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Selected aspects of edible insect rearing and consumption – A review

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Abstract: The presented work brings a comprehensive study of edible insect farming with an impact on the environment and human health. The review focuses not only on commonly monitored parameters such as carbon footprint or feed conversion but also on waste management. It also highlights the positive and negative aspects of eating edible insect regarding human health. Compared to other livestock, the rearing of edible insect brings less environmental burden and higher environmental protection. This review aimed to summarise current knowledge and broaden the complex view of the issue.

Keywords: allergy; carbon footprint; chitin; global warming potential

Insects as animal species exist in the world for more than 300 million years, and since the beginning of mankind, they are considered a "miracle of nature" for medical, religious, and food use purposes (Ramos-Elorduy 1998; Meyer-Rochow 2017).

Edible insects have been used by humans since time immemorial and have been one of the most available food ingredients of animal origin (Sponheimer et al. 2005; Lesnik 2014). Currently, edible insects are consumed by more than one-third of the world's population (more than 2 billion people) (van Huis et al. 2013). Considering the growing world population [according to UN (2015), it may be up to 10 billion people in 2050], the need to look for alternative sources of food implies, and edible insects appear to be a suitable alternative source of protein.

The nutritional value of edible insects varies greatly, mainly due to the variability of species and consumption possible at different developmental stages. The protein content in the insect body ranges from 13% to 81% of dry matter (Ramos-Elorduy et al. 1997; Xiaoming et al. 2008). Edible insects contain nutritionally valuable amino acids, including a high content of phenylalanine and tyrosine. According to Xiaoming et al. (2008),

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the content of essential amino acids may be 46–96% of the total amino acids. Some insect species also contain large amounts of lysine, tryptophan, and threonine, which are deficient in some cereal proteins (Kouřimská and Adámková 2016). Therefore, it is possible to fortify conventional bakery products to increase their content. Fat variability depends on many factors and is usually in the range of 10% to 55% of dry matter (Bednářová et al. 2013). Insect fat can be widely used, e.g. for food purposes in terms of saturated fatty acids (palmitic acid) content. The total content of polyunsaturated fatty acids, which provide prophylaxis against cardiovascular diseases, such as oleic, linoleic, or linolenic, can be up to 70% of total fatty acids (Tzompa-Sosa et al. 2014). Some species of edible insects can be a valuable source of minerals, e.g. iron and zinc contents are especially important in developing countries (Rumpold and Schlüter 2013; Manditsera 2019). In the case of commonly bread mealworm larvae, Zielińska et al. (2015) report a zinc content of 11.2 mg kg^{-1} and Finke (2004) 137 mg kg^{-1}. Edible insects also contain vitamins such as B vitamins, vitamins A, D, E, K, and C. In general, most edible insect species provide sufficient energy and protein, meet amino acid requirements for humans, have a high content of mono and polyenoic fatty acids, and are rich in trace elements such as copper, iron, magnesium, manganese, phosphorus, selenium, and zinc, as well as riboflavin, pantothenic acid, biotin and in some cases folic acid (Rumpold and Schlüter 2013). In Central European countries, the insect is currently most often sold as part of bakery products, protein bars, mixtures for the preparation of meatballs or vegetable cakes with insects, or as a delicacy prepared by roasting or other cooking techniques.

Edible insect as a food bears certain positives and negatives, like other food commodities. Van Huis et al. (2013) listed the following benefits of edible insect rearing:

– Insects can high feed conversion (Mancini et al. 2019; Chow et al. 2020; Imathiu 2020);
– Insect rearing can be environmentally friendly, reducing environmental pollution (Chow et al. 2020);
– Insects can convert organic waste;
– Insects produce relatively low quantities of greenhouse gases and ammonia (Mancini et al. 2019; Orsi et al. 2019);
– Insect farming requires much less water and land than livestock farming (Garino et al. 2019);
– Insects pose a low risk of zoonotic transmission;
– Insects are more efficient in rearing.

Van Huis et al. (2013) stated that conversion of the house cricket (*Acheta domestica*) feed is twice as effective as chicken, four times higher than a pig, and more than twelve times higher than cattle. For the production of 1 kg of live weight of insect, feed consumption of 1.7 kg for domestic cricket (*Acheta domestica*) is needed (Collavo et al. 2005). For comparison, Ayieko (2007) stated the feed requirements to produce 1 kg of meat as follows: 7.7 kg for beef, 6.3 kg for lamb, 3.6 kg for pork, and 2.2 kg for chicken. Pimentel and Pimentel (2003) calculated an even lower conversion rate for conventional livestock. Schlup and Brunner (2018) mention that insect needs up to ten times less feed in comparison to cattle to produce the same amount of animal protein. One of the basic advantages of insect is the conversion of organic waste into protein. For example, black soldier fly (*Hermetia illucens*), mealworm (*Tenebrio molitor*), and house fly (*Musca domestica*) are very effective in organic waste biodegradation. Together, they can process 1.3 billion tons of bio-waste per year (Veldkamp et al. 2012). Insect farming also has an environmental impact (Figure 1).

In the study of Premalatha et al. (2011) on greenhouse gas and ammonia emissions, greenhouse gasses production of pig and bovine breeding were compared to the rearing of mealworm (*Tenebrio molitor*), migratory locust (*Locusta migratoria*), house cricket (*Acheta domesticus*), and orange-spotted cockroach (*Blaptica dubia*). The study has shown that insects produced comparable or even lower amounts of both greenhouse gases and CO_2 alone, per kilogram of meat obtained, when compared to pigs, and much less than cattle. Ammonia formation in all four insect species was lower than that of the farm animals. The fact that insect rearing requires much less water and soil than livestock breeding is also significant (Pimentel and Pimentel 2003; Oonincx and de Boer 2012). Entomophagy may also involve some risks that must be considered. Collecting the freely living insect could seriously interfere with the landscape ecosystem. It is therefore recommended to consume insect reared under controlled and defined conditions. By selecting an appropriate and safe

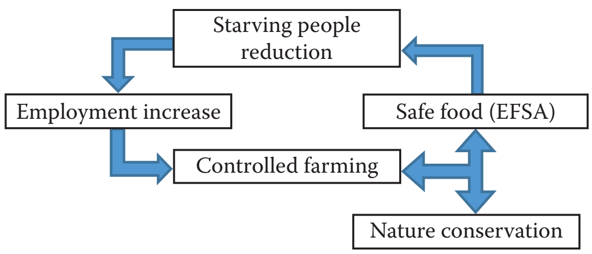

Figure 1. Impact of controlled farming on the environment (inspired by Halloran et al. 2018)

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feed, the consequent health of edible insect is ensured. Other possible hazards of eating edible insect include eating unsuitable developmental stages, inadequate handling, and inappropriate culinary treatment. Eating can also trigger an allergic response. The insect has an external skeleton made of chitin, which is difficult for humans to digest. Today, due to chitin-free food, there is a decrease in chitinase production in humans. Some people have such a small amount of the enzyme that an allergic reaction occurs after eating an insect (Mlček et al. 2014). The most threatened are people suffering from allergies to seafood, such as shrimps. If the correct starving, heat treatment, and appropriate storage conditions are not ensured, the edible insect can become dangerous, even from the microbiological point of view (Giaccone 2005; Klunder et al. 2012). EFSA (2015) recommends further research of edible insects while focusing on rearing safety and health risks for consumers. This review aimed to summarise the findings and spread information on edible insects as a possible alternative source of protein for food and feed.

INSECT REARING FOR FOOD AND FEED PURPOSES, AND ITS ECONOMIC AND ENVIRONMENTAL EFFICIENCY

At present, livestock production is the single largest anthropogenic use of land. It makes up 70% of all agricultural land use (including feed crop production) and 30% of the land surface area on Earth. It is also a large source of greenhouse gases and the main cause of biodiversity loss through land degradation, water pollution, and soil erosion (Steinfeld et al. 2006). Furthermore, in developed countries, resources, including vast areas of land, are used to generate animal protein for pet animals. Another advantage is the fact that the edible insects also contain micronutrients (minerals and vitamins) (Dreassi et al. 2017; Montowska et al. 2019; Yoo et al. 2019; Kwon et al. 2020; Wu et al. 2020). A further benefit of edible insects may be the number of lipids contained therein. For example, Berezina (2017) claimed that the amount of lipids in the insect is 30–50% on a dry matter basis. Megido et al. (2018) mentioned that mealworm contains ~33% of lipids. Having this knowledge, the potential of the insect as human food should not be ignored any longer, especially its ability to provide the needed protein for hungry people all around the world. The significance of entomophagy is highlighted even more by the fact that every sixth person on Earth dies from malnutrition and hunger (FAO et al. 2017). In case the insect is used as a major food resource, it will be necessary to have a considerable amount available. Freely living insect will probably not meet the demand; moreover, ecosystems may be damaged if we will be using wildlife sources (Mitsuhashi 2010). For food use, insect used should be reared on farms, which would produce a clean specimen with known nutritional values. This will help to contribute to sustainable ecosystems while avoiding overexploitation of freely living insect. Several farms already produce insect in large quantities, for example, projects to eradicate fruit flies and screwworms. Most of the larvae raising procedures are automatic, and insect continuous cell lines have been created. This could be a model for the vast scale edible insect production in the future (Mitsuhashi 2002). The rearing procedures are well developed, for example, for silkworms, mealworm, and others (Finke 2004; Katayama et al. 2005). Silkworm feeds on mulberry leaves, and mulberry has many cultivars available. Silkworm can be made polytrophic. Artificial feed tasting like mulberry has already been developed. Pupa in a cocoon or adult moth might be suitable as a food source (Katayama et al. 2005). However, it is not possible to cultivate some insect group cells using nowadays techniques, but in the future, we may find a solution to this (Mitsuhashi 2010).

Carbon Footprint. Greenhouse gasses (GHG) production is one of the possible causes of climate change. The most important greenhouse gases are nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4). Up to 18% of total anthropogenic GHG emissions and 64% of all anthropogenic NH_3 emissions are produced by the livestock sector (Steinfeld et al. 2006). By assigning a CO_2 value of 1 global warming potential (GWP), the warming potentials can be expressed on a CO_2-equivalent basis: CH_4 has a GWP of 25, and N_2O has a GWP of 298 (IPCC 2007). A vast amount of NH_3, produced by livestock, leads to soil acidification and nitrification. Increased practice of entomophagy could help with this problem (Premalatha et al. 2011). Furthermore, other factors that lead to greenhouse gas emissions are closely linked with the production of foods from animal products or animal husbandry (production of greenhouse gases in feed production, energy for the production and processing of animal products, transportation).

Oonincx and Dierenfeld (2012) evaluated the contribution to the GWP and energy utilisation (EU) and compared them with other animal products – milk, pork, chicken, and beef. The contribution to GWP was lower for mealworm than for other commodities – reduced by twelve times, compared to beef (Figure 2). The energy used to produce 1 kg of edible mealworm

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protein was comparable to or higher than other commodities (e.g. up to 79% for milk) (Figure 3). The reason is the heating of the insect farms at low ambient temperatures. Considering this, mitigation measures have been proposed, whereby larger larvae produce the excess of metabolic heat, thereby heating the smaller larvae that require it (Oonincx and Dierenfeld 2012).

Oonincx and Dierenfeld (2012) also compared the area utilisation of insect farming with other animal food commodities (Figure 4). The utilisation of area is again lower for edible insect than for other compared commodities (up to fourteen times).

Oonincx et al. (2010), who also dealt with greenhouse gasses production, states in his work that GHG emissions of 4 of the 5 insect species were much lower than of pigs when expressed per kg of mass gain and only about 1% from GHG emissions produced by ruminants. The measured NH_3 emission levels of all insect species in this experiment were lower than reported NH_3 emission levels for conventional livestock. Moreover, insect average daily gain (ADG) in this study was higher than in conventional livestock, while CO_2 production related to weight gain was comparable or lower, suggesting higher insect feed conversion efficiency. CH_4 was produced only by termites, cockroaches, and scarab beetles. The reason is hindgut *Methanobacteriaceae* fermentation (Oonincx et al. 2010).

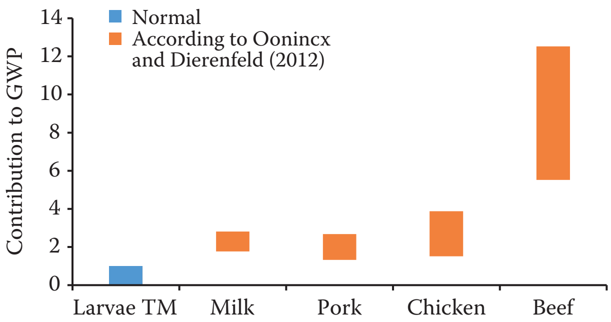

Figure 2. Contribution to global warming potential (GWP) by mealworm (*Tenebrio molitor*) production with comparison to other commodities

Data were normalised to 1 kg of digestible proteins from mealworm larvae [processed according to Oonincx and Dierenfeld (2012)]

Nutrient conversion. The body growth: CO_2 production ratio indicates the feed conversion efficiency, and thereby it is a relevant environmental impact indicator. The main three factors that cause the difference in life cycle assessment are: feed conversion efficiency, enteric CH_4 emissions, and reproduction rates (de Vries and de Boer 2010). Many studies show that insects and small animals, in general, are relatively efficient converters (Beets 1997). The insect is more effective than macrolivestock in assimilating matter – more than ten times as many plant resources are needed to produce one kilogram of meat than to produce one kilogram of insect zoomass. Thus, the production of insect-based foods puts much less pressure on ecosystem services than livestock-based foods (Premalatha et al. 2011). The explanation of this difference is quite simple. The insect is poikilothermic and therefore does not spend as much food energy and nutrients as the warm-blooded livestock (Lindroth 1993). Therefore, insect produces much more animal protein per kilogram of phytomass consumed than ordinary livestock. Insects have much higher fertility and a much faster growth rate: thousands of offspring are produced by a single insect individual, while only a few are produced by normal livestock. These

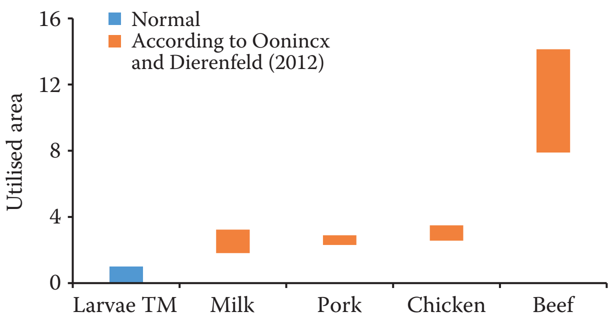

Figure 3. Energy utilisation to produce 1 kg of digestible proteins of mealworm larvae (*Tenebrio molitor*) compared to other commodities

Data were normalised to 1 kg of digestible proteins from mealworm larvae [processed according to Oonincx and Dierenfeld (2012)]

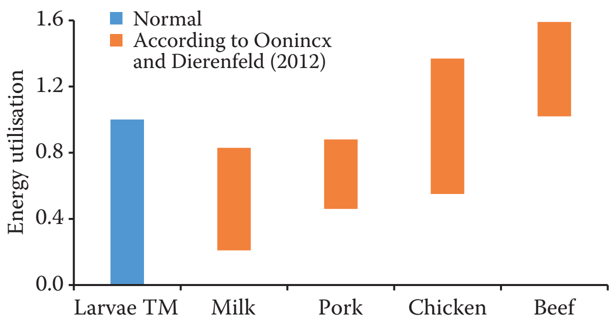

Figure 4. Energy utilisation to produce 1 kg of digestible proteins of mealworm larvae (*Tenebrio molitor*) compared to other commodities

Data were normalised to 1 kg of digestible proteins from mealworm larvae [processed according to Oonincx and Dierenfeld (2012)]

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offspring mature within a few days, while in poultry and ruminants, it takes months or even years. Combined with a very good nutritive value, these properties have impressed space scientists to include the use of insect as human food into space travel and habitation plans (Hu et al. 2010). That is not all, as by modelling the situation in space modules, where the need will be to ensure food sources within a much smaller space, proposals were also made to support and develop a sustainable civilisation on Earth (Katayama et al. 2005). There is an even better outcome for insect while comparing the possibilities of biomass production in an area.

Some collectively living insect species are very successful animals regarding biomass and diversity (Hunter 2010). Social insects – notably termites, wasps, bees, and ants have developed the ability to live in colonies with much higher population density than beetles, often since they are "clones" – individuals genetically identical. Although social insects make up only two per cent of insect species, they make up more than half of the total insect mass (Wilson 1990). The social insect needs to utilise resources more effectively to increase biomass, which is accomplished by creating communities that work together to collect food in wide areas (Hunter 2010).

THE RISKS, ALLERGIES, TOXICITY, AND MICROBIAL RISKS OF EDIBLE INSECT

Consumption and handling of insects are not without risk. Collecting insect in unsuitable areas, wrong culinary preparation, the consumption of inappropriate developmental stages, and handling without protective equipment may result in unfavourable reactions.

Risks. Bouvier (1945) observed in his research that consuming grasshoppers and locusts without removing the legs may lead to intestinal constipation, caused by the large spines on the tibia. Often the only solution is the surgical removal of these legs. The autopsy showed that the deaths of the monkeys during the locus raids had the same cause.

Toxicity. The African silkworm pupae *Anaphe* spp. has a high activity of relatively heat resistant thiaminase (Nishimune et al. 2000). In southwestern Nigeria, acute ataxic syndrome epidemics occur annually during the rainy season. Reported symptoms, which appeared after the consumption of a carbohydrate meal, were impaired consciousness, intention tremors, and ataxia (Adamolekun et al. 1997). Enzyme reaction can decrease cellular free thiamine concentration or influence carbohydrate metabolism or energy production. The enzyme could influence the metamorphosis of the insect. Its gene expression in the different steps of silkworm metamorphosis, which has many apoptosis-like steps, is interesting. A thiaminase I gene has already been sequenced using a cloned bacterial gene (Abe et al. 1987; Costello et al. 1996). The activity of thiaminase in Japanese silkworms (*Bombyx mori*) is more than two-thirds lower that of *Anaphe* spp. This suggests the need for proper heat treatment for detoxification of the African silkworm if it should be a safe source of high-quality protein (Nishimune et al. 2000). Pesticide applications against locusts and grasshoppers must also be taken into consideration, as it can cause problems due to toxic residues (van Huis 2003; Yen 2009).

Allergy. Overly zealous T-helper type 2 response to environmental antigens is the cause of the allergy, which can have fatal consequences. Our bodies constantly encounter potential allergens, either through breathing or eating. Sensitivity to insect proteins may manifest itself, for example, by asthma, rhinitis, conjunctivitis, dermatitis, contact urticaria, or rhinoconjunctivitis (Bernstein et al. 1983; Schroeckenstein et al. 1990; Freye et al. 1996). In extreme cases, a strong allergic reaction may occur – anaphylactic shock. It is a serious allergic reaction that occurs quickly and can cause death (Belluco et al. 2013). Allergies usually occur in the work environment where the employee encounters insects.

Allergic reactions to insect are mostly reported concerning chitin, which is the second most abundant biopolymer in nature. Its role in nature is mostly the protection of parasites, fungi, and crustaceans from the dangers in their environments (Elias et al. 2005). Chitin is not considered a common allergen; however, it can cause sensitisation due to frequent exposure (Burton and Zaccone 2007). It is also a recognition element for tissue infiltration by innate cells implicated in allergic and helminth immunity, and this process can be negatively regulated by a vertebrate chitinase (Reese et al. 2007). The amount of chitin in edible insects is in the range of 2–5% of dry matter (Berezina 2017). Allergic reactions have been documented mainly for mealworm and Orthoptera, either for contact or respiratory form (Linares et al. 2008; Garino et al. 2019). Combined allergies to more than one species of insect are not uncommon (Bleßmann-Gurk et al. 2007). Studies show that inhaled particulates from mealworm exoskeletons are potent sensitisers and elicit IgE-mediated occupational asthma, which confirms the fact that Tenebrionid family beetles are potentially significant allergens for employees working with grains or grain products (Bernstein et al. 1983; Schroeckenstein et al. 1990).

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For the mealworm, Marono et al. (2015) report an average of 5% of chitin, unlike Finke (2015), who states 1.2%. The content of chitin in field cricket (*Gryllus Testaceus Walker*) determined by Wang et al. (2004) was 8.7% of chitin on a dry matter. Finke (2007) detected 81.5 g kg^{-1} on a dry matter of chitin in the nymph of the house cricket (*Acheta domesticus*). Goodman (1989) reports an average of 10% chitin in insects. However, chitin does not appear in the pure form but is bound to many amino acids, most likely cuticular protein. Yet, the chitin content is usually evaluated as the total content of these chitinous substances (Barker et al. 1998; Finke 2002).

Chitin exposure originating from shellfish, moulds, dust mites, or insects might be the primary external trigger in allergy development. Discontinuous low-level exposure can cause allergies in people with a genetic predisposition. It is crucial to understand the allergenic role of chitin, partially because of its abundance in the environment but also because it is commonly used in healthcare and cosmetics. Various studies suggest chitin can quicken wound healing; its molecules are already used in medicines today (Muzzarelli 1997). Chitin can activate macrophages, which is beneficial for stimulating tissue repair; yet chitin might also recruit polymorphonuclear leukocytes, which starts the allergic reactions (Kodelja et al. 1997). Toxicological tests are mostly performed on animals whose chitinase activity could be higher. Therefore, further research is required to reveal the genetic basis of differences in chitinase functions and allergy in humans.

Moreover, chitinase has an important role in the innate immunity to various infectious agents, including parasites. Therefore, we can hypothesise that, when produced in a dysregulated fashion, they also have a relevant role in the pathogenesis of allergy and/or asthma (Elias et al. 2005).

It has also been found that a prototypic chitinase, acidic mammalian chitinase, was induced during TH2 inflammation by an IL-13-dependent mechanism. It has also been shown to have a crucial role in the pathogenesis of TH2 inflammation and activation of the IL-13 effector pathway and is overexpressed in human asthmatic tissues. The finding that chitinases contribute to the host's antiparasitic responses and asthmatic TH2 inflammation supports the notion that asthma could be a parasite with an independent antiparasitic response (Elias et al. 2005; Burton and Zaccone 2007; Sutherland et al. 2009). Chitin is a recognition element for tissue infiltration by congenital cells involved in nematode allergy and immunity, and this process may be negatively regulated by vertebrate chitinases. Mammalian chitinase (AMCase) and chitotriosidase (ChT) have chitinolytic activity, but the knowledge about their role in nasal polyps is scarce. Nasal polyps appear to eliminate chitinase levels, and the presence or growth of pathogens with the content of chitin may increase chitinase expression, which leads to the formation and growth of nasal polyp in susceptible individuals (Park et al. 2009).

Another potential allergen is tropomyosin protein, which is found in muscle and non-muscle cells of all vertebrate and invertebrate species. It may have more isoforms (Belluco et al. 2013). Cross-reaction studies in crustaceans show that tropomyosin is one of their major allergens, responsible for the immunological relationship between crustaceans, house dust mites and cockroaches. Shrimps can cross-react with arthropods such as mites and insect species, including cockroaches, grasshoppers, and fruit flies (Leung et al. 1996; Reese et al. 1999). Verhoeckx et al. (2014) and van Broekhoven et al. (2016) also report similar findings in their study. The results of van Broekhoven et al. (2016) further show that heat treatment can weaken allergies, but the risk is not always ruled out.

Microbial risk. Insects, especially their intestines, can be a suitable environment for the growth of microbial fauna (Rumpold and Schlüter 2013), which may be harmful to humans. Therefore, the risk of transmission of infectious diseases must also be considered. However, from the point of view of human nutrition, the composition of the microflora of live edible insect species may not be hazardous to the final food if the insect is properly reared and processed using preservation and storage techniques such as cooking or refrigeration (Belluco et al. 2013). Edible insects can become microbiologically dangerous if proper rearing, shedding, heat treatment, and suitable storage conditions are not ensured (Giaccone 2005; Klunder et al. 2012).

Klunder et al. (2012) documents the microbiological content of fresh, processed, and stored edible insects. The study focused on the larvae of mealworm (*Tenebrio molitor*) and crickets (*Acheta domesticus* and *Brachytrupes* sp.). The results showed that in fresh insects, various species of bacteria of the family Enterobacteriaceae can be detected and subsequently isolated, as well as sporulating bacteria, which are most likely to enter the insect upon contact with the soil.

Cooking insects for 5 min is an effective procedure for removing *Enterobacteriaceae* (Klunder et al. 2012). Grabowski (2017) documents that cooking for 10 min and drying for 24 h at 80 °C reduced the total number of microorganisms [total microbial count (TMC)] below a dangerous level for 5 days of storage. If the drying

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temperature was 60 °C, the TMC was not reduced below the maximum allowable limit, and the food remained unfit for human consumption. The last heat treatment tested was cooking for 30 min followed by drying at 80 °C for 12 h and drying at 100 °C for 12 h. Interestingly, this heat treatment reduced the TMC below the maximum allowable limit only on the first day of storage, and in the following days, the TMC rose above the allowed safe limit. On the other hand, *Staphylococcus* was not detected in these samples, in contrast to other thermal treatments. Microbial analyses performed by Adámek et al. (2018) show that, from a microbiological safety point of view, killing, drying, and subsequent storage are more appropriate than killing and freezing samples.

INSECT IN WASTE MANAGEMENT

Modern agriculture involves the keeping of many dairies, pigs, chickens, and other animals. This causes the accumulation of a significant amount of manure, and that is hazardous to the environment (Li et al. 2011b). On the other hand, manure and bio-waste can also be used as a principal resource for larvae of many insect species such as the black soldier fly, *Hermetia illucens* (Booram et al. 1977; Bondari and Sheppard 1981; St-Hilaire et al. 2007; Myers et al. 2008; Li et al. 2011b; Rabani et al. 2019). Such information can provide an incentive for establishing an adequate method for the mass production of protein-rich dipterous larvae (Larde 1990). Black soldier fly larvae (BSFL) possess another advantage – besides manure liquidation, they can reduce *Escherichia coli* counts (Liu et al. 2008). Very promising in many aspects appears to be the finding that BSFL not only can help us with the disposing of the manure but at the same time being a source of quality protein and fats; they are also useful for the production of biodiesel instead of crop oil, which is a limited and expensive food resource. 1000 BSFL growing on 1 kg of cattle manure can be used to produce 35.5 g of biodiesel. For pig manure, it is 57.8 g, and for chicken manure, 91.4 g (Li et al. 2011a). Petroleum ether could be used to extract grease from BSFL; then, the two-step method is applied to produce biodiesel. The "waste" from this process, the dry matter residues of BSFL can be utilised as a protein feed (Li et al. 2011a). The integration of large-scale insect rearing into small-scale farming ventures may pose an interesting challenge. An example can be to include insect into organic waste recycling systems (De Foliart 1995; Ramos-Elorduy 2008). Insects are a basic substance that feeds on organic matter in nature. They make efficient use of all organic resources and feed on all levels of plants and animals. Due to these properties and the need to recycle vast amounts of waste generated by up-to-date lifestyles, the insects could be used as bio-transformers for converting organic waste into protein-rich animal biomass suitable for use in animal nutrition (Ramos-Elorduy 1996). The nutritional value of the insects increased. There were differences based on the medium used, but it was generally slightly better than the control. The recycling time of the waste depended on the species of insect and the substrate used. For substrates that provide a balanced diet, 92% to 95% of the medium was consumed and transformed into insect tissues (Ramos-Elorduy and Pino 1990). The degree of protein transformation ranged from 5% to 8% for poor quality proteins in substrates to 43% to 61% for higher quality proteins (Ramos-Elorduy et al. 1988). All these facts show the possibilities of recycling organic matter as a culture medium for insects to obtain nutritious insect biomass. Experiments with insects in animal nutrition show that they can replace soy or fishmeal when fed poultry or fish with the same or better results (De Foliart et al. 1982; Ramos-Elorduy et al. 1988; Ramos-Elorduy 1996). Black soldier fly (*Hermetia illucens*) could be successfully used to reduce animal waste in breeding facilities and produce animal feed high in protein and fat, which is thanks to a high rate of conversion of biomass to protein and fats (Rabani et al. 2019). If their diet contains fish offal, the flies contain eicosapentaenoic acid (EPA), α-linolenic acid (ALA), and docosahexaenoic acid (DHA). St-Hilaire et al. (2007) examined the difference in feeding with fish offal and cow manure, where the results showed that if the larvae were fed by fish offal, the lipid amount was on average 30%, which was 43% more than if the larvae were fed by cow manure. Besides, the omega-3 fatty acid content reached this level within 24 h after feeding the offal. Omega-3 fatty acid elevated pre-pupae may be as well usable as fish meal and fish oil substitution for carnivorous fish and other animal feeds. This could also be an efficient way to reduce and recycle fish offal from processing factories (St-Hilaire et al. 2007).

CONCLUSION

The review summarises existing information on the impact of edible insect on the environment, including waste management, and compares the benefits and risks of this food commodity with other commodities of animal origin. The study demonstrates a lower environmental burden by insect farming, evaluating the need for the production of 1 kg of protein compared to other live-

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stock. In particular, it proves lower greenhouse gas emissions and higher feed conversion. It also draws attention to the risks and safety of rearing and eating edible insect that is comparable to other livestock. The key is controlled insect farming, which ensures significant protection of the environment without disturbing its diversity.

The review provides a comprehensive view of this issue. In general, the main advantages of insect rearing are fast feed conversion, high insect reproduction capacity, low demands on the rearing area, and the ability to rear insects on multiple floors. On the contrary, a negative energy load in colder rearing areas is possible. In the food industry and human nutrition, the basic disadvantages of consuming edible insects are the possibility of severe allergic reactions (chitin), possible toxicity, as well as complicated legislation in the rearing of insects for food purposes and the associated current high price. On the contrary, the advantages are nutritional values such as high protein content, good digestibility, and appropriate representation of essential amino acids and polyunsaturated fatty acids, and a valuable source of minerals.

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