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Insect as an Alternative Source of Animal Protein in Ethiopia

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Insects as an Alternative Source of Animal Protein in Ethiopia" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague on ……………………

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Abstract

Insects are consumed in many countries around the World. In Ethiopia, eating insects is a rather rare occurrence. However, the insect's nutritional potential cannot be denied. Insects are very rich in protein as well as other macronutrients and micronutrients. Consuming insects is an effective way to avoid the excessive water and surface area required by traditional livestock. The objective was the investigation of available literature sources and electronic information databases to analyse insects as an alternative source of animal protein in Ethiopia. This study described 31 species of insects that occur in Ethiopia and have a high potential to become edible. The summary table describes the individual species of edible insect, dry matter protein percentage, processing methods and consumption stage. Subsequently, two of the most promising representatives were selected namely *Schistocerca gregaria* and *Hermetia illucens*, and their possible contribution to the people of Ethiopia was described. The highest percentage of protein in dry matter was found in the order Orthoptera, which reached 61 % on average, and the order Blattodea reached 57 %. Followed by the order Lepidoptera 45 % and the order Coleoptera 41 %. The insects represented in the table were mostly consumed at the adult 64.5 %, larval 41.9 %, or nymphal 35.4 % stages. The most common preparations methods for these insects include frying 58 %, drying 54.8 %, roasting 16 % and boiling 12.9 %. Some of the insects could also be consumed in raw form 25 %.

Key words: nutritional value, proteins, human nutrition, insects, entomophagy, insect farming, food processing, Ethiopia.

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List of abbreviations

PDCAAS - Protein digestibility-corrected amino acid score

TVP - Textured vegetable protein

WHO - World Health Organization

FAO – Food and Agriculture Organization of the United Nations

ATP - Adenosine triphosphate

BC - Before Christ

LC-PUFA - Long chain polyunsaturated fatty acids

ALA - Alpha-linolenic acid

ADF - Acid detergent fibre

HPLC – High-performance liquid chromatography

Lao PDR - Lao People's Democratic Republic

Icipe - International Centre of Insect Physiology and Ecology

EFSA - European Food Safety Authority

1. Introduction

Nowadays, it is an almost superhuman task to provide enough food for every person on Earth. Plant production would be sufficient for humanity if a significant proportion went directly to humans. Unfortunately, at present only 55 % of the world's crop production goes directly to people, about 36 % is used as livestock feed, and another 9 % is used as biofuels and other industrial products (Foley 2015). Not to mention that humanity must contend with a whole host of other factors that can affect food production such as pandemics, war, global problems, disparities in purchasing power and many others. Livestock production is not in the best ecological position either. Livestock production is one of the most damaging anthropogenic activities ever. It causes significant land degradation and contributes to worsening global warming. According to Gerber et al. (2013) livestock alone accounts for almost 14.5 % of the increase in greenhouse gases from the year 2000. Not to mention the amount of water livestock consume. In addition to the fact that current livestock farming for animal protein production is environmentally damaging, the upper limit of animal protein production has already been achieved in terms of pasture area availability and productivity development of edible zoomass using science and technological inputs (Abbasi et al. 2016). As a result of these consequences, demand will continually outstrip supply. Therefore, it is now necessary for us to focus more on alternative ways of obtaining protein. One of the possible sources could be insects. There are many advantages over conventional animal husbandry such as fast growth, rapid reproduction, high efficiency of food-to-mass conversion and wide global distribution (Sachs 2009).

In many African countries, insect consumption is widely practised, especially in the Democratic Republic of Congo, Congo, the Central Africa Republic, Nigeria, Uganda, Zimbabwe, and Zambia. However, in Ethiopia, insect consumption is not so popular. Despite its proven nutritional quality and the documented presence of some edible species in Ethiopia. (Ghosh et al. 2020).

2. Objectives

This thesis aims to investigate available literature and electronic information databases to analyze the alternative sources of insect protein in Arba Minch Zuriya district, Gamo zone, SNNPR, Ethiopia, and map out promising potential species and possible processing methods.

3. Methodology

The thesis was based on online research on alternative sources of insects protein in Ethiopia. A systematic literature review was conducted using electronic searches in databases such as: Google Scholar, ScienceDirect, Web of Sciences and ResearchGate. Reports from organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) were also used for the thesis. Primary search terms used were: “proteins”, “insect”, “human nutrition”, “insect processing”. Subsequently, the two most promising representatives of insects with the highest protein content and according to parameters such as occurrence, nutritional values were selected and described in more detail.

Additionally, a pilot questionnaire survey on eating insects was prepared and planned to be carried out within the project titled: “Arba Minch Fruit Value Chain, Gamo zone, SNNPR, Ethiopia”. Unfortunately, due to the Covid-19 pandemic and the current political situation in the country, it was not possible to complete the survey in time. For this reason, the questionnaire form without results was added just to Annex A of this thesis.

4. Literature Review

4.1. Human Diet

It is well known that macronutrients and micronutrients ensure human health. Macronutrients include protein, fat and carbohydrates, these components are a source of energy and are necessary to sustain life. Protein is an agglomeration of amino acids; fat consists of fatty acids from glycerol (simple polyol compound). Carbohydrates are sugars that occur either as simple monosaccharides (consisting of one sugar unit), the best-known representatives are glucose (grape sugar), which can then form more complex chains of oligosaccharides (sucrose), the most complex sugars include polysaccharides, which are formed more than ten sugar units and the best known is starch as an energy store. Their bonds can be hydrolyzed to simpler sugars in the human small intestine, or they will be resistant to hydrolysis (Venn 2020). We refer to these resistant sugars as dietary fibre. Our diet requires the right number of macronutrients to maintain good health and the associated longevity, yet it is undetectable, whether there is a combination of macronutrients that provides optimal health when expressed as a percentage (Venn 2020). People have had different percentages of these macronutrients in the past. For a closer comparison, the Alaskan Inuit diet consists of approximately 33 % protein, 41 % fat and 26 % carbohydrates (Bang 1972). At this percentage, the Inuit turned out to have a lower incidence of dental execution and was beneficial to the human heart, a claim that was later refuted. On the other hand, it was found that the percentage of macronutrients of Irish farm workers who fed mainly skim milk and potatoes was predominantly in the past 12 % for protein, 1 % fat and 87 % carbohydrates. This result has long been associated with low diabetes mellitus mortality as was presented in the research of (Crawford 1987). A diet high in carbohydrates has a beneficial effect on the treatment of diabetes and vascular disorders as was presented in the research of (Kempner 1958). Starches in rice and potatoes contain 12 % protein, 7 % fats and 81 % carbohydrates and have a positive effect on health markers (McDougall 2014). Metabolic risk factors can be improved by consuming low-fat starchy foods together with whole grains, legumes, fruits and vegetables, and weight can be reduced in obese people or overweight patients (Wright et al. 2017). Humans are well adapted to the digestion of starch from an evolutionary point of view (Pajic et al. 2019).

According to the World Health Organization (WHO), the recommended dietary representation should be in the range of 10 - 15 % for proteins, 15 - 30 % for fats and 55 – 75 % for carbohydrates to achieve basic prevention of chronic diseases (World Health Organization 2003). These recommendations vary depending on the country in which they are published, for example, New Zealand and Australia recommend 15 – 25 % protein, 20 - 35 % fat and 45 - 65 % (Australian Government and New Zealand Ministry of Health 2006). It is visible that the range of individual macronutrients is quite wide, which allows for more variety in the diet. The higher representation of the carbohydrate component reported by the World Health Organization compared to New Zealand and Australia may be due to the observation of good health associated with traditional diets containing unrefined carbohydrate-containing food sources (Venn 2020). Carbohydrate content of 50-55% is associated with a lower risk of death in the modern environment (Seidelmann et al. 2018). Furthermore, it should be determined whether there is an optimal lifetime distribution of the macronutrient. The results should be detectable after an intervention study where people consume diets varying in macronutrient composition for 6 months (Wan et al. 2017). Modelling protein intake for a middle-aged person should be around 6 % and then increase to 17 %, such protein representation should have a beneficial effect on Alzheimer's disease (Studnicki et al. 2019). Foods such as legumes, vegetables and other grains traditionally eaten around the world should be replaced by diets higher in protein, fats, vegetable oils and refined carbohydrates. In terms of planetary resources, plant proteins and naturally occurring proteins are more sustainable than animal proteins (Venn 2020). Although animal protein is less sustainable from an agricultural point of view, its positive aspects should not be taken lightly. For example, protein intake from animal sources has been found to play a key role in the birth of a child of normal body weight. This research was conducted on over 500 pregnant women, and it was found that a lower intake of these animal proteins led to lower birth weight (Godfrey et al. 1996).

In many developing countries, the daily calorie intake is inadequate in 2000 to 2300 kcal. Cereals account for up to 80 % of total calorie intake. It is very important to add that without proper micronutrients, the body cannot produce important hormones, enzymes and other substances for proper and healthy development. Although they are present in very small quantities in the human diet, their deficiency can be fatal to the human body. Deficiency or malnutrition of micronutrients has negative effects on human health. It is also widespread throughout the world and especially in developing countries. It can affect all age groups, but it is most important to ensure proper levels of these macronutrients in children and pregnant women. The most common malnutrition in the world includes iron deficiency anaemia (45 % of the general population), inadequate iodine intake (54 %), and vitamin A deficiency (22 %) in preschool children (World Health Organization 2021).

4.1.1. Importance of protein in the human diet

The word protein comes from the Greek "proteios", which means primary. This meaning is very suitable because protein is the main component for the formation of new and existing tissues in the human and animal bodies (Reeds et al. 2000). The protein has zero nutritional value until it is hydrolysed to amino acids by protease and peptidase. Dipeptides and tripeptides are hydrolysed in the small intestine in the lumen. Therefore, it is necessary to add that the relative proportions in amino acids and the coefficient of digestibility determine the nutritional value of protein (Tomé 2013). Amino acids are essential because they provide nitrogen, sulphur, and hydrocarbon skeletons. Therefore, they cannot be replaced by other nutrients. Because the body is not able to spontaneously produce nitrogen or sulfur (Gabriel & Uneyama 2013). The main metabolic fuels include glutamate, aspartate, and glutamine. These amino acids are a source of fuel for the small intestines of mammals. Glutamine provides a significant source of energy in the blood and provides 50 % of ATP in lymphocytes and 35 % in macrophages, resulting in the proper functioning of immune responses. Amino acids are essential for the survival of the body as they allow healthy growth, development, lactation, reproduction (Li et al. 2007). Amino acids are of significant physiological importance, especially to produce low molecular weight metabolites. Protein deficiency results in several negative aspects, such as stunting, anaemia, weakness, vascular dysfunction, oedema, and weak immunity. Short-term nitrogen balance studies have shown that the recommended protein dose for an adult with negligible physical activity is 0.8 g protein per kilogram body weight per day (Wu 2016).

4.1.2. Protein Sources

Protein can be taken into the body from a variety of sources. However, these are primarily animal and plant foods. Several factors determine the quality and digestibility of protein. For protein quality, is spoken about the availability of the amino acids it supplies and digestibility describes the way in which the protein is effectively used. In general, proteins of animal origin in the diet are considered complete proteins because they contain all the essential amino acids (Hoffman & Falvo 2004). Therefore, people who consume protein only from plant sources have a slight disadvantage, as a plant-based diet does not capture the intake of all essential amino acids, hence the need to consume a variety of grains, legumes, fruits and vegetables. Nevertheless, it is possible for vegetarians to get their daily requirements without consuming poultry, pork, beef or dairy products. Plant sources of protein have another minor disadvantage. They do not achieve such values in biological value assessment, net protein utilization, and efficiency ratio as animal proteins, which are unrivalled in this respect. The following section will mention specific sources for both animal and plant proteins (Hoffman & Falvo 2004). Proteins from animal sources include eggs, milk, fish, poultry, etc. As already mentioned, these proteins have the highest quality ratings, and this is due to the completeness of the amino acids. However, it should be added that animal proteins are associated with a high intake of saturated fat and cholesterol, but some studies have shown positive benefits of these proteins in a variety of population groups (Pannemans et al. 1998: Campbell et al. 1999). A diet consisting largely of animal protein led to an increase in lean mass in subjects compared to subjects on a lacto-ovo-vegetarian diet (Campbell et al. 1999). Pannemans et al. (1998) showed that diets containing a high component of these proteins have a more favourable effect on net protein synthesis than, a diet of plant proteins. Although it may seem that the animal side is completely uncontroversial, concerns have been raised about consuming mainly animal protein, cardiovascular disease due to high fat and cholesterol intake has been discussed, followed by bone health due to sulphur-containing amino acids (Hoffman & Falvo 2004).

Among other substances that are very beneficial to the body, we can take whey, which is the translucent part of milk that remains after cheese making. Whey is one of the two main groups of proteins in beef milk and makes up about 20 % of the rest is casein.

In addition, whey is very rich in vitamins and minerals. Another relatively important protein component in beef milk is casein. Milk proteins have beneficial effects on nutrient and vitamin intake. They contain significant amounts of minerals such as calcium and phosphorus. It is also a source of biological peptides (Deutz et al. 1998).

If we consider plant proteins in a combination that provides all the essential amino acids, plant proteins are responsible for reducing saturated fat and cholesterol intake. The most well-known plant proteins can include nuts, legumes, and soy. These proteins can also be found in textured vegetable protein (TVP). This plant textured protein is obtained from soy flour, in which the proteins are isolated. We know TVP primarily as a meat substitute in many vegetarian shops, fast foods, etc. It represents a low-fat source of vegetable protein for humans. It should not be forgotten that these protein sources contain a range of phytochemicals and fibre, which is also an essential component of the human diet (Hoffman & Falvo 2004). The most widespread and well-known plant protein is soy. Soy belongs to the legume family and was first recorded in China as early as 2838 BC. Soy has the same nutritional component as wheat, rice, or barley. According to the protein digestibility-corrected amino acid score (PDCAAS), soybean has been found to have an equal rating with animal protein with a score of 1.0, this is also the highest rating that can be obtained (Hasler 2002). Therefore, soy is a wonderful substitute for people looking for a protein other than animal protein. Soy has been found to have many positive health and performance benefits, specifically lowering plasma lipid profiles, and lowering blood pressure (Hoffman & Falvo 2004).

4.1.3. Protein Composition and Structure

Proteins are nitrogen-containing substances that are formed of amino acids. They are involved in the construction of muscles and other tissues in the body and are also called the main structural component. Moreover, they are used to produce a variety of hormones, enzymes, and haemoglobin. Protein is also a source of energy but not the primary choice. To add, people who consume food or a combination of foods high in protein reduce their food intake either at a later meal or from a meal eaten immediately afterwards (Porrini et al. 1997). Eating high-protein foods has been shown to consume significantly less energy than low-protein foods. Subsequent measurements have observed that protein is more satiating than fat or carbohydrate and delays the return of hunger (Marmonier 2000). In order to be used by the body, proteins must be metabolized into simpler forms, namely amino acids. Twenty amino acids have been identified as being important for metabolism and healthy human growth. The amino acids are divided into essential and non-essential, of which eleven are non-essential in children, and twelve are non-essential in adults. Non-essential means that the body can create or synthesize them on its own and does not have to take them in the diet. The remaining eight amino acids are referred to as essential amino acids, which are also amino acids that we must only take into the diet. If the body lacks any of the amino acids, the ability of tissues to repair, maintain or grow is compromised. (Hoffman & Falvo 2004). The composition of proteins can be so unique that their effect on the physiology of the human body can be quite different. Therefore, it is necessary to assess the quality of protein to determine the nutritional benefits. Protein quality is determined by the composition of essential amino acids, bioavailability, and digestibility. Currently, there are several scales by which we assess the value of protein: protein efficiency ratio, net protein utilization, biological value, protein digestibility corrected amino acid scale (Hoffman & Falvo 2004).

When looking at a protein from a structural point of view, a protein is a linear chain arranged from building blocks known as amino acid residues. The uniqueness of the proteins is due to the amino acid sequence. This sequence allows the protein to fold into a particular three-dimensional shape. In nature, proteins are represented by 50 to 500 amino acid residues. As mentioned above, there are 20 different amino acids in nature, and each of them has its own characteristic properties such as charge size, polarity, and charge (Dorn et al. 2014). If the polarity of the amino acid side chain differs, this allows us to distinguish the hydrophilic (tends to be attracted to water) or hydrophobic (a substance that repels water) character (Dorn et al. 2014). According to the effect of the interaction of amino acid residues, we can find out the importance of physical properties in the three-dimensional structure. The distribution of hydrophobic and hydrophilic amino acids helps to identify the tertiary structures of polypeptides. To better understand the structure and composition of the polypeptide, it is necessary to know what a polypeptide means. The peptide is a molecule that is composed of two or more amino acid residues that are joined together by a chemical bond, or peptide bond (Dorn et al. 2014). This bond is formed by the following agent: when the carboxyl group of one residue reacts with the amino group of the other residue, this interaction releases a water molecule. Thus, peptides include two or more amino acid residues, and larger peptides are called polypeptides or proteins (Creighton 1990).

Four levels of structures can be investigated for proteins (Dorn et al. 2014): primary structures, secondary structures, tertiary, and quaternary structures. These structures help facilitate protein hierarchy. Yet they are not intended to be an exact description of physical laws. It is an abstraction that is intended to simplify the study of protein structure (Dorn et al. 2014). Primary structures describe the linear order of amino acid residues (Branden & Tooze 2012). Each residue binds to a different residue via a peptide bond. The stable amino acid arrangements of their polypeptide residues form structural patterns, which constitute the secondary polypeptide structure (Dorn et al. 2014). Secondary structures contain in their polypeptide chain the presence of hydrogen bonds between hydrogen atoms of amino groups and oxygen atoms of carboxyl groups. These intermolecular interactions maintain the spatial conformation and regularity of these structures. Two secondary regular structures are distinguished: α-helices (Pauling et al. 1951) and β-sheets (Pauling & Corey 1951). The tertiary structure is distributed as a secondary structure in 3D space. Often the tertiary structure is called the functional structure or also the native structure. The functional structure of proteins consists of a variation of thermodynamic factors such as covalent interactions, hydrophobic interactions, hydrogen bonds and electrostatic interactions (Gibas & Jambeck 2001). Moreover, side chains have an important role in the formation of the quaternary structure of the polypeptide. We can predict and analyze the function of a protein in cells due to the tertiary structure of the protein; we can also identify the active site and binding sites on a receptor or find the recombination site of another protein (Dorn et al. 2014). The tertiary structure of a protein is associated with its folding (topology). The folding of a protein is determined by the sequence of secondary structures that together form a certain shape in three-dimensional space. Polypeptide chains can have different proteins that form a quaternary structure. The quaternary structures of a protein are connected to each other by hydrogen bonds, hydrophilic and hydrophobic interactions similar to secondary and tertiary structures (Dorn et al. 2014).

4.1.4. Food and Environment

With an ever-increasing population, it is very complicated to satisfy demanding consumers, humanity will need to produce more food. This trend will put severe pressure on already limited resources including land, fertiliser, water, oceans, and energy. If agricultural production does not move up a level, greenhouse gas emissions and deforestation will increase enormously, simply worsening the whole environment. Attention needs to be paid to the environmental problems focused on livestock farming. Livestock and fish are important sources of protein in many countries. According to (van Huis et al. 2013) 70 % of agricultural land is currently used for livestock production. If we expect exponential growth in demand for livestock products as before, 465 million tonnes of livestock products will be needed to meet demand in 2050, compared with half that in 2000, when demand was 229 million tonnes. Therefore, it is necessary to come to an innovative solution. Hand in hand is the consumption of fish, which has increased abnormally in recent years. As a result, aquaculture is enjoying a major boom, accounting for 50 % of global fish production. The sustainability of the industry is based on the supply of land and plant proteins for animal feed. This provides a suitable opportunity for insects to meet the growing demand for meat products and replace fish oil and fishmeal (van Huis et al. 2013).

Intensive livestock facilities and fish production are very productive from an economic point of view, this type of farming in the long term puts a lot of pressure on the environment (Fiala 2008). For a closer comparison, manure is highly polluting to ground and surface water with heavy metals and pathogens (Thorne 2007). Subsequent storage of manure or spreading it around can release large emissions of ammonia, which acidifies the environment and thus also negatively affects the ecosystem. Increasing livestock production due to increasing population requires additional feed that cattle need to increase their growth, which requires more arable land that will most likely trigger further deforestation, which is already very devastating. A sad example is the Amazon, forage crops now make up 70 % of the formerly forested land (Steinfeld et al. 2006). Sachs (2009) believes that current agriculture is the main cause of climate change and that it is necessary to develop agricultural technologies or change current ones and introduce foods into the diet that are healthier and more sustainable for humanity. With the current demand for meat, the consumption of grain and other feedstuffs is growing rapidly. This is due to the fact that the same amount of animal protein requires a lot more vegetable protein. It has been shown that for every 1 kg of high-quality animal protein, cattle consume about 6 kg of vegetable protein (Pimentel & Pimentel 2003). Regarding the feed-to-meat conversion ratio (explained as the amount of feed needed to achieve 1 kg of gain), this varies according to the grade of feed and the methods of post-processing and breeding. In general terms, the United States of America states that the following amounts of feed are required to achieve 1 kg of live weight: 2.5 kg for piglets, 5 kg for pork and a multiple (10 kg) for beef (Smil 2002). Therefore, according to Sachs (2009), it is necessary to switch to alternative sources of protein such as seaweed, beans, mushrooms, and thematic insects. For insects, the feed requirement is noticeably less.

4.2. Entomophagy

Entomophagy is the process of eating insects as a food source. It is often referred to as micro-livestock or mini-livestock, which is not entirely accurate (Gahukar 2011). To clarify, it is important to add that the term entomophagy refers to a group of insects that can be consumed by humans (Paoleletti 2005). Insects simply provide a high source of protein, vitamins, and mineral substances and have low-fat content. Nowadays, edible insects are consumed by many ethnic groups, and it is considered a full-fledged food resource, especially in Latin America, Mexico, Asia, and Africa (Gahukar 2011). Hundreds of insect species are used as food sources for humans. The most important groups include caterpillars, grasshoppers, beetles, termites, bees, wasps, cicadas and countless aquatic insects. More than 2000 species of insects are currently listed as edible insects (Temitope et al. 2014).

4.2.1. The Benefits of Entomophagy

For example, for crickets, only 1.7 kg of feed is needed to gain 1 kg of live weight (Paoletti 2005). If we adjust these values to edible weight, the advantage of eating insects is even higher (livestock cannot be consumed whole). Subsequently, it was revealed that almost 80 % of a cricket is edible and digestible. The digestibility in chickens and pigs is only 55 % and in cattle, it is only 40 % (Nakagaki & DeFoliart 1991). In simple terms, we can state that crickets are twice as efficient at converting feed as chickens, 4 times more than pigs and up to 12 times more than cattle. This phenomenon can be explained by the fact that, unlike other animals that are warm-blooded, insects are cold-blooded and do not need food to maintain a constant internal temperature (van Huis et al. 2013). Insects have many other advantages, which will be mentioned in the following section.

- Insects can be found practically anywhere, both in forest areas and in water resources. Insects can be mass-collected in a very short time, whenever their populations are more numerous. Also, Insects can be bred practically everywhere thanks to the short life cycle and fast growth rate. Due to the fact that edible insects do not require grain feeding for their subsistence, they are much more environmentally friendly than traditional cattle. In addition, insects can reduce environmental contamination when kept on environmentally friendly side streams and can add value to waste (Oonincx et al. 2010).

- Traditional cattle breed very slowly compared to insects. For a more accurate example, the female house cricket Acheta domesticus L. (Orthoptera: Gryllidae) can lay up to 1500 eggs in 4 weeks and the cost of water is minimal, while in comparison with beef the ratio is four animals per animal marketed (Capinera 2008).

- An important point for practising entomophagy is that insects produce smaller quantities of greenhouse gases (especially nitrous oxide and methane) per kilogram of meat than other cattle (Oonicx et al. 2010). For closer comparison, a pig produces up to a hundred times more greenhouse gases than mealworms. The ammonia emissions that ordinary cattle cause help eutrophication (groundwater acidification). For example, pigs produce up to 12 times more ammonia than crickets. In contrast, locusts produce up to 50 times less ammonia than pigs (Oonincx et al. 2010).

- Insects could be useful for many people who face the problem at the beginning of the rainy season when the cattle are thin or do not have the required slaughter weight and new crops are just sown and stocks stored from the previous season are insufficient; they have to rely on food including only insects mostly only in low-income areas. That’s why the local markets in many countries are overflowing with packed insects before the rainy season so that people have “something” to consume before they can harvest (Yen 2009).

- In the event of imminent natural disasters such as epidemics, droughts, and floods or in many conflicts caused by humans, whether long-term or short-term. The above-mentioned insects can easily serve as emergency food in the affected areas.

- Insects have very little problem with living conditions, unfortunately, this is largely due to ignorance of the extent to which insects deal with pain.

- Transmission of zoonotic infections is significantly lower in insects than in conventional livestock (van Huis et al. 2013).

Despite the advantages mentioned above, public acceptance is the biggest obstacle to the spread of this protein source. Nevertheless, we know from the past that eating habits and opinions of the general public can change from day to day, as in the case of sushi (van Huis et al. 2013).

4.2.1.1. Nutritional Value of Insects

Insects could be a very important food in humans' diet due to their high levels of fats and especially proteins. (Raksakantong et al. 2010; Bednářová et al. 2013). It should not forget that they are also a rich source of vitamins and minerals, especially iron and zinc (Akinnawo & Ketiku, 2000). However, the nutritional value of insects depends on many factors such as the sex of the individuals, the species, the stage of development, the quality of the environment and the methods of measure (Falade & Omojola 2010). Studies show how the same insect species may nutritionally differ depending on the different habitats (Finke 2004). The nutritional value of insects can vary in commercial breeding species of insects and the occurrence of insects in the wild. Above all, the content of substances varies both in adults and in their larval stage (Mlcek et al. 2014). For an illustrative example, adults *Tenebrio molitor* and *Zophobas atratus* contained much more protein in their larval counterparts than literature reported and one-half of the fat in their larval stages (Mlcek et al. 2014). Insect processing can cause changes in protein digestibility and vitamin levels. Depending on the heat treatment, protein s may be reduced due to changes in disulfide bonds (Mercier et al. 1989), or on the other hand to raise the temperature and unwrap the polypeptide chain and make the protein more susceptible to the digestive microflora (Kinyuru et al. 2010). Toasted samples dried in the sun at a temperature of 30 °C had lost up to 64 % of the riboflavin content, compared to the dried fresh sample, which had 46 %. Similar processing results were observed for all other vitamins. The increases in temperature and heating time accelerate the destruction of vitamins.

4.2.1.2. Proteins

Insects are undoubtedly an important energy source of protein for humans or as a dietary supplement for cattle such as poultry and pigs (DeFoliart 1989). However, more developed countries have a higher protein consumption than the average of about 95 g per person per day, of which 65 % is animal protein. Protein consumption in developing countries is around 56 g per person/per day and the proportion of animal protein is only about 25 % of this 56 g (Yen 2010). Due to the high protein content of insects, it can be said that insects have a very high potential to replace higher animal proteins in humans and animals that are not normally found in the diet of developing countries (Banjo et al. 2006). Protein content can vary considerably depending on the sex of the insect, species, and developmental stage, but in general, insects have good digestibility (Ramos-Elorduy et al. 1996). In general, the protein content is in the range of 13 - 77 % in dry matter (XiaoMing et al. 2008). It is very important to note that protein digestibility can be strongly affected by the presence of the exoskeleton (van Huis 2016). Exoskeletons with higher chitin content are generally less digestible for humans (Schlüter et al. 2017). Therefore, one of the possibilities is to remove the exoskeleton when processing insects (Rumpold and Schlüter 2013a). Some studies have confirmed that the ability to digest protein without an exoskeleton is about 75 – 98 % (DeFoliart 1992). Insect digestibility is slightly lower than that of animal protein sources for a closer look, eggs have a digestibility of about 95 %, beef at 98 % and casein has a digestibility of over 98 % (Mlcek et al. 2014). For a closer look, the protein digestibility of fresh termites (*Macrotermes subhylanus)* was 90.50 %, for green grasshoppers (*Ruspolia differens*)*,* the digestibility was around 82 % and for brown grasshoppers (*Ruspolia differens*), the value was slightly higher, up to 85.70 % (Kinyuru et al. 2010). The protein component in insects includes values between 10 – 25 % of fresh weight and about 30 – 60 % dry matter, which is demonstrably more than in plant sources such as lentils, soybeans and cereal (Bukkens 1997). This is also the case with digestibility, which is higher in insects than in plants

(Finke 2004). In insects, the proportion of amino acids is about 40 – 95 % of all nitrogenous substances (Finke 2004).

4.2.1.3. Fats

In most cases, the fat content of edible insects is between ranges of 10 – and 50 % (Chen et al. 2009). The study showed that many edible insects are very rich in fat, many of them have a fat content of about 40 %, which is approximately similar to the composition of olive oil (Naughton et al. 1986). The fat content of insects also depends on several factors such as sex, species, the weight of the insect, season, age, period, the diet of the insect and the environment in which it lives (Schlüter et al. 2017). The fat content of an insect varies depending on the developmental stage of the insect, for example, there is a bigger fat content at the larval stage of the insect than in the adult stage (Feng et al. 2018). In general, females have a higher fat content than males (Oonincx & Finke 2021). It should not be forgotten that insects contain more essential fatty acids than animal fat (Chen et al. 2009). The composition of fatty acids may also differ for insects of the same species, as several factors play a role here, but above all, it is affected by the plant on which the species of insect feeds. (Bukkens 1997). However, we must distinguish whether it is a specialist species of insects, which consume a limited diet (only one type of plant food) and occur in a narrow niche, the values will be similar for insects of the same species. In contrast, the generalist species of the insects, which can feed on a wider variety of food and occur in a wider area, will have some variations in fatty acid content between individuals of the same species, a good example could be house cricket (*Acheta domesticus*), values in fatty acid will vary depending on the diet (Finke 2004). Fats are essential for the biological and structural functioning of cells, and thanks to them it is possible to receive essential substances such as vitamins, which are fat-soluble (Omotoso 2006). Long-chain omega 3 polyunsaturated fatty acids (LC-PUFA) play an important role in human beings, as they provide elements suitable for the formation of brain tissues (Carlson & Kingston 2007). Edible insects provide human beings with high-quality long-chain fatty acids like alpha-linolenic acid (ALA), which belongs to substances called omega 3 fatty acids, in addition to the formation of brain tissues they help the proper function of cell walls, immunity and the proper functioning of the heart and blood vessels. (Yang et al. 2006). The main cause, why they are inside the insect polyunsaturated fats are caused by diet and enzymatic activity. Terrestrial insects (living on the ground or in the soil) contained the following polyunsaturated fats in particular linoleic acid and alpha-linolenic acid (Yang et al. 2006). It should not be forgotten that one of the most relevant polyunsaturated fats is docosahexaenoic acids, which play an important role in the proper development of the eye and has a beneficial effect on the cardiovascular system, reduces inflammatory reactions and promotes brain development during pregnancy.

4.2.1.4. Carbohydrates

In insects, a significant part is represented by a carbohydrate called chitin. Edible insects have carbohydrate range components in the following range 6.70 % for sting bugs and 16 % for cicadas (Raksakantong et al. 2010). In the past, research has been conducted into the possible effect of polysaccharides on the human body. Research has shown that polysaccharides that contain insects can have a positive effect on the human immune system (Sun et al. 2007). Because chitin is a macromolecular-based compound that has a proven high nutritional and health value for humans (Burton & Zaccone 2007). As a low-calorie food, chitin also has health benefits, chitin can stop bleeding, help heal wounds and can even help stop bleeding (Chen et al. 2009). Insect skin contains more than 90 % chitin, depending on the type of insect, the proportion of chitin may vary, usually values from 5 – 15 % dry weight (Guo et al. 2008). Chitin does not usually occur in nature, it usually occurs in complex matrices with other compounds such as proteins, lipids and small amounts of minerals. Chitin-containing insect fibre is structurally similar to cellulose because acid detergent fibre (ADF) contains nitrogen similar to cellulose (Finke 2002). The study showed that the content of ADF in insects consists not only of chitin but also largely of amino acids, which are cuticular proteins. The results do not indicate that insects with a significantly harder body contain more chitin than insects with softer bodies. Rather, ADFs in harder insect bodies have been shown to contain a much higher percentage of amino acids than in insects with softer bodies (Finke 2007). It is very important to note that protein digestibility can be strongly affected by the presence of the exoskeleton (van Huis 2016). Exoskeletons with higher chitin content are generally less digestible for humans (Schlüter et al. 2017). At present, it is not sure if people can digest chitin (Muzzarelli et al. 2012). Therefore, one of the possibilities is to remove the exoskeleton when processing insects (Rumpold and Schlüter 2013a). Some studies have confirmed that the ability to digest protein without an exoskeleton is about 75 – 98 % (DeFoliart 1992). Chitin can present digestibility and assimilation problems in some cases. But we should not forget the growing interest in chitin and chitin derivative chitosan, in some key fields such as medicine, agriculture and industry. If the time came when insect food was produced on a large scale and was positively perceived by the public, chitin as a by-product could have significant value (Chen et al. 2009). Chitin has several positive effects. Chitin lowers cholesterol, acts as a hemostatic (an agent that controls bleeding) for tissue regeneration, helps to properly heal wounds and burns, acts as an anticoagulant, protects against pathogens mainly in the blood and skin, chitin is non-allergenic, so it can be used in a variety of drugs. When we deviate from medicine chitin provides quality degradable plastic for consumers, chitin also helps remove pollutants from wastewater, improves the washability of textiles that have an antistatic character. Chitin has a positive aspect in agriculture, it assists the growth of pathogenic fungi in the soil, which promote proper growth and form widespread root hair so they can increase yields of crops (such as wheat, barley, peas and oats) by up to 20 % (Chen et al. 2009).

4.2.1.5. Vitamins

Studies dealing with vitamins in edible insects are not sufficient, it is stated that insects mainly represent carotene and the following vitamins: B1, B2, B6, D, E, K and C (DeFoliart 1991). Vitamin A (retinol) values vary depending on the type of insect, the occurrence, but also the type of method used and the method of preparation. In the case of the honeybee (*Apis mellifera*), high-performance liquid chromatography (HPLC) were used. No retinol was detected in both the larval and pupal stages of the honeybee (*Apis mellifera*). Therefore, it was found that bees are not a source of retinol for both consumer and all known cosmetic purposes (Barker et al. 1998). Commercially bred insects have little or no beta carotene, most wild-caught insects contain a variety of carotenoids, which they get into the body from their natural food resources, such as alpha-carotene, astaxanthin, beta-carotene, lutein, and lycopene. Some vertebrates can convert carotenoids to retinol, this may be a key food for insectivorous vertebrates. Therefore, insects with high carotenoid levels could be an important source for these vertebrates (Finke 2004). Insects can be considered a very stable and high-quality source of vitamin

B, but most insect species appear to contain very negligible levels of thiamine. These low values are most likely caused by heat treatment. But it must be borne in mind that low values have been observed in insects before any processing method, this applies to domestic crickets and super worms (Finke 2004).

4.2.1.6. Mineral Elements

Minerals in particular play an important role in the proper functioning of biological processes. It is therefore not surprising that in many developing countries, many people are exposed to several health complications due to mineral deficiencies, such as delayed growth or impairments in growth, and a negatively functioning immune system (Zielińska et al. 2015). In addition, insects are richer in minerals than ordinary cattle. If we take minerals such as iron and calcium, edible insects have more of these minerals than cattle, pigs, or chickens (Bukkens 2005). The mineral composition is also largely influenced by the species of insect, developmental stage, sex and place of occurrence, but especially by the diet of the insect. Mineral components in insects can be divided into those that are in the gastrointestinal tract or those that are incorporated into insects' bodies and are more affected by the diet that the insect consumed (Finke 2004). For an illustrative example, if we feed domestic crickets, wax worms or mealworms with a diet that has a high calcium content, we can increase the calcium content of these species by up to 20-fold the original value. Such a large increase in calcium most likely results in residual food in the gastrointestinal tract. This diet contains little calcium, which includes the insect body (Mlcek et al. 2014). Insects are generally very rich in phosphorus, which is due to the ratio between phosphorus and calcium. Phosphorus is reported to have a ratio of less than one to calcium (Mlcek et al. 2014). For a closer look, animal phosphorus in monogastric is 100 % available, which cannot be said for plant phytate phosphorus, which has an availability of about 30 %. Some values of insects for human consumption showed increased values, specifically for iron and copper, in this case, the release of these substances is caused by the increased temperature that was released from the dishes during the preparation (Finke 2004).

4.2.1.7. Energy Balance

Fats provide the body with most of the energy for the proper functioning of the body and thus keep the body alive. The larval stages of insects include much more polyunsaturated fat than the adult stages. However, as has been mentioned several times in this work, it should be added that the energy content of edible insects varies depending on the species, location, diet, and developmental stage of the insect (Mlcek et al 2014). Compared to energy values for livestock are 166-710 kcal /100 g, for vegetables the values are less than 310 – 350 kcal /100 g, while edible insects provide approximately 220 – 780 kcal /100 g, insects bred for bio-waste provide energy values in the range of 290-580 kcal /100g Some species of poultry, ostriches, fish and pigs, which were enriched with insects at an early stage, had increased conversion values of 1.20: 1 - 2.80: 1 (Mlcek et al. 2014). On the other hand, it describes the efficiency of nutrient conversion in chickens when fed 2 kg of grain per 1 kilo of chicken (Pimentel & Pimentel 1985). In terms of energy costs, the collection of vertebrates is greater than that of edible insects. Because insects can provide vital processes in our body that need energy, some species of edible insects contain mainly polyunsaturated fats (DeFoliart 1992). This is due to the fact that insects eat vegetables with mostly unsaturated fats. (Krause & Mahan 2003).

4.2.2. Insect Harvesting in the Wild

Insects are an integral part of the food chain for birds, reptiles and other animals. The free collection of insects in nature can lead to a number of problems. The biggest problem with insect collecting is the loss of natural habitat for certain insects and the resulting loss of biodiversity. In the Lao PDR, insects are a highly valued food but intensive collection, excessive or unsustainable collection practices can have a negative impact on insect populations, particularly the loss of insect regeneration capacity and thus reducing the availability of insects as a food source. At the same time, the situation is not helped by the excessive clearing of forest areas, which can also affect the natural habitat of insects. The organisation Fao is at this moment trying to implement a project called “sustainable insects harvesting” in countries with high a wild collection of insects, which aims to increase the viability of wild collection and thus preserve insect biodiversity (Hanboonsong & Durst 2014).

4.2.3. Insect Farming

Edible insects are mostly collected in the wild, the rest of the insects are domesticated because they contain valuable commodities such as silk, honey, wax etc. The most valuable domesticated species are probably silkworms and bees. Silkworm farming is almost 5000 years old and has its roots in China (van Huis et al. 2013). The domesticated form of silkworm has much larger cocoons, faster growth and can live in shady conditions. Domesticated adults cannot fly; thus, they are dependent on humans. Both bee larvae and silkworm pupae are consumed as a by-product. Some insects are bred for the food industry. Crickets and mealworms are good examples; these are kept as pet food. This is often the case in Europe, North America and parts of Asia (van Huis et al. 2013). Columbia has a dual production system for silkworms. When the domesticated silkworm (*Bombyx mori*) is used to produce fibre and on the other hand it can serve as a good source of food for humans or animals. Estimated production is in the range of 1.2 million - 1.4 million cocoons per mulberry bush and one pupa weighs 0.33 grams. In simple terms, the by-product yield is up to 460 kilograms per hectare. In addition, the excreta can be used as fertilizer for plants or fish feed (DeFoliart 1989).

If we look at East Africa, we can find several insect species that are good candidates for breeding *Scapsipedus icipe*, *Acheta domesticus*, *Gryllus bimaculatus*, *Schistocerca gregaria*, *Hermetia illucens*, *Ruspolia differens*, *Tenebrio molitor* and *Rhychophorus phoenicis* (Magara et al. 2021). It is a quite pity that not enough attention is paid to this sector. As insect farming is still in its infancy in many parts, it is slowly becoming a rapidly expanding agribusiness (Govorushko 2019). Within a few years, insect farming has expanded significantly in East Africa due to its low cost and available organic waste (Chia et al. 2020). Several farms have been established in Kenya, Uganda and Tanzania. Around 95 % of these farms are running as microenterprises with the possibility of converting to more automated systems in the future, as the edible insect market continues to grow in the region. Edible insect farming already has over 1,000 cricket, black fly, and cricket farms in East Africa (Tanga et al. 2021). There are currently 378 farmers in Kenya and 140 cricket farmers in Uganda. These high numbers compared to other countries are due to the long history of entomophagy in these countries. The most commonly farmed cricket species are *Scapsipedus icipe*, *Gryllus bimaculatus* and *Acheta.*

domesticus. Smaller products can produce up to 30 tonnes of cricket powder per year (Magara et al. 2021). There is a company in Kenya, InsectiPro, which produces 1 tonne of cricket powder per month using an automated system.

A good example of how insects can be bred is the breeding of crickets in Thailand and Vietnam. In these countries, crickets are kept quite simply in shelters in the garden. The advantage of cricket farming is that no expensive equipment is needed. They are kept in concrete rings. They use rings of certain dimensions: 0.5 metres in height and 0.8 metres in diameter. Each circle is lined with husks (usually rice husks) at the bottom. Poultry feed or other pet food can also be used to feed them, as can vegetables, rice, and grass (Tanga et al. 2021). Plastic bottles are most commonly used for watering, but a plastic bowl of water can also be used. The water mustn't be too deep so that the insects cannot drown. Another important part is to use adhesive tapes or line a howling circle so that the insects cannot climb the walls. Egg boxes and hollow logs are also often used to make more space for the crickets. More bowls are laid for the females, who then lay their eggs in small bowls that are filled with sand and rice husks. These bowls are covered with a layer of rice and are transferred to another room where they are stored.

The crickets are prevented from escaping the boxes by mosquito nets. These nets also serve as protection against other animals that might potentially want to eat the insects. Each concrete circle is surrounded by a moat of water containing small fish, which prevents ants from entering (Yhoung-Agree et al. 2005).

Other insect breeds such as locusts, scavengers, etc., are still in the early stages of development. The costly part of cricket farming is the high price of feed (Oloo et al. 2021). Therefore, further research on more efficient feeds for insect farming is necessary to make farming affordable (Mmari et al. 2017). There was a need to influence opinion regarding the adoption of cricket farming in the area, opinions were positively influenced by the degree of awareness and the degree of risk averseness (Cheseto et al. 2020). The price of whole crickets, dried or powdered, ranges from 10 – 18 $ per kilo. This price is much higher than that of grasshoppers *(Ruspolia differens*) which are widely consumed in Uganda or Tanzania. There, the average price is between 4 and 4.5 $ per kilo (Chia et al. 2019). As can be noticed the cost of edible insects is relatively high, it has been shown that the price of insect meal is higher than the price of fish meal in Europe (Madau et al.

2020). In Africa, it is obvious that as this trend increases and mass production becomes greater, the price of these foods will in turn decrease, making insect proteins an even more cost-effective option than other vertebrates. Nevertheless, such cost information is insufficient and future research on edible insects in Africa is still needed (Chia et al. 2019).

4.2.3.1. Legal Framework

When it comes to insect consumption in the European Union, it is not very common. It is currently considered a 'novel food' and is subject to assessment by the European Food Safety Authority (EFSA) (de Boer & Bast 2018). Subsequently, the decision must be approved by the ministry in each country separately. In Belgium, for example, consumers can find 10 species of edible insects in shops, mainly mealworms, house crickets and grasshoppers (Caparros Megido et al. 2017). In the Netherlands, the results of risk evaluations on three different insect species are used to justify the marketing of entire insects as regular food. Insects are therefore very often sold in the Netherlands supermarkets freeze–dried (Raheem et al. 2018).

In Africa, many edible insect farms are based on evidence from the International Centre of Insect Physiology and Ecology (ICIPE). This organisation enables the production, handling and subsequent processing of edible insects for feed. According to ICIPE standards, breeding is carried out in Kenya and Uganda. Rwanda is in the process of adopting a similar standard. ICIPE has facilitated the mass rearing of insects, thus enabling the use of insects for agri-food systems in Africa. In Ethiopia, the situation is somewhat more complicated, as species such as the black soldier fly are taken as unknown insects and therefore not possible to breed. While in Europe it is forbidden to use certain substrates as feed, only seven species of insects can be reared. In Uganda and Kenya, the legislation is open to any possible edible insect and any substrate used (Ravi et al. 2020).

4.2.4. Insects processing and consumption

After collection both in the wild or from other farm facilities, the insects are subsequently processed by: freeze-drying, sun-drying, frying, roasting, or boiling are most commonly used. Generally, there are 3 ways in which the insects can be further prepared and subsequently consumed: ingestion of the whole insect, in-ground or paste form, and as an extract of fats, chitin, or protein to enrich food and other feeds. Another widely used method is frying alive and then consuming. Insect meals can be added to bakery products and as animal feed protein (Sumbule et al. 2021). Most commonly, insect meal is added to the following foods: buns, cakes, crackers, various biscuits, bread, porridge, and others. Insect meal is added for a simple reason namely, to increase the nutritional value and to increase consumer acceptability (Vogel et al. 2018). To improve nutritional properties, reduce the chance of contamination and increase palatability, various processing techniques such as oven baking, boiling, frying and extrusion are used. These techniques increase consumer acceptability (Erickson et al. 2004).

A survey conducted in 2014 in the Lagos States focused on what method of insect processing people in Nigeria prefer. Out of the 100 respondents, it came out that almost 62 % of people preferred roasting the most, followed by 28 % for frying and the lowest percentile was boiling 7 %. Next, the respondents were asked how they preserve insects, subsequently, it was found that 50 – 52 % of the respondents preferred salting/sun drying over frying. Frying preferred 30 – 32 % of respondents. Very low on this was preservation by roasting 8 %, followed by smoking 6 % and the lowest representation was preservation in refrigerator or freezer 5 % (Adeoye et al. 2014).

In many countries where it has been eaten since time immemorial, eating habits have changed towards a more Western diet. In other countries like Mexico, foods like tortillas are fortified with yellow mealworms (Aguilar-Miranda et al. 2002).

4.2.3.1 Whole insects

When returning back where were mentioned the 3 ways of processing insects, in Tropical countries it is widely practised to eat whole insects. However, this is not possible for several species, because it is necessary to remove some parts of the body such as wings or legs, especially in locusts and grasshoppers. The insects can then be processed by baking, cooking, and frying, depending on the species and the dish. Interestingly, in Lao PDR, insects are commonly eaten as a ready-made snack or lightly fried and limes are added for flavouring (van Huis et al. 2013).

4.2.3.2 Granular or Paste forms

Grinding is one very frequent approach to processing larger volumes of food. To illustrate, soybeans are used for the meat analogy in the form of tofu. For meat, the products are processed into widely popular foods such as hamburgers and hotdogs, and for fish, they are turned into widely popular fish sticks. In the case of insects, it is similarly possible to process them into a more palatable form by grinding. Grinding to a powder or paste allows these insects to be incorporated into low-protein dishes, thereby increasing their nutritional and dietary value (Ayieko et al. 2010). The easiest way to obtain this powder is to dry the insect and then grind it. In Thailand and the Lao People's Democratic Republic, widely used chilli with ground bugs (*Lethocerus indicus*) this food is called chilli paste (jaew maeng da in Lao PDR and nam phik in Thailand) is very popular among the local population. The great advantage of granulated insects is the easy acceptance of insect protein into a society that otherwise does not have a positive food propensity to consume whole insects. In this way, one can become more familiar with this alternative diet (van Huis et al. 2013).

4.2.3.3 Insect Proteins Extracted

Many people in the western parts of the Earth may not accept insects as a legitimate source of protein because insects have not played a significant role in the country's diet in the past. Extracted insect proteins can be very beneficial for human food products. As it can increase acceptability for cautious consumers like the ground or paste forms. Extracting and isolating protein from insects to increase the protein content of feed may be desirable. But supplementing a food product with insects in this way can be very complicated as a comprehensive knowledge of the extracted proteins is required. It is important to know the amino acid profile, solubility, emulsifiability, foamability and thermal stability (Yi et al. 2013). According to the solubility in solvents, there is a fraction that is not soluble in water and that is soluble in water and to which they can be applied for the separation of extracted proteins and for which applications in the feed or food industry can be used. To obtain proteins with specific proton lengths, alternative methods for protein separation such as liquid chromatography and ultrafiltration are needed. Unfortunately, these methods are currently too costly to be carried out daily. Therefore, continued research into the industry is needed to develop the process and make it profitable and globally applicable. This method is being explored by Wageningen University (between 2010 - 2013), which has investigated the potential of extracting protein from insects to fortify human food. There is a project called Supro2, where the breeding of edible insects is carried out on side streams, where the protein is separated, characterised, and purified for the appropriate production of a specific food product. These extracted proteins can be used in feed products, but appropriate steps need to be taken for economic viability (van Huis et al. 2013).

4.3. Ethiopia

4.3.1. Country Profile

Ethiopia is located in eastern Africa and is considered an arid region. Currently, it is home to more than 115 million people and is also the second-most populous country after Nigeria. It is also home to a wide range of ethnic groups such as Oromo 35 %, Amhara 24.1 %, Somoli 7.2 %, Tigray 5.7 %, Sidama 4.1 %, other 23.2 % and a wide range of religious followers. The largest representation is Ethiopian Orthodox Christianity 43.8 %, Muslims 31.3 %, Protestants 22.8 %, Catholics less than 1 % and others 1.4 % (The World Factbook 2022). However, the population will continue to grow significantly at the current total fertility rate, which is currently 4.05 children per woman (Knoema 2021). Although its economy has grown rapidly in recent years, it has seen a slight decline due to the COVID-19, drought, and the locust outbreak. Nevertheless, it is one of the poorest countries (The World Bank 2021). Ethiopia currently has a gross domestic product (GDP) of nearly 108 billion US dollars according to The World Bank, which is 936.34 US dollars per capita (The World Bank 2020). Ethiopia is an important coffee exporter, accounting for nearly 27 % (US$837 million) of its total export earnings of 3.11 billion USD in 2019. It was followed by other oilseeds 11.2 % ($347M) and cut flowers ($7.66M). Gold was the next most valuable commodity at 8.23 % ($256M) and zinc at 6.4 % ($199M). These commodities are most imported to China 16.6 % ($518M), the United States 15.6 % ($484M) and Saudi Arabia 6.33 % ($197M). If we look at imported commodities, aircraft, helicopters and/or spacecraft are the most imported ($717M), followed by gas turbines 6.79 % ($608M), packaged drugs 4.5 % ($402M) and lastly cars 2.51 % ($225M). In total, Ethiopia pays $8.95 B for all imported commodities.

The top importers include China 26.5 % ($2.37B), India 9.25 % ($828M), UAE 8.81 % ($788M), and from Europe, most notably France 8.8 % ($787M) and the UK 6.95 % ($622M) (The Observatory of Economic Complexity 2019).

Despite a seemingly improving economy, Ethiopia faces many challenges that impair food security such as high food prices, poverty, conflicts over natural resources, lack of education, sanitation, and the rapid increase in the number of young people. Crop production and pastoralism are almost 100 % dependent on rainfall, but this is compounded by excessive drought and water scarcity (USAID 2016). At present, the situation is not helped by armed political conflict (Humans Rights Watch 2022).

Twelve river basins make up Ethiopia's enormous water resources, although they are unevenly distributed. Drought frequency is expected to rise, as is evaporation and evapotranspiration, as well as potential changes in rainfall patterns and runoff. These factors could further diminish water availability in water-scarce areas. Changes in rainfall and evaporation lead to changes in surface water infiltration and groundwater recharge rates. The country's reliance on erratic rainfall patterns is exacerbated by a lack of water storage capacity. Hydropower has the potential to enhance energy access, but it is sensitive to shifting rainfall dynamics, which can limit river flow volume. By 2050, numerous Nile tributaries are expected to have a 30 % reduction in flow volume, according to projections (USAID 2016).

4.3.2. Factors connected with food security

4.3.2.1 Livestock and Pastoralism

Ethiopia has a large livestock sector. Some publications state that the largest is in Africa (USAID 2016). Almost 88 % of households in Ethiopia keep some livestock. Pasture represents 60 % of the total land area and is used by up to 15 million pastoralists. Livestock provides the people of Ethiopia with many services and resources such as draught power, meat, eggs, milk and hides etc. And it becomes a very important source of livelihood in case crop production fails. It is reported that livestock accounts for more than 75 % of the annual income of the Eastern Region of Oromia (Gezie 2019). Livestock rearing and pastoralism face similar problems as crop production, with minor variations, most commonly climatic stressors, frequent conflicts over water and land, and poor-quality practices carried out on open pasture. Pastoralists, too, often have minimal knowledge and access to quality feed, reproductive tools or vaccines (USAID 2020). Often, pastoralists are therefore influenced by declining livestock productivity to switch to livelihoods such as agro-pastoralism or crop cultivation. Climate change, therefore, poses a major threat to the livestock sector (USAID 2020). Because high temperatures can cause animals to deteriorate or even die. Especially for chickens, which can tolerate less heat and fewer temperature fluctuations. Inadequate rainfall reduces the amount of food that livestock can consume and reduces productivity and increases susceptibility to diseases.

4.3.2.2 Crop Production

A significant proportion of crops are produced by farmers who have to rely solely on rainfall and, in addition, 90 % of gross agricultural production is from farmers who have no cultivated area larger than 2 hectares (CIAT & USAID 2017). However, production can vary greatly, usually, farmers are exposed to a wide range of stressors.

Very often, production is adversely affected by delayed rainfall, lack of rainfall and the nowadays widely discussed drought. These are the key factors that negatively affect yields (USAID 2016). Agricultural production in Ethiopia is highly dependent on the quality and duration of rainfall, as only 1% of the land is irrigated. Droughts in 1984, 2003, and 2015 – 2017 collectively damaged more than 30 million people's livelihoods and have heavily influenced food security (CIAT & USAID 2017). Another problem is that a large number of farmers grow crops that require two rainy seasons to mature which is due to frequent droughts the big disadvantage, however, is that they are slow to mature.

Other events that can negatively affect crops include floods, landslides, torrential rains and hailstorms (USAID 2016). A survey between 2015 – and 2016 found that some extreme events have also significantly damaged crops. These extreme events include floods (9 %) hail (7 %) and at least heavy rains (5 %). Not to mention the loss of human life or animals that these events have claimed. In 2006, extreme floods claimed 20,000 injuries and more than 800 deaths (USAID 2016).

A very significant stressor for local farmers is plant diseases and pests. Among the most feared diseases are fava bean leaf and stem gall, wheat rust and the deadly necrosis of wheat disease. The fall armyworm (*Spodoptera frugiperda*), which is adapted to Ethiopia's warm and humid conditions, has also been on the rampage in Ethiopia in recent years and has already attacked nearly 642,000 hectares of maize since it was accidentally introduced into the country in 2017 (Assefa & Ayalew 2019). We must not forget the worst locust outbreak in recent years, which is plaguing not only Ethiopia but virtually the whole of East Africa. The desert locust in high numbers can change crops beyond recognition, severely threatening food security in this country (USAID 2020). The outbreak is caused by heavy rainfall and high temperatures, which give the desert locusts an ideal opportunity to reproduce. At present, the situation is not much better, with total crop losses of 4 % (FAO 2019).

Currently, Ethiopia is also plagued by desertification, land degradation and fragmentation which reduce crop production this issue is due to inappropriate agricultural practices as well as pressure on natural resources and the growing population. The availability of arable land has decreased dramatically due to a reduction in soil fertility as well as an increase in soil erosion (USAID 2020). In the highlands, where the majority of Ethiopians reside, soil erosion affects 40% of the land surface, resulting in 1.5 billion tons of topsoil loss per year and hurting regional and national food production. Land fragmentation and instability have also resulted from population growth; as a result, highland farmers are left with increasingly limited land holdings and are sometimes unwilling to engage in better management practices (The U.S Government´s Global Hunger & Food Security Initiative 2019). In the highlands, people have so little land to produce enough food for a household of 5 people, let alone sell the crops afterwards. Because most people have such small landholdings in Ethiopia, it is very difficult for them to adopt practices such as agroforestry, using better seeds and fertilizing with more efficient technologies that can positively affect soil quality and productivity (CIAT & USAID 2017). Not to mention poor access to financial resources and improved procedures. Local farmers often do not have sufficient funds to buy or borrow better farm machinery. Often they don't even have access to online platforms where they can expand their knowledge on crop production (USAID 2020).

Invasive species are very common in East Africa and affect the livelihoods of the rural populations there. It is typical for invasive species to outcompete native plant species and can be toxic to animals as well as humans. They compete or smother with other crops and contribute to soil degradation (Witt et al. 2018). Climate change has facilitated the free spread of those invasive plants in Ethiopia and thus also allowed them to spread to other areas (Shiferaw et al. 2018). Increased droughts help some invasive species to spread more easily into the surrounding area; these species include the winged pondweed (Agavaceae) (Witt et al. 2018). It has been found that native plants that help the local ecosystem can also be displaced by invasive species (Shiferaw et al. 2018).

Other problems that negatively affect agriculture in Ethiopia include the overuse of pesticides. Pesticides are used to control insects that damage crops and reduce their nutritional value. In a 2016 survey, it was found by local farmers that insect pests and excessive use of pesticides resulted in almost 18 % crop damage. In Ethiopia, there was a marked increase in use from 0.2 to 0.6 kilograms per hectare between 1997 and 2014 (Mulas et al. 2018). There is no doubt that pesticides kill pests, but on the other hand, many of them are harmful to agriculture and also to people. 150 dangerous pesticides were found in 2017, which simply means they are toxic or deadly when in contact with humans. Some pesticides may contain carcinogens or other toxins and mutagens (Mulas et al. 2018).

A final reason that does not contribute significantly to food safety was the finding of inadequate storage space. Some surveys have shown that post-harvest losses reach almost 40 %. Post-harvest losses were highest in maize (Vermeulen et al. 2012). The Ethiopian government has decided to invest funds in inroads to link rural farms to storage facilities, home-based businesses or production sites to reduce post-harvest losses. Due to the severe heat in Ethiopia, which often coincides with the harvest season, crop losses are catastrophic. All of the above examples of unsuitable conditions work very strongly together. For example, flooding can damage the roads that connect different farms and, due to this flooding, the crop will not arrive in time for the location and will most likely spoil. More intense rainfall may further complicate the situation. On the other hand, high temperatures often associated with dry seasons can also cause food to spoil more quickly because a significant proportion of farmers in Ethiopia have no or very limited cold storage facilities if we are talking about smaller farmers (FAO 2016).

4.3.2.3 Nutrition Problem

The most common nutrition problem in Ethiopia is clearly malnutrition. Malnutrition is one of the leading causes of premature death of children under 5 in

Ethiopia. Statistical indicators show that this scale is not only the highest in sub-Saharan Africa but is one of the largest worldwide. (Endris et al. 2017). Malnutrition leads to anthropometric deficits, which are abundant in less developed countries. It is caused by the interaction between poor diet and disease. Malnutrition in Ethiopia affects women and children the most and as mentioned, contributes to more than half of all infant and child deaths in Ethiopia. Stunting due to malnutrition was 37 % in children under 5 years, followed by 7 % wasted children and 21 % underweight children. For women in 2016, malnutrition was 22 % (USAID 2020).

Securing food for people is an increasingly difficult task with a growing population and with rising consumption growth. Deteriorating agricultural productivity results in chronic malnutrition in many developing countries not only in Ethiopia, but it is a long-standing problem in Ethiopia. Nutritional problems in this country are often caused by natural factors such as worsening climatic conditions due to global warming, deteriorating soil fertility, the incidence of pests and plant diseases, as well as rising food prices, unsatisfactory purchasing power, disparities in food distribution and availability, inadequate sanitation, and often compounded by poor eating habits. All the above factors are the cause of food shortages (Kumar 2010).

4.4. Entomophagy in Ethiopia

If we look at entomophagy in Ethiopia, it may surprise us that people in Ethiopia are for the most part unwilling to accept insects as their food compared to other African countries where insects are consumed on daily basis. The 2020 survey, which randomly selected a total of 203 people from Ethiopia (109 men and 94 women) of various ages, helped us reach this conclusion. This survey compared the importance of entomophagy to people from two different cultures. This survey showed that Ethiopian respondents are less willing to accept insects as a full-fledged source of livelihood compared to Koreans. However, it can be said that men in both cultures are more inclined to consume insects than their female counterparts. It was found that only 11.1 % of Ethiopians would be willing to accept food containing insects (Ghosh et al. 2020). Other parts of the questionnaire asked respondents who had at least a little knowledge regarding edible insects how they received this knowledge. It was found that vertical transmission (from parent to offspring) played almost no role among Ethiopians (15 %). The following percentages was found only among the elderly population above 50 years. Ethiopians aged 10 - 49 years had a noticeably poorer view of insect consumption than individuals over 50 years of age (Ghosh 2020). A slightly strange finding was that Ethiopians were mostly unaware that insects were commonly consumed in some places in Ethiopia (Benishangul, Gumuz). When respondents were asked a question that would result in acceptance or rejection of insects as a food source the main reason was the taste. 55.3 % of respondents said that taste would be a key factor. Right behind, 14.3 % of Ethiopians said that nutritional composition was important to them. texture played the least role 5.4 %. Depending on the environment, only 6.9 % of Ethiopians would be willing to accept insects as a food source. A very interesting finding was that some respondents stated that eating insects were not culturally appropriate. In addition, many Ethiopians added that their religious affiliation does not allow them to eat insects.The majority of the population is Christian almost 44 %. Even in the third book of the Old Testament called Leviticus, says that locusts, crickets, and grasshoppers can be eaten. However, other insects are unfortunately forbidden (Guzik 2021).

Although it can be stated that there is a majority unacceptability of entomophagy in Ethiopia. Nevertheless, some species can be very nutritious and easy to breed and thus can serve as a source of livelihood in many parts of Ethiopia. In the Table 1 are presented insects species that are possible to find in Etiopia and are of high nutritional value and have a high potential to become a food source.

Table 1. Insect occurring in Ethiopia with high potential to become edible.

Scientific Name	English Name	Order	Family	Consumption Stage	Consumption Method	Protein Content (% in Dry Matter)	Sources
Schistocerca gregaria	desert locust	Orthoptera	Acrididae	Adults, nymphs	Boiling, drying and frying	50 - 60	Mariod 2020
Hermetia illucens	black soldier fly	Diptera	Stratiomyidae	Larvae	Raw, milling	40 - 55	Diener et al. 2009
Ruspolia differens	long-horned grasshopper	Orthoptera	Tettigoniidae	Adults	Raw (after the wings have been pulled of), frying	35 - 37	Kinyuru et al. 2010
Sitophilus zeamais	maize weevil	Coleoptera	Curculionidae	Larvae, adults	Drying	23 - 66	Omotoso et al. 2007
Locusta migratoria cinerascens	migratory locust	Orthoptera	Acrididae	Adults and nymphs	Boiling, drying and frying	23 - 65	McCaffery 1975: Kouřimská & Adámková 2016
Sitophilus granarius	grain weevil	Coleoptera	Curculionidae	Larvae, adults	Drying	23 - 66	Omotoso et al. 2007
Acheta domesticus	house cricket	Orthoptera	Gryllidae	Adults	Drying, roasting and milling	60 - 70	Udomsil et al. 2019
Gryllus bimaculatus	two - spotted cricket	Orthoptera	Gryllidae	Adults	Drying, roasting and milling	60 - 70	Udomsil et al. 2019
Anaphe panda	N/A	Lepidoptera	Notodontidae	Larvae	Roasting	14 - 68	Nishimune et al. 2000
Tenebrio molitor	mealworm beetle	Coleoptera	Tenebrionidae	Larvae	Boiling, frying and drying	45 - 60	Hong et al. 2020
Apis mellifera	honeybee	Hymenoptera	Apidae	Larvae and pupae (adult)	Drying	39 - 53	Crailsheim et al. 2015

Table 2. Insect occurring in Ethiopia with high potential to become edible (continued).

Scientific Name	English Name	Order	Family	Consumption Stage	Consumption Method	Protein Content (% in Dry Matter)	Sources
Macrotermes subhyalinus	N/A	Blattodea	Termitidae	Adults (alates,soldiers)	Roasting, drying,frying and smoking	46	Sogbesan & Ugwumba 2008
Alphitobius diaperinus	Lesser/Buffalo mealworm	Coleoptera	Tenebrionidae	Larvae	Boiling, frying and drying	42-54	Leni et al. 2020
Rhynchophorus phoenicis	african palm weevil	Coleoptera	Curculionidae	Larvae	Frying, boiling, smoking or raw	22-66	Ekpo & Onigbinde 2005
Pseudacanthotermes militaris	sugarcane termite	Blattodea	Kalotermitidae	Adults	Frying, raw, drying and smoking	34	Kinyuru et al. 2013
Macrotermes bellicosus	N/A	Blattodea	Termitidae	Adults	Frying, raw, drying and smoking	39	Kinyuru et al. 2013
Pseudacanthotermes spiniger	N/A	Blattodea	Termitidae	Adults	Frying, drying and smoking	38	Kinyuru et al. 2013
Agonoscelis puberula	african cluster bug	Hemiptera	Pentatomidae	Nymphs	Drying	15-81	Mariod 2013
Aspongubus viduatus	melon bug	Hemiptera	Pentatomidae	Nymphs	Drying	27	Mariod et al. 2011
Heliothis armigera	african bollworm	Lepidoptera	Noctuidae	Larvae	Drying, milling	38-33	Ghaly & Alkoaik 2010
Spodoptera exigua	beet armyworm	Lepidoptera	Noctuidae	Larvae	N/A	26-72	Lemoine & Shantz 2016

Table 3. Insect occurring in Ethiopia with high potential to become edible (continued).

Scientific Name	English Name	Order	Family	Consumption Stage	Consumption Method	Protein Content (% in Dry Matter)	Sources
Lepisiota canescens	N/A	Hymenoptera	Formicidae	Adult,larvae	Raw, drying, roasting, baking and frying	55	Chakravorty et al. 2016
Encosternum delegorguiei	N/A	Hemiptera	Pentatomidae	Adults, nymphs	Raw, drying	35	Teffo et al. 2007
Nezara viridula	green stink bug	Hemiptera	Pentatomidae	Adults, nymphs	Raw, drying	35	Teffo et al. 2007
Cilnia humeralis	N/A	Mantodea	Mantidae	Adult, nymphs	Frying	N/A	Razeng & Watson 2015
Sphodromantis abessinica	N/A	Mantodea	Mantidae	Adult, nymphs	Frying	N/A	Lombardo 1997
Sphodromantis aethiopica	ethiopian mantis	Mantodea	Mantidae	Adult, nymphs	Frying	N/A	La Greca & Lombardo 2013: Vatican 2019
Sphodromantis citernii	N/A	Mantodea	Mantidae	Adult, nymphs	Frying	N/A	Lombardo 1997: Vatican 2019
Sphodromantis congica	congo mantis	Mantodea	Mantidae	Adult, nymphs	Frying	N/A	Roy & Cherlonneix 2009: Vatican 2019
Pseudoclanis abyssinicus	N/A	Lepidoptera	Sphingidae	Larvae	Grilling frying	20-76	Su et al. 2021
Cadiouclanis bianchii	N/A	Lepidoptera	Sphingidae	Larvae	Grilling, frying	20-76	Su et al. 2021

From Table 1 it is clear that various orders and families of insects can be consumed. However, the most commonly consumed insects in many countries are Coleoptera, Orthoptera, Lepidoptera and Blattodea, which are also abundant in Ethiopia. Of the order Coleoptera, the following insects occur in Ethiopia: *Sitophilus zeamais, Sitophilus granarius, Alphitobius diaperinus* and *Rhynchophorus phoenicis*. Individuals of the order Coleoptera are most commonly consumed in the larval 100 % or adult stage 40 %. The most common methods of preparation for this order are boiling in water 60 %, frying 60 %, or drying 100 %. The average dry protein content of the Coleoptera order is 40.69 % (Rumpold & Schlüter 2013b). As for the order Orthoptera, *Schistocerca gregaria, Ruspolia differens*, *Acheta domesticus*, *Gryllus himaculatus* occur in Ethiopia. Insects of the order Orthoptera are frequently consumed in adult stage 100 % or in nymphal stage 40 %. Most often, these representatives of insects are prepared for consumption by drying 80 %, frying 60 %, boiling 40%, roasting 40%, and milling 40%. Protein representation in dry matter for this order is 61 % on average (Rumpold & Schlüter 2013b). For the order Blattodea, the following individuals occur in Ethiopia: *Macrotermes subhyalinus, Macrotermes bellicosus, Pseudacanthotermes militaris*, and *Pseudacanthotermes spiniger*. Adult developmental stages are most consumed 100 %. Processing methods for this order are 100 % for drying, frying 100 %, and smoking 100 %, raw 75 % and roasting 20 %. Protein representation in dry matter of Blattodea insects is 57 % on average (Rumpold & Schlüter 2013b). Lepidoptera insects are also found in Ethiopia: *Anaphe panda*, *Spodoptera exigua*, *Heliothis armiger, Pseudoclanis abyssinicus* and *Cadiouclanis bianchii*. In this order, consumption of the larval developmental stage is often preferred 100 %. Processing methods for these insects are grilling 40%, frying 40%, roasting 20 %, drying 20 %, and milling 20 %. Average dry protein content of Lepidoptera 45 %. The Hemiptera order (*Agonoscelis puberula, Aspongubus viduatus*, *Encosternum delegorguiei* and *Nezara viridula)*, which is not so widely consumed was also found in Ethiopia. Nymphal 100%, and adult 50 % stage are preferred for this order. Processing methods are drying 100 %, or raw form 50 %. In the table is mentioned quite often the order Mantodea, which is also edible (Vatican 2019). At present, there is little information on how to consume this order. No publications have been found that mention the protein abundance of this order (Razeng & Watson 2015). In

Ethiopia, there are very many moths of the family Eribidae. Unfortunately, only a small number of moths are currently edible (Helmenstine 2019). Therefore, they were not included in the Table 1.

Overall, the table shows that most insects are consumed in the adult 64.5 %, larval 41.9 %, and nymphal stages 35.4 %. The most clearly preferred processing methods are: frying 58 %, drying 54.8 %, roasting 16 % and boiling 12.9 %. Some of the insects could also be consumed in raw form 25 %. The highest average percentage of protein in dry matter was in the Orthopeda order. It is very important to mention that protein abundance can vary on the sex of the insect, location of occurrence, diet, developmental stage, and many other factors.

4.4.1 Potential use of *Schistocerca gregaria*

Schistocerca gregaria also known as desert locusts have become a threat in many developing countries, but also, especially in Ethiopia. Thanks to the ability to survive in the harshest climatic conditions, the ability to change physiology and behaviour due to climatic conditions (Meynard et al. 2020). Individuals do not pose the greatest threat to farmers but can create huge swarms that can consume huge amounts of agricultural land. Locusts spend most of their day trying to find annual vegetation to hide and lay eggs after intermittent rain. It is often referred to as an area of recession, where climatic conditions are in equilibrium at one point and there is no spread at the other hand heavily infested (Cressman 2016). Most of these infestations build up during heavy rains and locusts take advantage of it and multiply quickly. Under favourable conditions. They can enlarge up to 20 times every 3 months. When their habitat begins to dry up, they are forced to move to other areas with green vegetation. They go into very strong contact with each other and start behaving as a whole. From the beginning, they form small groups, which then turn into dense bands and swarms. This gradual formation of a dense swarm is called gregarization (Symmons & Cressman 2001). In the case of extensive and severe infestation, there is talk of a so-called plague if more than two areas are affected at the same time. In other countries, the situation is relatively preventable thanks to early monitoring and preventive measures, but in Ethiopia, it is not; infestations of desert locusts contribute to malnutrition and overall food insecurity (Samejo et al. 2021). On the other hand, malnutrition and food security could be greatly improved by consuming these insects.

Figure 1. ***Schistocerca gregaria*** **(World Meteorological Organization and Food & Agriculture Organization of the United Nations 2016).**

Rural communities often have no options to fight locusts effectively, they are reliant on using their own methods such as tire noise and burning to relieve locusts. Burning locusts as they perch in the vegetation at night, digging ditches and using embankment belts and ploughing fields to destroy laid eggs. Other control tactics may be replaced by harvesting locusts for food (Samejo et al. 2021).

While collecting locusts as a food source can replace other methods. The manual collection is practised all over the world and serves as a relatively high-quality control method to reduce the population. It should not be forgotten that the consumption of the collected insects could partially compensate for the damage to the crop (van Huis 2020). In addition, it was found that the energy value of the desert locust was 179 kcal/100 g, and the protein content was in the range of 14 – 18 (g/100 g fresh weight) high levels of zinc and iron were also found in this insect (Mariod 2020).

The locust nymphs are easy to collect, creating 40 cm deep trenches along their migration route. These trenches should be vertical so that the insects cannot climb up the walls. Fallen nymphs can then be collected and further processed. As this insect specie is cold-blooded (like all insects), the best way to capture it is in the evening or early morning hours, as it is almost immobile in colder weather. Before the insect can take flight, it must spend some time in the sun to warm up. Therefore, trapping in the morning and evening hours is the best way. Adult locusts can be trapped using hands, buckets, or bags. Insects can also be prepared for consumption by dropping them into boiling water, drying them, or frying them. Insects can be seasoned with available spices for the best flavour results (Samejo et al. 2021).

Figure 2. Trapping *Schistocerca gregaria* in the evening in the field (A) Lights from the vehicle as a trap (B) Light and containers for collection (C) Placing insects in a bag (D) Cargo of insects ready for transport (Samejo et al. 2021).

4.4.2 Potencional use of *Hermetia iilucens*

This species is more commonly known as the black soldier fly. This insect species is currently highly debated due to its ability to consume large amounts of organic material in his larval stage such as rice straw (Zheng et al. 2012) food waste (Green & Popa 2012), animal entrails, and many others (Nguyen et al. 2015). The variety of substrates they can effectively process is probably the highest among flies (Kim et al. 2011). Another advantage is that they are edible. It is believed that the feed conversion ratio is better than that of mealworms and crickets (Oonincx et al. 2019). Percentages of crude protein ranged from 31.7 % to 47.6 % for fats, with values ranging from 11.8 % to 34.3 % for fats (De Marco et al. 2015). When the larvae are at the pre-pupa stage, they are known to instinctively leave the substrate and move spontaneously to an elevated cleaner spot, this instinctive behaviour is referred to as "self-harvesting" which helps to facilitate the collection. These abilities make it a very suitable helper in the fight against organic waste, and it is also a suitable candidate to become a sustainable source of feed for livestock and potentially for the people. Potential for humans because these insects feed principally on organic matter such as manure and so on. At present, there are no published studies sufficient to refute the possibility of harm to humans (Wang & Shelomi 2017).

Black soldier fly larvae are often used in poultry feed as a substitute for corn or soybeans, and the species spontaneously colonizes and decomposes poultry droppings to reduce pollution (Bradley et al. 1984). Feeding the larvae had no negative effects on the taste perception of the meat, nor on the oxidative state or cholesterol composition. However, it did somewhat increase the proportion of monounsaturated fatty acids (Cullere et al. 2018). Nevertheless, it is a suitable source of feed for poultry (Schiavone et al. 2017). It may also have the advantage of being very palatable to hens. Overall, therefore, it can be concluded that black soldier fly larvae guarantee quality production performance, carcass traits and overall meat quality for chickens (Schiavone et al. 2016).

Figure 3. ***Hermetia illucens*** **in the adult and larval stage (Chia et al. 2018).**

Black soldier fly meal and oil are already being considered as an alternative to fish meal and fish oil as fish feed. This is because the larvae contain a high protein and lipid content (Kroeckel et al. 2012). Larvae can accumulate lipids in their bodies if fed a diet suitably enriched with lipids. These enriched larvae produce omega - 3 fatty acids when the diet is supplied with fish guts (St-Hilaire et al. 2007). Such enriched larvae are very high quality and suitable food even compared to fish meal. Experiments with African catfish (*Clarias gariepinus*) confirmed that replacing fishmeal with black soldier fly larvae did not affect altering growth rate or other growth rate utilization, so they were recommended as a suitable alternative that is also more affordable (Aniebo et al. 2009). This has led to suggestions that they can completely replace fishmeal and thus contribute to sustainable aquaculture (Diener et al. 2009).

In Ethiopia, an alternative to aquaculture called aquaponic could be applied. Aquaponic is a system that is based on the functioning of two ecosystems that depend on each other, where the two ecosystems work together to form one ecosystem. The fish in an aquaponic system provides nutrients for the plants to grow. The plants in turn serve as a biofilter, cleaning the water of impurities for the survival of the fish (Tyson et al. 2011). Filters are needed to clean the water of solid and dissolved particles so that the water can be effectively purified. The first thing needed is a mechanic filter to remove solid particles. Next, the water is passed through a biofilter, which processes the dissolved waste. The biofilter provides a suitable place for bacteria to convert the ammonia excreted by the fish into nitrates and other nutrients for the plants. This process is known as the nitrification cycle and is important for plant growth.

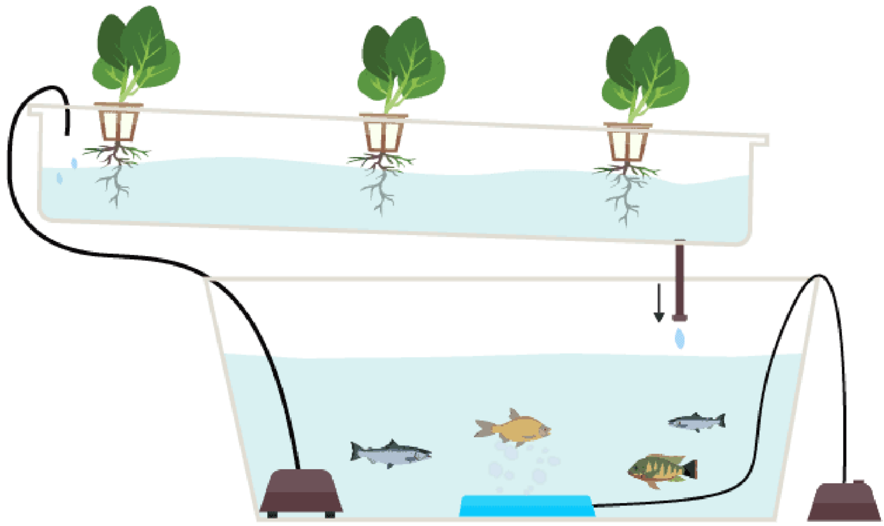

Figure 4. Aquaponic system (Aquaponics Education Centre 2019).

The advantage of the aquaponic system is that its operation uses 90 % less water than conventional crop production and can increase crop yields by up to ten times and help reduce pressure on soil (Javis 2014). As a result, it has enormous potential to reduce impacts on natural resources in Ethiopia. However, this system is an facing initial problem with fish feed. Quality feed is needed for proper functioning. It is in this system that the black soldier fly larva could be applied, which could be a food source for fish in an aquaponic system due to its high nutritional value. Fish food is very expensive in these areas, so black soldier fly larvae could be a good solution. Although the climatic conditions in Ethiopia for rearing these larvae appear favourable, the options for Ethiopian aquaponic farmers are severely limited, mainly due to rapid population growth, food shortages are a severe concern in wide regions of Ethiopia, and waste streams are not well managed, resulting in the loss of precious resources. Until 2016, according to Koop (2016), the black soldier fly was considered an unknown species, hence the need for a proper environmental assessment of its occurrence in Ethiopia. According to International Centre for Insect Physiology and Ecology (2021), progress has been made in research and development activities on the black soldier fly and foraging insects in Ethiopia. Nevertheless, these were the only outputs that could help in the future introduction of edible insects in Ethiopia.

5. Conclusions

Edible insects represent not only a quality source of protein but also other nutrients such as fat, carbohydrates, minerals, vitamins, and fibre. This study described 31 species of insects that occur in Ethiopia and have a high potential to become edible. The individual insect species and their taxonomic classification, stages of consumption, processing methods and percentage of dry matter were described in the table. The highest percentage of protein in dry matter was found in the order Orthoptera, which reached 61 % on average and the order Blattodea reached 57 %. Followed by the order Lepidoptera 45 % and the order Coleoptera 41 %. The insects represented in the table were mostly consumed at the adult 64.5 %, larval 41.9 %, or nymphal 35.4 % stages. The most common preparations methods of these insects include frying 58 %, drying 54.8 %, roasting 16 % and boiling 12.9 %. Some of the insects could also be consumed in raw form 25 %. All information used for this thesis was based on scientific publications and summaries of reports from organizations of other countries, as insects are not consumed in Ethiopia compared to other countries. Therefore it is important to add that this thesis was about the potential use of edible insects in Ethiopia.

Residents in Ethiopia in past studies have stated that not consuming insects is associated with their religious beliefs. Therefore, they cannot consume insects. Although the majority religion is Christian. The Bible does not prohibit the consumption of certain insects. As in the case of the desert locust *(Schistocerca gregaria*), which has contributed significantly to food insecurity in Ethiopia in recent years, due to its ability to reproduce quickly, and consume large agricultural areas. The capture and subsequent consumption of the desert locust could partially offset crop damage in Ethiopia, and its high protein content could improve malnutrition in this country.

In case of persistent disinterest, the black soldier fly (*Hermetia illucens*) can be used. Specifically, its larval stage, which is more nutritionally valuable, could be used as livestock feed or a source of fish feed in aquaponic systems. At present, the use *Hermetia illucens* can only be speculated, as it is considered as an unknown species by the Ethiopian government, and therefore cannot be commercially bred, although it is naturally occurring in Ethiopia.

Because eating insects has undeniable advantages such as rapid reproduction, low water, space, feed requirements and low greenhouse gas emissions compared to livestock. It can contribute significantly to food security and reduce malnutrition in Ethiopia. Awareness-raising is, therefore more than appropriate at present. One of the options may be the use of a questionnaire, which was compiled for this thesis but could not be used due to the pandemic and political situation and is attached to this thesis. Data collection and analysis using the questionnaire could provide valuable information in the future.

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Annex A

Insects as na Alternative Source of Animal Protein inArba Minch, Zuriya district, Gamo zone, SNNPR,Ethiopia

1. What gender are you ?

Mark only one oval.

- Male
- Female
- Prefer not to say

2. In which age group are you ?

Mark only one oval.

- Under 20 years
- 20-25 years
- 26-30 years
- 31-35 years
- 36-40 years
- Over 40 years

3. What is your level of education ?

Mark only one oval.

- No Formal Education
- Primary Education
- Middle Education
- Secondary Education
- Vocational Education
- Tertiary Education

4. What is your religion?

Mark only one oval.

- Orthodox
- Protestant
- Catholic
- Muslim
- None
- Other: ____________________

5. How big your household is ?

Mark only one oval.

- I live alone
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- More than 9

6. Are you the head of the household ?

Mark only one oval.

- Yes
- No
- Partly

7. Have you experienced a food shortage in your country ?

Mark only one oval.

- Yes
- No
- Partly

8. Do you think food shortages could be caused by the invasion of desert locusts or other insects ?

Mark only one oval.

- Yes
- No
- This is due to many factors
- I don´t know

9. If you marked in the last question "This is due to many factors" , please specify them.

____

____

____

____

____

10. Have you ever heard about "Enthomophagy" (technical term for eating insects) ?

Mark only one oval.

- Yes
- No

11. Almost 8 million people are estimated to be in need of food assistance in Ethiopia. Do you think enthomophagy could reduce that number ?

Mark only one oval.

- Yes
- No
- I Don't know
- Other: ______________________

12. What is your opinion on insects in general ?

Mark only one oval.

	1	2	3	4	5	
Negative	◯	◯	◯	◯	◯	Positiive

13. Have you ever consumed an insect ?

Mark only one oval.

- Never
- Once
- Few times
- Several times

14. Do you believe insects are safe to eat ?

Mark only one oval.

- Yes
- No
- I don´t know
- Depends on processing
- Other: ______________________

15. If you ever consumed an insect, what type it was ?

____

16. Which method/methods of preparation of edible insects would you prefer ?

Mark only one oval.

- Raw form
- Frying
- Boiling
- Roasting
- Drying

17. What was/would be the reason that made you try it for the first time?

____

18. Do you know someone who eats insect on a daily basis ?

Mark only one oval.

- Yes
- No

19. What is your source of awareness about edible insect ?

Mark only one oval.

- Market
- Forest
- Farm
- Media (TV, radio, internet etc)

20. Does your religion allow eating insects ?