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Edible Insects: A Sustainable Solution for the Future Food and Feed Security

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Abstract

The COVID-19 pandemic exposed that we as a global society are not prepared enough to deal with food security amid unexpected situations. The global population is steadily increasing, posing significant challenges to food and feed security. With the world's population projected to reach 9.7 billion by 2050, finding alternative protein sources that are environmentally friendly and economically viable is becoming increasingly important. In recent years, there has been growing interest in using insect protein as a sustainable alternative to traditional meat production. This interest stems from several factors, including the increasing global population, the environmental impact of meat production, and the need for more sustainable practices in the food and feed industry. This paper will explore the potential advantages and limitations of edible insects as a source of protein for future food and feed security.

Keywords: Entomophagy, Edible insects, Insect Protein, Food security, Environmental sustainability.

INTRODUCTION

The exponential growth in the global population has significant implications for food security. As the world's population continues to increase, the demand for food also rises, posing challenges to ensure an adequate and sustainable food supply. This phenomenon has led to concerns about the ability of current agricultural practices to meet the growing demand for food, as well as the potential impact on natural resources, environmental sustainability, and social stability. Insects as food and feed emerge as an especially relevant issue in the twenty-first century due to the rising cost of animal protein, food and feed insecurity, environmental pressures, population growth, and increasing demand for protein among the middle classes. Thus, alternative solutions to conventional livestock and feed sources urgently need to be discovered. Although entomophagy has been practiced by humans for thousands of years, until recently, edible insects have gained special attention due to their high nutritional value and lower environmental impact that could help alleviate the global food demand. The consumption of insects, or entomophagy, contributes positively not only to the environment but to health and livelihoods as well.

Global Population and Future Food Security

The world's population has grown exponentially over the past few centuries. In 1800, the global population was estimated to be around 1 billion people. By 1927, just over a century later, the population had doubled to 2 billion. The rate of growth continued to accelerate, reaching 3 billion by 1960, 4 billion by 1974, 5 billion by 1987, and 6 billion by 1999. Currently, the global population stands at over 7.8 billion (FAO, 2021). This growth is primarily driven by factors such as improved healthcare, reduced infant mortality rates, increased life expectancy, and declining fertility rates. The Food and Agriculture Organization (FAO) of the United Nations has predicted the world's population to reach 9.7 billion by 2050 and 11.2 billion by 2100. The rapid increase in population has raised concerns about food security, as the demand for food continues to rise. The challenge of feeding a growing population is further compounded by factors such as climate change, limited

arable land, water scarcity, and the need for sustainable agricultural practices (Van Huis *et al*., 2013).

Global Hunger and Malnutrition

The number of people in the world affected by hunger increased in 2020 under the shadow of the COVID-19 pandemic. In terms of population, it is estimated that between 720 and 811 million people in the world faced hunger in 2020. It is projected that 660 million people may still face hunger in 2030, in part due to the lasting effects of the COVID-19 pandemic on global food security (FAO, 2021). According to the World Food Programme (WFP), there is an estimated 805 million people who are without enough food to maintain a healthy and active lifestyle (WFP, 2015). Although not as widespread in developed nations, food insecurity and malnutrition are still a serious and prevailing issue for much of the world (Muller and Krawinkel, 2005). Developing countries, especially those in Sub-Saharan Africa and South Asia, have the highest rates of hunger. Although Asia contains the largest population of hungry people, about two-thirds of the total, Africa has the highest prevalence (WFP, 2015).

In 2019, approximately 687.8 million people worldwide suffered from malnourishment (Szmigiera 2021). Approximately 150 million children worldwide do not have access to the required amounts of energy or nutrients for growth and development, with more than half (52%) of these children residing in South Asia and almost a quarter (21%) living in Sub-Saharan Africa (UNICEF, 2001). About half of all avoidable deaths in children under five are caused by malnutrition. Malnourishment occurring in early childhood and if untreated results in life-threatening consequences. Chronic malnutrition will lead to irreversible stunting and has been reported to be the most important risk factor for illness and death from diseases (WFP, 2015). Madagascar is one of the 10 countries with the highest occurrences of chronic malnutrition (UNICEF, 2013). With at least 50% of the population moderately or severely malnourished, food insecurity remains a critical concern in this nation.

In developing countries, most people are poor and can only afford low-quality diets that contribute to all forms of malnutrition (Lartey *et al*., 2018; Siddiqui *et al*., 2020). Consequently, these countries suffer the greatest productivity losses due to malnutrition, causing a significant negative impact on their economies. Yet, nutrition is one of the most cost-effective ways to solve malnutrition and its consequences problems (Shekar *et al*., 2016). To address the nutritional requirements of poor people in developing countries, affordable, high-quality foods are needed (Bhargava 2015). Insects are a low-cost, high-quality, and nutritious food (Tang *et al*., 2019). Thus, edible insects may be a viable solution for traditional entomophagous developing countries where malnutrition persists, such as Myanmar, Nigeria, and Madagascar (Ancha *et al*., 2021; Dürr and Ratompoarison 2021; Meysing *et al*., 2021).

Food Security

Food security is a crucial aspect of global health and development that ensures everyone has access to sufficient, safe, and nutritious food to maintain an active and healthy life. It encompasses various aspects such as agricultural productivity, distribution systems, economic factors, and environmental sustainability. *Food security* refers to the availability, accessibility, affordability, and utilization of nutritious and safe food for all individuals at all times (Behnassi *et al*., 2011). This concept is essential for ensuring the well-being and development of individuals and communities. With the world's population projected to grow from 7.8 billion in 2021 to approximately 9.7 billion in 2050, food security is facing significant challenges.

Components of Food Security

Food security is a multifaceted issue that encompasses various components, including food availability, accessibility, utilization, and stability (Aborisade and Bach, 2014).

1. **Availability:**

Food availability refers to the physical availability of food in a region or country. It involves sufficient production and distribution of food to meet the needs of the population. Food availability includes factors such as the cultivation of crops, raising livestock, and fishing, as well as the efficient transportation and storage of food.

2. **Accessibility:**

Access to food is another critical aspect of food security. It is influenced by factors such as income, geographical location, and social networks. Food accessibility relates to the ability of individuals and communities to acquire food through affordable prices and stable markets. It also includes access to information on nutrition and food preparation.

3. **Utilization:**

Food utilization focuses on the consumption of nutritious and safe food by individuals and communities. It is influenced by factors such as food preparation, food hygiene, proper storage, and consumption practices to prevent diseases related to food.

4. **Stability:**

Food security must be maintained over time, ensuring that people have consistent access to food. Stability is influenced by factors such as climate change, economic shocks, and political instability.

Challenges to Food Security

Food security is a complex issue influenced by various factors such as population growth, climate

change, economic conditions, and access to resources. The challenge of ensuring food security for a growing population is multifaceted and requires comprehensive solutions (FAO, 2013). Agricultural productivity must increase significantly to keep pace with population growth. However, this must be achieved while minimizing the environmental impact of agriculture, conserving natural resources, and adapting to climate change. Additionally, issues such as land degradation, water scarcity, and loss of biodiversity further complicate efforts to sustainably expand food production (Rosegrant and Cline, 2003).

1. Climate Change:

Climate change poses a significant threat to food security. Rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events can disrupt agricultural production, leading to crop failures and reduced yields. Additionally, climate change can contribute to the spread of pests and diseases that affect crops and livestock.

2. Limited Arable Land:

The expansion of urban areas and degradation of fertile land due to factors like deforestation and soil erosion pose challenges to agricultural production in meeting the food demands of a growing population. Additionally, climate change impacts such as droughts, floods, and extreme weather events further reduce arable land availability.

3. Water Scarcity:

Water scarcity is a critical issue for agriculture, as it is essential for crop irrigation and livestock production. With increasing demand for water from various sectors and the impact of climate change on water availability, ensuring sustainable water management in agriculture is crucial for food security (Rosegrant and Cline, 2003).

4. Sustainable Agricultural Practices:

Adopting sustainable agricultural practices is essential for enhancing food security while minimizing environmental impact. Practices such as conservation agriculture, agroforestry, precision farming, and organic farming can contribute to increased productivity while preserving natural resources (Behnassi *et al*., 2011).

5. Loss of Biodiversity:

The loss of biodiversity due to habitat destruction, pollution, and intensive farming practices affects ecosystem services essential for agriculture, such as pollination and natural pest control.

6. Food Waste:

Significant amounts of food are wasted throughout the supply chain, from production to consumption. Reducing food waste can contribute to improving food security by ensuring that available resources are utilized efficiently.

The United Nation's Food and Agriculture Organization (FAO) projects the world population approaching to 9 billion by 2050. As the global population swells, natural resources such as land and water are being rapidly degraded. Edible insects, with their high feed conversion efficiency and fecundity, as well as their minimal space for rearing, certainly represent as an advantageous solution for present and future food insecurity (Van Huis *et al*., 2013).

Rise in Global Population and Meat Production

One significant consequence of the global population increase is the surge in meat production. Meat consumption has traditionally been associated with affluence and cultural preferences. As people's incomes rise and lifestyles change, there is a growing demand for animal-based protein sources. Meat consumption has more than doubled over the past five decades and is expected to continue rising (Katare *et al*., 2020). However, the exponential increase in meat consumption over the past few decades has raised concerns regarding its environmental impact, animal welfare, and human health implications.

Among agricultural practices, livestock sector is a significant contributor to the global climate change, contributing between 12% and 18% to the total green-house gas (GHG) emissions (Gomez-Zavaglia *et al*., 2020, Allen and Hof, 2019). Large areas of forests are cleared to create pastureland or grow feed crops like soybeans and corn for livestock. Deforestation contributes to climate change by releasing carbon dioxide stored in trees and reducing the planet's capacity to absorb greenhouse gases. Moreover, meat production requires substantial amounts of water and contributes to water scarcity in many regions. It also generates significant amounts of greenhouse gas emissions, particularly methane from ruminant animals like cattle. Additionally, intensive animal farming practices often involve the use of antibiotics and hormones to enhance growth rates and prevent diseases. Agricultural overexploitation – larger farm and field sizes, and more use of pesticides and fertilizers causes a loss of natural biodiversity and habitats (Geiger *et al*., 2010).

To mitigate these negative impacts, various initiatives have emerged to promote sustainable meat production practices. These include reducing meat consumption through dietary shifts towards plant-based diets or alternative protein sources, improving animal welfare standards, implementing regenerative agriculture techniques, and developing lab-grown or cultured meat. The exploration of insects as a sustainable food source has gained traction in recent years due to its potential to address the challenges associated with rising population and meat production. Insects are highly

nutritious and rich in protein, vitamins, minerals, and healthy fats. They also have a significantly lower environmental footprint compared to traditional livestock.

Insects and Their Role in Ecosystem

Insects are the most diverse group of animals on the planet. The total number of insect species is estimated at 5.5 million, of which about 1 million have been described and named (Stork, 2018). These constitute around half of all eukaryote species, including animals, plants, and fungi (Erwin, 1982). The term insect is derived from the Latin word insectum meaning "with a notched or divided body". Insects are the largest group within the arthropod phylum that have a chitinous exoskeleton, a three-part body (head, thorax, and abdomen), three pairs of jointed legs, compound eyes and two antennae. The most diverse insect orders are the Hemiptera (true bugs), Lepidoptera (butterflies and moths), Diptera (true flies), Hymenoptera (wasps, ants, and bees), and Coleoptera (beetles), each with more than 100,000 described species (Stork, 2018).

Insects are distributed over every continent and almost every terrestrial habitat. There are many more species in the tropics, especially in rainforests, than in temperate zones (Gullan and Cranston, 2014). Some 30–40,000 species inhabit freshwater; very few insects, perhaps a hundred species, are marine (Crook, 2018). Insects such as snow scorpionflies flourish in cold habitats including the Arctic and at high altitude (Hagvar, 2010). Insects such as desert locusts, ants, beetles, and termites are adapted to some of the hottest and driest environments on earth, such as the Sonoran Desert.

Insects play many critical roles in ecosystems, including soil turning and aeration, dung burial, pest control, pollination and wildlife nutrition (Schowalter, 2006). For instance, termites modify the environment around their nests, encouraging grass growth; many beetles are scavengers; dung beetles recycle biological materials into forms useful to other organisms (Losey and Vaughan, 2006). Insects are responsible for much of the process by which topsoil is created. Many insects are considered pests by humans. These include parasites of people and livestock, such as lice and bed bugs; mosquitoes act as vectors of several diseases. Other pests include insects like termites that damage wooden structures; herbivorous insects such as locusts, aphids, and thrips that destroy agricultural crops, or like wheat weevils damage stored agricultural produce (Gullan and Cranston, 2014).

At least 66 insect species extinctions have been recorded since 1500, many of them on oceanic islands (Briggs, 2017). Declines in insect abundance have been attributed to human activity in the form of artificial lighting, land use changes such as urbanization or farming, pesticide use, and invasive species (Wagner *et al*., 2010). A 2019 research review suggested that a large proportion of insect species is threatened with extinction in the 21st century (Sanchez-Bayo *et al*., 2019), though the details have been disputed (Saunders, 2019). A larger 2020 meta-study, analyzing data from 166 long-term surveys, suggested that populations of terrestrial insects are indeed decreasing rapidly, by about 9% per decade (Van Klink *et al*., 2020)

Insects as a Source of Food: A Historical and Cultural Perspective

Insects have been a part of the human diet for centuries, with evidence of their consumption found in prehistoric archaeological sites. The remains of insect integuments, wings, and other body parts have been found in the fossilized feces (coprolites) of ancient humans in caves in the USA and Mexico (Mannino and Thomas, 2023). Cave art, dating back tens of thousands of years, provides valuable insights into the beliefs, practices, and daily life of prehistoric human societies. Although large, hunted animals such as bison, mammoths, and deer are commonly depicted in cave paintings, insects also appear in some of these works (Mithen and Mithen, 1999). Bees, wasps, beetles, and other flying insects are often depicted in hunting scenes, feeding on plants or entangled in webs. In south-western France, in the Magdalenian cave of Les Trois Frères (Upper Paleolithic, dating from around 17,000–12,000 years ago), there is a remarkable representation of a 'cave grasshopper' engraved on an animal bone (Sonneville-Bordes, 1963). The presence of this engraving has been interpreted by some researchers as a possible link between insects and feeding practices (Renfrew and Bahn, 2016). Another archaeological site in Europe that provides insights into insect consumption in prehistoric times is Altamira, a famous cave in northern Spain known for its remarkable paintings of animals, such as bison and horses, as well as abstract designs. The paintings provide insights into the daily life and beliefs of the prehistoric peoples who inhabited the region during the Upper Paleolithic, some 36,000 years ago, and also depict a collection of edible insects and nests of wild bees. Incidentally, the consumption of insects likely played a crucial role in the diet of early humans due to their abundance and nutritional value (Baiano, 2020).

Food practices are influenced by traditions and cultures, which have been influenced historically by religious beliefs. The practice of eating insects is cited throughout religious literature in the Christian, Jewish and Islamic faiths. The consumption of insects has been mentioned in the Bible, particularly in the Old Testament. In Leviticus 11:20–23, for example, it is written that any winged insect that walks on "four" legs is considered unclean, while other winged insects, such as locusts, crickets, and grasshoppers are considered clean and can be eaten by the Israelites (Beck, 1939). There are several references in Islamic tradition to insect

eating – including locusts, bees, ants, lice and termites (El-Mallakh and El-Mallakh, 1994). The large majority of references are to locusts, specifically mentioning permission to consume the creatures: It is permissible to eat locusts (Sahih Muslim, 21.4801), Locusts are game of the sea; you may eat them (Sunaan ibn Majah, 4.3222), Locusts are Allah's troops, you may eat them (Sunaan ibn Majah, 4.3219, 3220). Human consumption of insects is also present in Jewish literature (Landa, 1946). Amar (2003) suggested that eating certain species of kosher locusts was largely accepted in ancient times. The practice, however, declined among a considerable part of the Jewish diaspora due to a lack of knowledge about the various types of "winged swarming things" mentioned in the Torah. The tradition was only preserved among Jews of Yemen and in parts of northern Africa. Amar (2003) argued that westernization caused Jews who previously ate locusts to reverse their habits.

The history of human insect consumption is well documented by Bodenheimer (1951). In the Middle East, as far back as the eighth century BCE, servants were thought to have carried locusts arranged on sticks to royal banquets in the palace of Asurbanipal (Ninivé). The first reference to entomophagy in Europe was in Greece, where eating cicadas was considered a delicacy. Aristotle (384–322 BCE) wrote in his Historia Animalium: "The larva of the cicada on attaining full size in the ground becomes a nymph; then it tastes best, before the husk is broken [i.e. before the last moult]". He also mentioned that, of the adults, females taste best after copulation because they are full of eggs. In the second century BCE, Diodorus of Sicily called people from Ethiopia Acridophagi, or "eaters of locusts and grasshoppers" (Acrididae family, Orthoptera order). In Ancient Rome, author, natural philosopher and naturalist Pliny the Elder – author of the encyclopedia Historia Naturalis – spoke of cossus, a dish highly coveted by Romans. According to Bodenheimer (1951), cossus is the larva of the longhorn beetle Cerambyx cerdo, which lives on oak trees. Literature from ancient China also cites the practice of entomophagy. Li Shizhen's Compendium of Materia Medica, one of the largest and most comprehensive books on Chinese medicine during the Ming Dynasty in China (1368–1644), displays an impressive record of all foods, including a large number of insects. The compendium also highlights the medicinal benefits of the insects.

Despite their potential as a sustainable and nutritious food source, insects have historically been viewed as a last resort or a delicacy, rather than a mainstream food source (Meyer-Rochow, 2009). However, as the world's population continues to grow and the demand for protein-rich foods increases, the consumption of insects as a source of food is gaining popularity once again. One of the main reasons for the resurgence of insect consumption is the growing awareness of the environmental and health benefits of insect-based foods. Insects are high in protein, low in fat, and require minimal resources to produce, making them a more sustainable alternative to traditional livestock. Additionally, insects are a good source of micronutrients such as iron, zinc, and calcium, which are essential for human health. Despite the potential benefits of insect-based foods, there are still many challenges to overcome before they can become a mainstream food source. One of the main challenges is the cultural and social acceptance of insect consumption, as many people are still hesitant to try insects as a food source (Kellert, 1993). Additionally, there are concerns about the safety and regulation of insect-based foods, as well as the potential for insects to be contaminated with harmful chemicals or bacteria.

Entomophagy: A Sustainable Food Resource

As the global population continues to grow, there is increasing interest in alternative sources of food that can supplement traditional agricultural and meat production. One such alternative is entomophagy. The term *"entomophagy"* is derived from the Greek words "entomon," meaning insect, and "phagein," meaning to eat. Therefore, entomophagy refers to the practice of consuming insects as a food source by humans. However, other animals that eat insects are referred to as insectivores. *Entomophagy*, the practice of consuming insects as food, is an ancient culinary tradition that has gained renewed interest in recent years due to its potential as an alternative food resource (Van Huis, 2013).

With the human population expected to reach 9.7 billion by 2050, there is an increasing demand for sustainable and nutritious food sources. The current rate of food production must be increased to feed the growing global population (FAO, 2009). For that, an extension of agriculture must be done. However, extending agriculture to produce more feed is not a practical solution due to limitations in land availability. To meet the protein requirements of the growing population, more livestock must be reared. Feed requirements of livestock are so high that more and more feed sources must be found out. Livestock is the major contributor to the anthropogenic emission of greenhouse gases, so extending production might prove costly to the environment (Vetter *et al*., 2017). Therefore, considering all these factors together, there is an urgent need to discover alternative sustainable protein sources. Insects have emerged as a promising option due to their high nutritional value, low environmental impact, and ease of farming. In comparison with livestock, insects have minimal resource requirements in terms of feed, land resources, and water. Apart from this, the carbon footprint of insects is negligible compared to conventional livestock (Van Huis, 2013). Insect meat is rich in micronutrients like iron, calcium, manganese, copper, and several essential amino acids. It has a low amount of carbohydrates and fat. Insects release minimal

greenhouse gases compared to livestock (Oonincx *et al*., 2010). Studies have shown that insects for animal feed can be even reared in organic side streams and kitchen waste, thus tackling the problem of organic waste management.

Acrossthe globe, more than 2000 insect species are consumed in over 100 countries, with the most well-known examples being Chapulines (grasshoppers) in Mexico, mopane worms in Southern Africa, and witchetty grubs in Australia (Jongema, 2017). Most species of insects that are eaten by humans fall within the following taxonomic groups: Coleoptera (beetles), Lepidoptera (moths and butterflies), Hymenoptera (wasps, bees, and ants), Orthoptera (crickets, grasshoppers, and locusts), Hemiptera (also called Heteroptera; true bugs), Isoptera (termites), Odonata (dragonflies), and Diptera (flies).

The most common insects consumed are beetles (31 percent). This is not surprising given that the Coleoptera group contains about 40 percent of all known insect species. The consumption of caterpillars (Lepidoptera), especially popular in sub-Saharan Africa, is estimated at 18 percent. Bees, wasps and ants (Hymenoptera) come in third at 14 percent (these insects are especially common in Latin America). Following these are grasshoppers, locusts and crickets (Orthoptera) (13 percent); cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) (10 percent); termites (Isoptera) (3 percent); dragonflies (Odonata) (3 percent); flies (Diptera) (2 percent); and other orders (5 percent). Lepidoptera are consumed almost entirely as caterpillars and Hymenoptera are consumed mostly in their larval or pupal stages. Both adults and larvae of the Coleoptera order are eaten, while the Orthoptera, Homoptera, Isoptera and Hemiptera orders are mostly eaten in the mature stage (Cerritos, 2009).

Over 3000 ethnic groups in mainly African, Asian, and Latin American countries eat insects as part of their normal diet (Van Huis *et al*., 2013). They can be eaten at various life stages including eggs, nymphs, and adults, depending on the species and processing method. In Asia, 349 kinds of bugs are munched on across 29 countries (Raubenheimer and Rothman, 2013). The people of the Arunachal Pradesh state in Northern India collectively consume 81 different species of bugs, not including the silk worms commonly sold at the markets. (Chakravorty *et al*., 2011). In Chang Mai, Thailand, one can collect giant winged red ants, two hours of hunting resulting in one liquor-bottle full. These ants are delicious in a stir-fry, and add a bacon-like flavor. Like the Venezuelans, Cambodians also like to enjoy themselves a nice skewer of tarantulas from time to time. Children from Bali, Indonesia, are still taught to catch dragonflies. A strip of palmwood is first coated in the white sap of the jackfruit tree, which then ensnares the wings of dragonflies. In Irian Jaya, sago-palm trees are cut down to make flour. The stump is resourcefully left behind for sago-grubs to invade, and to later be harvested. In China, scorpions can be found for sale in the markets of Guangzhou, both for consumption and medicinal purposes. Though traditionally scorpions are cooked, they can also be munched on while in a comatose state induced by being soaked in rice wine (Menzel and D'Aluisio, 1998).

Even though over two billion people eat insects, it is still met with great resistance by many Western consumers. Most have grown up viewing all insects as 'bugs', initiating feelings of disgust or fear (Looy *et al*., 2014). However, there has been an increasing interest in edible insects' due to the nutritional and sustainable benefits. The global market for edible insects is expected to grow rapidly in the coming years, driven by factors such as population growth, increased awareness of the nutritional benefits of insects, and the search for sustainable food sources. In 2013, United Nations' Agriculture and Food Organisation released a detailed report (Van Huis *et al*., 2013) on the potential of insects as food and feed. The commercial production and distribution of insects and insect products such as cricket flours, protein bars, and chips has increased over recent years in Western societies. Schösler *et al*., (2012) indicated a trend towards more modern and gourmet insect products sold at specialist stores. Countries such as Canada, Netherlands, Belgium, and others are at the forefront of insect consumption, with a few insect products already on the market (Balzan *et al*., 2016; Schösler *et al*., 2012; Verbeke, 2015).

Benefits of Using Insects as a Source of Food

In recent years, the consumption of insects as a food source has gained traction as a sustainable and nutritious alternative to traditional protein sources. There are several benefits associated with using insects as a food source, which include environmental, nutritional, and economic advantages (Van Huis *et al*., 2013).

1. Environmental Benefits

a. Sustainable Agriculture:

Insects have a higher feed conversion rate than traditional livestock, meaning they require less feed to produce the same amount of protein. This reduces the pressure on agricultural land and water resources.

b. Greenhouse Gas Emissions:

Rearing insects produces fewer greenhouse gas emissions than livestock farming, as they require less land, feed, and energy. This helps to mitigate climate change and its effects on the environment.

c. Organic Waste Management:

Insects, particularly black soldier flies and houseflies, can be used to process organic waste, such as food scraps and manure. This helps to reduce the amount

of waste that ends up in landfills and contributes to the production of valuable fertilizers.

2. Nutritional Benefits

a. Complete Protein Source:

Insects are a complete protein source, containing all nine essential amino acids needed for human consumption. They are particularly rich in essential amino acids like tryptophan, which is often lacking in plant-based proteins (Kourimska and Adamkova, 2016).

b. High Nutrient Density:

Insects are packed with essential vitamins, minerals, and micronutrients, such as iron, zinc, calcium, and B vitamins. This makes them an ideal food source for individuals with nutrient deficiencies or those looking to improve their overall health.

c. Healthy Fats:

Many insects contain healthy fats, such as omega-3 and omega-6 fatty acids, which are essential for brain function, heart health, and maintaining healthy skin and hair (Raksakangtong *et al.*, 2010).

3. Economic Benefits

a. Local Production:

Insect farming can be done on a small scale, making it accessible to local communities and providing a sustainable source of income for small-scale farmers.

b. Job Creation:

The insect farming industry can create jobs in the processing, packaging, and marketing of insect-based products, helping to boost local economies.

c. Diversification of Diet:

Incorporating insects into human diets can help address food security issues, especially in areas where traditional protein sources are scarce or expensive.

Thus, using insects as a food source offers numerous environmental, nutritional, and economic benefits. By adopting insects as a sustainable protein source, we can help alleviate pressure on traditional livestock farming, improve human health through the consumption of nutrient-rich insects, and create job opportunities in the insect farming industry.

Insects as a Source of Food: Risks and Challenges

Insects are considered a sustainable and nutritious source of protein. However, there are several risks associated with their consumption. It is important to address these risks through proper regulation, hygiene standards, and education to ensure the safe and sustainable consumption of insects as a source of food. These risks can be categorized into three main areas: health risks, environmental risks, and socio-economic risks (Lange and Nakamura, 2021).

1. Health Risks

- ***Allergies and Intolerances***

Some people may be allergic or intolerant to certain insects or their byproducts. For example, crickets contain a protein called *tropomyosin*, which has been known to cause allergic reactions in some individuals. Additionally, insects may carry harmful bacteria, viruses, or parasites that can be transmitted to humans through consumption.

- ***Contamination and Hygiene***

Insects can carry harmful bacteria, viruses, or parasites, just like any other animal product. Improper handling, storage, and cooking can lead to contamination, which can pose health risks to consumers. Insect farming and processing facilities must adhere to strict hygiene standards to minimize the risk of contamination.

- ***Nutrient Deficiencies***

While insects are high in protein, they may be low in other essential nutrients like vitamins and minerals. Consuming insects as a primary source of sustenance can lead to nutrient deficiencies if not properly balanced with other food sources.

2. Environmental Risks

- ***Ecosystem Disruption***

Insect farming can have negative impacts on local ecosystems if not properly managed. For example, the large-scale cultivation of insects can lead to habitat destruction, water pollution, and soil degradation. Additionally, the use of pesticides and other chemicals in insect farming can harm beneficial insects and other wildlife.

- ***Climate Change***

Certain insects, such as crickets, require significant amounts of energy to produce. This can contribute to greenhouse gas emissions and climate change. Additionally, the transportation of live insects can lead to further carbon emissions.

3. Social and Economic Challenges

- ***Cultural and Social Barriers***

Insect consumption is not widely accepted in many cultures, leading to social and cultural barriers to adoption. Additionally, the high cost of insect production and processing can make it difficult for low-income communities to access insect-based foods.

- ***Regulatory Frameworks***

The regulation of insect-based foods varies widely around the world, with some countries having specific laws and guidelines for the production and sale of insect-based foods, while others have no regulations at all. The lack of a clear regulatory framework can create challenges for the industry, particularly in terms of food

safety and labeling. The insect industry is largely unregulated, which can lead to inconsistent quality control and potential health risks. There is a need for stricter regulations and oversight to ensure the safety and quality of insect-based foods.

- ***Production and Supply Chain***

The production of insect-based foods can be challenging, particularly in terms of scaling up production and creating a reliable supply chain. Insect farming requires specialized equipment and expertise, and the logistics of transporting and storing insects can be complex.

- ***Consumer Acceptance***

While some consumers may be willing to try insect-based foods, there may be a lack of awareness or understanding about the benefits of insect-based foods, or a reluctance to try new and unfamiliar foods. Additionally, the "ick" factor may be a significant barrier to consumer acceptance.

Insects as a Source of Feed: Benefits and Challenges

Insects play a significant role in the feed industry, particularly as a source of alternative protein and other valuable nutrients. The use of insects in animal feed has gained attention in recent years due to their high nutritional value, low environmental impact, and potential to address the growing demand for sustainable protein sources (Lange and Nakamura, 2021). Insects are rich in protein, essential amino acids, vitamins, minerals, and healthy fats. They can be used as a substitute for traditional feed ingredients such as soybean meal and fish-meal, which are limited in availability and have a higher environmental footprint. Insect-based feed offers a sustainable solution to meet the increasing demand for animal protein while reducing the reliance on conventional feed sources. Insect-based feeds can be used for livestock, poultry, aquaculture, and even pets. Insects such as black soldier flies and meal-worms can be reared on organic waste streams like food scraps or agricultural by-products, reducing waste and providing a sustainable source of animal feed.

Benefits of Insect-Based Feed:

1. Sustainable Protein Source:

Insects have a high feed conversion efficiency, meaning they can convert feed into body mass more efficiently than traditional livestock. For example, crickets can convert feed into body mass at a rate of 2:1 or even better. This efficiency makes insects an environmentally friendly alternative to conventional livestock production (Van Huis *et al*., 2013).

2. Reduced Environmental Impact:

Insect farming requires significantly less land, water, and feed compared to traditional livestock farming. It also produces fewer greenhouse gas emissions and generates less waste (Vetter *et al*., 2017). By incorporating insects into animal feed, the overall environmental impact of the feed industry can be reduced.

3. Circular Economy:

Insect farming can contribute to a circular economy by utilizing organic waste streams as feed inputs. For instance, black soldier fly larvae can be reared on food waste or agricultural by-products that would otherwise go to landfill. This not only reduces waste but also creates a valuable protein source for animal feed (Losey and Vaughan, 2006).

Regulatory Considerations

The use of insects in animal feed is subject to regulatory frameworks that vary across countries and regions. Some countries have already approved the use of certain insect species in animal feed, while others are in the process of developing regulations. These regulations ensure the safety and quality of insect-based feed, addressing concerns related to allergenicity, potential contamination, and the use of specific insect species (Baiano, 2020).

Challenges and Opportunities

While the use of insects in animal feed offers numerous benefits, there are still challenges to overcome. Some of these challenges include scaling up insect production, optimizing feed formulations, ensuring consistent quality, and addressing consumer acceptance (Verbeke, 2015). However, ongoing research and technological advancements are addressing these challenges and opening up new opportunities for the insect feed industry.

Insect Farming and Future Prospects

Insects are much more efficient in converting feed to body weight than conventional livestock and are particularly valuable because they can be reared on organic waste streams (e.g. animal slurries). Research into rearing insects as food and feed on a large scale remains a priority. Current production systems are still too expensive. A study in the Netherlands (Meuwissen, 2011) suggested that the production of meal-worms is still 4.8 times as expensive as normal chicken feed. In particular, labour and housing costs for large-scale feed production facilities are much higher for insects than for the production of chicken feed.

Most edible insects are harvested in the wild, but a few insect species have been domesticated because of their commercially valuable products. Silkworms and bees are the best-known examples. Sericulture – the practice of rearing silkworms for the production of raw silk – has its origins in China and dates back 5,000 years. The domesticated form has increased cocoon size, growth rate, efficiency of digestion, and is accustomed to living in crowded conditions. The adult can no longer fly and the species is completely dependent on humans for

survival. Both bee larvae and silkworm pupae are eaten as byproducts. Additionally, some insect species are reared for the pet-food industry. For example, meal-worms and crickets are reared primarily as pet food in Europe, North America, and parts of Asia.

A project in Kenya successfully linked forest conservation and livelihood improvement (Raina *et al*., 2009). By commercializing insects such as the mulberry silkworm, local forest communities were able to sell the silk produced, which proved to be a valuable alternative source of cash income. Leftover pupae were fed to chickens. These benefits gave local communities incentives to better manage their surrounding forest habitat.

In India, seriwaste is only used for biogas production and composting. Researchers are experimenting with feeding seriwaste to poultry (Krishnan *et al*., 2011). The poultry industry is one of the fastest-growing agro-businesses in India, yet sustainable feed products with high conversion rates are not widely available. Krishnan *et al*., (2011) argued that seriwaste is extremely viable because silk waste is not toxic and has even better conversion rates than conventional feed stocks.

In temperate regions there are companies that produce large numbers of insects as pet food and fish bait. The species most used are crickets (*Gryllodus sigillatus*, *Gryllus bimaculatus* and *Acheta domesticus*), mealworms (*Zophobas morio*, *Alphitobius diaperinus* and *Tenebrio molitor*), locusts (*Locusta migratoria*), sun beetles (*Pachnoda marginata peregrine*), wax moths (*Galleria mellonella*), cockroaches (*Blaptica dubia*) and maggots of the housefly (*Musca domestica*). Some companies even produce Mighty Mealys, or giant mealworms, which are *T. molitor* larvae treated with juvenile hormones. The hormone suppresses pupation and allows the larvae to grow to a size of about 4 cm, making them ideal as pet food and bait (Neelam and Wahied, 2021).

In addition, some insects serve medicinal purposes. The common green bottle fly (*Lucilla sericata*), for example, is produced for use in maggot therapy. Live, disinfected fly larvae are introduced into soft tissue wound(s) of humans or animals to clean out the necrotic tissue (debridement) and disinfect the traumatized area. House dust mites are also produced commercially for allergy-testing. The Research Institute of Resource Insects of the Chinese Academy of Forestry in Kunming has conducted extensive research on the rearing of insects for medical applications (Feng *et al*., 2009), and the use of insects as food in space is also being examined. It has been suggested that insects could be used as a protein source in space flights. Scientists in China, Japan and the United States are looking seriously into this food resource for space travel and use in space stations.

Other reasons for rearing insects include research into plant breeding and chemical control (e.g., screening of pesticides and testing side-effects on non-target arthropod species). Insects are also produced for educational and recreational purposes, for example in zoos and butterfly gardens. In some countries, insects serve as pets – such as walking sticks and singing or fighting crickets in Chinese culture (see section 2.1), and scarab beetles, such as stag beetles (Lucanidae) and rhinoceros beetles (Dynastinae) in Japan, Thailand and Vietnam. The potential uses of insects are vast. Recently, the use of insects for the bioconversion of manure and waste has been explored. It would be useful to engage industries already producing insects, for example as pet food, to promote production for animal feed and human consumption (e.g. mealworm, locusts and crickets).

Entomophagy: Future Implications

Insect consumption is becoming increasingly popular and is expected to continue to grow. Possible future directions for insect consumption are the following:

1. **The Expansion of Insects as a Mainstream Food Source:**

While insects are already consumed in many parts of the world, they are not yet a mainstream food source in many other regions. In the future, there may be a greater push to promote insects as a healthy and sustainable food source on a larger scale.

2. **Increased Use in Processed Foods:**

Insect derivatives, i.e., cricket flour, are already being used in various food products such as protein bars, snacks, and baked goods. As consumers become more familiar with insects as a food source, we can expect to see more processed food products incorporating insect-based ingredients (Olivadese and Dindo, 2023).

3. **Greater Emphasis on Sustainability:**

Insects are often promoted as a sustainable protein source due to their low environmental impact compared to traditional livestock. In the future, there may be a greater emphasis on exploiting the sustainability of insect farming practices, exploring factors such as feed sources, water usage, and waste management (Oonincx and Finke, 2020).

4. **Development of New Insect-Based Products:**

A wide range of insect-based products is already available, but we can expect the development of new products as insects become accepted as a food source. These may include new insect-based meat alternatives, beverages, and functional foods.

5. Increased Research into the Nutritional Benefits of Insects:

While insects are known to be a good source of protein, there is still much to be learned about their overall nutritional content and potential health benefits. In the future, more studies are expected to be performed to determine the nutritional value of insects and their potential role in promoting health and preventing disease (Maggioletti *et al*., 2013).

6. Gastronomy:

Making insects tasty and attractive is one of the major challenges of entomophagy, particularly in the Western world. To stress nutritional and environmental benefits is important, but consumers will only be convinced when palatability is appealing in terms of colour, texture, taste, and flavour. However, while food preferences are influenced by cultural history, experience, and adaptation, entomophagy in the Western world is also a matter of education. Cook books on insects can be used to help consumers identify appealing recipes.

CONCLUSION

The consumption of insects as a source of food has a long history and has been a common practice in many cultures around the world. Although eating insect is still adventurous for Western consumers, people are getting acquainted with this novel food. While there are still many challenges to overcome, the growing awareness of the environmental and health benefits of insect-based foods is leading to a resurgence of interest in insect consumption. As the world's population continues to grow and the demand for protein-rich foods increases, it is likely that insects will play an increasingly important role in the global food system. Insects may also serve as an animal protein source for astronauts during deep space exploration in the future (Tong *et al*., 2011).

The global rise in population, meat production, and the exploration of insects as a food source are interconnected phenomena that have significant implications for food security, environmental sustainability, and human health. The increase in human population directly influences the demand for meat production. As more people seek animal-based protein sources, the pressure on livestock farming increases. This leads to further deforestation, water scarcity, and greenhouse gas emissions. The exploration of insects as food offers an alternative to conventional meat production. By promoting insect consumption, it is possible to alleviate some of the environmental burdens associated with livestock farming. Insects can be reared using less land, water, and feed while emitting fewer greenhouse gases. However, it is important to note that insects alone cannot solve all the challenges associated with rising population and meat production. A comprehensive approach that includes sustainable agricultural practices, reduced food waste, and dietary diversification is necessary for long-term solutions.

While insects offer numerous advantages as a sustainable food and feed source, some challenges need to be addressed. Scaling up insect farming operations to meet the growing demand requires investment in research and development, infrastructure, and technology. Additionally, there is a need for further research on the nutritional composition of different insect species and their potential allergenicity. More exploration is needed into ways in which insect farming can be sustainable on a large scale, and into which species would be best suited for this practice—along with continued research on the future of processing, safety, and regulation of insects as human food. Collaborative efforts from researchers, insect farmers, food manufacturers, regulatory agencies, and consumers are needed to incorporate edible insects in our daily diet. Despite these challenges, the future looks promising for insects in the food and feed industry. The FAO has recognized the potential of insects as a sustainable protein source and has been actively promoting their use through various initiatives. Several startups and companies have also emerged in recent years, focusing on insect farming and developing innovative insect-based products (FAO, 2009).

In conclusion, insects have the potential to play a significant role in addressing the challenges of feeding a growing global population sustainably. Their high nutritional value, low environmental impact, and versatility make them an attractive option for both human consumption and animal feed. With continued research, investment, and regulatory support, insects could become an integral part of our future food system. *This article is a mere effort to raise awareness of the various important roles that insects play in sustaining nature and human life, and to boost the use of insects as food and feed. Entomophagy is the greatest and sustainable culinary revolution of present times. Let us take a step forward making a meal using edible insects! Let us educate others about the benefits of adding insects to our diet! Let us take a step forward to resolve the global food security issues!*

REFERENCES

- Aborisade, B., & Bach, C. (2014). Assessing the pillars of sustainable food security. *European International Journal of Science and Technology*, *3*(4), 117-125.
- Allen, A. M., & Hof, A. R. (2019). Paying the price for the meat we eat. *Environmental science & policy*, *97*, 90-94.
- Amar, Z. (2002). The Eating of locusts in Jewish tradition after the Talmudic period. *The Torah u-Madda Journal*, *11*, 186-202.
- Ancha, P. U., Ikyaagba, E. T., & Kaor, C. D. (2021). Consumers acceptance and willingness to pay for

edible insects in Makurdi metropolis, Benuestate, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, *13*(4), 159-170.

- Baiano, A. (2020). Edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications. *Trends in Food Science & Technology*, *100*, 35-50.
- Balzan, S., Fasolato, L., Maniero, S., & Novelli, E. (2016). Edible insects and young adults in a north-east Italian city an exploratory study. *British Food Journal*, *118*(2), 318-326.
- Beck, J. A (1939). Insects in Leviticus. *J. R. Entomol. Soc. Lond.*, *114*, 103–105.
- Behnassi, M., Draggan, S., & Yaya, S. (2011). Global food insecurity. Dordrecht, New York, Heidelberg, London, *Springer*. 127.
- Bhargava, A. (2015). Diet quality, child health, and food policies in developing countries. *The World Bank Research Observer*, *30*(2), 247-276.
- Bodenheimer, F. S. (1951). Insects as human food. In *Insects as Human Food: A Chapter of the Ecology of Man* (pp. 7-38). Dordrecht: Springer Netherlands.
- Briggs, J. C. (2017). Emergence of a sixth mass extinction?. *Biological Journal of the Linnean Society*, *122*(2), 243-248.
- Chakravorty, J., Sampat, G., & Victor, B. M. (2011). Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine*, *75*, 1-14.
- Crook, G. (2018). *Marine insects: small but significant*. Deutsche Welle. Retrieved 8 January 2023.
- de Sonneville-Bordes, D. (1963). Upper Paleolithic Cultures in Western Europe: The first cultures of modern man in western Europe were not so closely unified as had been thought. *Science*, *142*(3590), 347-355.
- Dürr, J., & Ratompoarison, C. (2021). Nature's "Free lunch": The contribution of edible insects to food and nutrition security in the central highlands of Madagascar. *Foods*, *10*(12), 2978.
- El-Mallakh, O. S., & El-Mallakh, R. S. (1994). Insects of the Qur'an. *American Entomologist*, *40*(2), 82-84.
- Erwin, T. L. (1982). Tropical forests: their richness in Coleoptera and other arthropod species. *The Coleopterists Bulletin*, *36*, 74–75.
- FAO, IFAD, UNICEF, WFP and WHO (2021). The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO.
- FAO. (2009). Food and Agriculture Organization of the United Nations, How to Feed the World in 2050.
- Feng, Y., Zhao, M., He, Z., Chen, Z and Sun L (2009). Research and utilization of medicinal insects in China. *Entomological Research*, *39*(5), 313–316.
- Food and Agriculture Organization (2013). The state of food insecurity in the world: The multiple dimensions of food security. http://www.fao.org/docrep/018/i3434e/i3434e.pdf (accessed 07 January 2024).
- Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., & Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology*, *11*(2), 97–105.
- Gomez-Zavaglia, A., Mejuto, J. C., & Simal-Gandara, J. (2020). Mitigation of emerging implications of climate change on food production systems. *Food Research International*, 134 (April).
- Gullan, P. J., & Cranston, P. S. (2014). *The Insects: An Outline of Entomology* (5th ed.). Oxford: Wiley Blackwell. ISBN 978-1-118-84616-2.
- Hågvar, S. (2010). A review of Fennoscandian arthropods living on and in snow. *European Journal of Entomology*, *107*(3), 281–298.
- Jongema, Y. (2017). List of edible insect species of the world. Laboratory of Entomology, Wageningen UR, Wageningen, the Netherlands.
- Katare, B., Wang, H. H., Lawing, J., Hao, N., Park, T., & Wetzstein, M. (2020). Toward Optimal Meat Consumption. *American Journal of Agricultural Economics*, *102*(2), 662–680.
- Kellert, S. R. (1993). Values and perceptions of invertebrates. *Conservation Biology*, *7*(4), 845–855.
- Kourimska, L., & Adámkova, A. (2016). Nutritional and sensory quality of edible insects. *NFS J.*, *4*, 22–26.
- Krishnan, R., Sherin, L., Muthuswami, M., Balagopal, R., & Jayanthi, C. (2011). Seriwaste as feed substitute for broiler production. *Sericologia*, *51*(3), 369–377.
- Landa, I. (1946). Insects in Jewish Tradition. *J. R. Entomol. Soc. Lond.*, *121*, 49–56.
- Lange, K. W., & Nakamura, Y. (2021). Edible insects as future food: chances and challenges. *Journal of future foods*, *1*(1), 38-46.
- Lartey, A., Meerman, J., Wijesinha-Bettoni, R. (2018). Why food system transformation is essential and how nutrition scientists can contribute. *Ann Nutr Metab*, *72*(3), 193-201.
- Looy, H., Florence, V. D., & John, R. W. (2014). How then shall we eat? Insect-eating attitudes and sustainable food ways. *Agriculture and Human Values*, *31*, 131-141.
- Losey, J. E., & Vaughan, M. (2006). The Economic Value of Ecological Services Provided by Insects. *Bioscience*, *56*(4), 311–323(13).
- Maggioletti, M., Alonzi, C. C., Paoletti, M. G., & Ricci, A. (2013). Edible insects in a food safety and

nutritional perspective: A critical review. *Compr. Rev. Food Sci. Food Saf*, *12*, 296–313.

- Mannino, M. A., & Thomas, K. D. (2023). Advances in the Archaeological Study of Invertebrate Animals and Their Products. *Handbook of Archaeological Sciences*, *2*, 769-796.
- Menzel, P., & Faith, D. A. (1998). *Man Eating Bugs: The art and science of eating insects.* Berkeley: Ten Speed Press.
- Meuwissen, P. (2011). Insecten als nieuwe eiwitbron: Een scenarioverkenning van de marktkansen. 's-Hertogenbosch: ZLTO projecten.
- Meyer-Rochow, V. B. (2009). Food taboos: their origins and purposes. *J Ethnobiology Ethnomedicine*, 5, 18.
- Meysing, A., Forneck, S., Razafindrakotomamonjy, A., & Dürr, J. (2021). Why socio-economic and attitudinal factors cannot predict entomophagy in rural areas of Madagascar. *J Insects*, 1–14.
- Mithen, S., & Mithen, S. J. (1999). The Prehistory of the Mind: The Cognitive Origins of Art, Religion and Science; Thames and Hudson: London, UK, 1999; ISBN 978-0-500-28100-0.
- Müller, O., & Krawinkel, M. (2005). Malnutrition and health in developing countries. *Cmaj*, *173*(3), 279-286.
- Olivadese, M., & Dindo, M. L. (2023). Edible insects: a historical and cultural perspective on entomophagy with a focus on Western societies. *Insects*, *14*(8), 690.
- Oonincx, D. G. A. B., & Finke, M. D. (2020). Nutritional value of insects and ways to manipulate their composition. *J. Insects Food Feed*, *7*, 639–659.
- Oonincx, D. G., Van Itterbeeck, J., Heetkamp, M. J., Van Den Brand, H., Van Loon, J. J., & 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.
- Raina, S. K., Kioko, E. N., Gordon, I., & Nyandiga, C. (2009). Commercial Insects and Forest Conservation: Improving Forest Conservation and Community Livelihoods through Income Generation from Commercial Insects in Three Kenyan Forests. In *ICIPE Science Press*.
- Raksakantong, P., Meeso, N., Kubola, J., & Siriamornpun, S. (2010). Fatty acids and proximate composition of eight Thai edible terricolous insects. *Food Research International*, *43*(1), 350-355.
- Raubenheimer, D., & Rothman, J. M. (2013). Nutritional ecology of entomophagy in humans and other primates. *Annual review of entomology*, *58*, 141-160.
- Renfrew, C., & Bahn, P. G. (2016). Archaeology: Theories, Methods, and Practice; Thames and Hudson: London, UK, ISBN 978-0-500-29210-5.
- Rosegrant, M. W., & Cline, S. A. (2003). Global food security: challenges and policies. *Science*, *302*(5652), 1917-1919.
- Saba, N., & Balwan, W. K. (2021). Redescription of Dalader acuticosta (Coreidae: Coreinae: Daladerini): First report from Jammu and Kashmir, India. *J. Ent. Zool. Stud*, *9*, 1359-60.
- Sánchez-Bayo, F., & Wyckhuys, K. A. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological conservation*, *232*, 8-27.
- Saunders, M. E. (2019). Insectageddon is a great story. But what are the facts? Ecology is not a Dirty Word.
- Schösler, H., De Boer, J., & Boersema, J. J. (2012). Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. *Appetite*, *58*(1), 39-47.
- Schowalter, T. D. (2006). Insect Ecology: An Ecosystem Approach (2nd (illustrated) ed.). *Academic Press*. 3, 572. ISBN 978-0-12-088772-9.
- Shekar, M., Dayton Eberwein, J., & Kakietek, J. (2016). The costs of stunting in South Asia and the benefits of public investments in nutrition. *Maternal & Child Nutrition*, *12*, 186-195.
- Siddiqui, F., Salam, R. A., Lassi, Z. S., & Das, J. K. (2020). The intertwined relationship between malnutrition and poverty. *Frontiers in Public Health*, *8*, 453.
- Stork, N. E. (2018). How many species of insects and other terrestrial arthropods are there on Earth?. *Annual review of entomology*, *63*, 31-45.
- Szmigiera, M, (2021). Prevalence of starving people worldwide 2020, by region. https://www.statista.com/statistics/273291/number-of-people-with-malnutrition-worldwide/. Accessed 07 Jan 2024
- Tang, C., Yang, D., Liao, H., Sun, H., Liu, C., Wei, L., & Li, F. (2019). Edible insects as a food source: a review. *Food Production, Processing and Nutrition*, *1*(1), 1-13.
- UNICEF (2001). Progress since the World Summit for Children: A statistical review. Review of the World Summit for Children; New York City, USA, 29–30 September 2009. UNICEF.http://www.unicef.org/publications/files/pub_wethechildren_stats_en.pdf. Accessed 07 January 2024.
- UNICEF. (2013). Statistics. Madagascar. http://www.unicef.org/infobycountry/madagascar_statistics.html. Accessed 07 January 2024.
- Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual review of entomology*, *58*, 563-583.
- Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). *Edible insects: future prospects for food and feed security* (No. 171). Food and agriculture organization of the United Nations.

- Van Klink, R., Bowler, D. E., Gongalsky, K. B., Swengel, A. B., Gentile, A., & Chase, J. M. (2020). Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science*, *368*(6489), 417-420.
- Verbeke, W. (2015). Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. *Food quality and preference*, *39*, 147-155.
- Vetter, S. H., Sapkota, T. B., Hillier, J., Stirling, C. M., Macdiarmid, J. I., Aleksandrowicz, L., ... & Smith, P. (2017). Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. *Agriculture, ecosystems & environment*, *237*, 234-241.
- Wagner, D. L., & Van Driesche, R. G. (2010). Threats posed to rare or endangered insects by invasions of nonnative species. *Annual review of entomology*, *55*, 547-568.
- WFP. (2015). Hunger Statistics. Hunger. http://www.wfp.org/hunger/stats. Accessed 7 January 2024.