ugwumba S. A (2008). A Nutritional evaluation of termite (Macrotermes subhyalinus) meal as animal protein supplements in the diets of Heterobranchus longifilis, Turk. J. Fish. Aquat. Sci. 8 (2008) 149–157.
97. University of Nebraska (2023). Field Guide to Common Texas Insects: Order Diptera - True Flies. University of Nebraska, Department of Entology. Available: https://entomology.unl.edu/order-diptera-true-flies
98. Valerie S, and Patz J (2020). Research and policy priorities for edible insects. Journal of Sustainability Science. Volume 15. doi- 10.1007/s11625-019-00709-5
99. Van der Spiegel, M (2016). Safety of foods based on insects. In: Prakash, V., Martin-Belloso, O., Keener, L., Astley, S., Braun, S., McMahon, H. and Lelieveld, H. (eds.) Regulating safety of traditional and ethnic foods. Elsevier Academic Press, New York, NY, USA, pp. 205-216.

100. Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, and Vantomme P (2013). Edible Insects. Future Prospects for Food and Feed Security, FAO, Rome, P. 201.

101. Van Huis A. (2003). Insects as Food in Sub-Saharan Africa Insect Sci. Applic. Vol. 23, No. 3, pp. 163–185, 2003.

102. Van Huis, A (2015). Edible insects contributing to food security? Agric. Food Secur. 2015, 4, 20.

103. Verhoeckx K, Lindholm Bøgh K, Constable A, Epstein MM, Hoffmann Sommergruber K, Holzhauser T, Houben G,

104. Wanaratana, S., Amonsin, A., Chaisingh, A., Panyim, S., Sasipreeyajan, J. and Pakpinyo, S (2013) Experimental Assessment of Houseflies as Vectors in Avian Influenza Subtype H5N1 Transmission in Chickens. Avian Diseases, 57, 266-272. https://doi.org/10.1637/10347-090412-Reg.1

EFSA and ECDC (2018). The European Union Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and Food-Borne Outbreaks in 2017. EFSA Journal, 16, e05500. https://doi.org/10.2903/j.efsa.2018.5500

105. Wilkinson K, Muhlhausler B, Motley C, Crump A, Bray H, Ankeny R. 2018. Australian Consumers' Awareness and Acceptance of Insects as Food. Insects 9:44.

106. Wynants, E., Frooninckx, L., Crauwels, S., Verreth, C., De Smet, J., Sandrock, C., Wohlfahrt, J., Van Schelt, J., Depraetere, S., Lievens, B., Van Miert, S., Claes, J. and Van Campenhout, L., (2019). Assessing the microbiota of black soldier fly larvae (Hermetia illucens) reared on organic waste streams on four different locations at laboratory and large scale. Microbial Ecology 77: 913-930.

107. Xiaoming C, Ying F, and Hong Z (2010). Review of the nutritive value of edible insects. Edible insects and other invertebrates in Australia: future prospects, Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19-21 February 2008, Bangkok 2010, pp. 85–92.

108. Yen, A. L. (2009). Edible insects: traditional knowledge or western phobia? *Entomological Research, 39,* 289e298. http://dx.doi.org/10.1111/j.1748-5967.2009.00239.x.

109. Zagrobelny M, Dreon A.L, Gomiero T, Marcazzan G.L, Glaring M.A, Moller B.L, and Paoletti M.G (2009). Toxic moths: Source of a truly safe delicacy, J. Ethnobiol. 29 (2009) 64–76.

LIST OF ABBREVIATIONS

BT: Bacillus Thuringiensis

CFU: Colony Forming Unit

CI: Confidence Interval

HACCP: Hazard Analysis Critical Control Point

ID50: Infectious Dose 50

LAB: Lactic Acid Bacteria

MPN: Most Probable Number

OTU: Operational Taxonomic Unit

QMP: Quality Management Program

RR: Risk Ratio or Related Risk

rRNA: ribosomal Ribonucleic Acid

STEC: Shiga Toxin Escherichia coli

TMA: Total Mesophilic Aerobes

TAC: Total Aerobic Count

FAO: Food agriculture organisation