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Review article

# Benefits and food safety concerns associated with consumption of edible insects

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ABSTRACT

Many types of edible insects in raw and processed forms have been consumed by many cultures globally since time immemorial, particularly in developing countries where they are mostly traditionally viewed as a delicacy besides provision of nutrition. As a food type, they are consumed in two main forms; whole insects or incorporated in various food products as an ingredient, the choice of which is consumer preference driven. Recently, there has been a lot of research interest in edible insects farming, processing and consumption mainly in an effort to eradicate food insecurities prevalent in many developing countries and boost nutrition. Inclusion of edible insects in human diets has been shown to improve the nutritional quality of foods due to their high micro- and macronutrient levels comparable and sometimes higher than those of animal-derived foods. It is in this regard that they can actually be used in directly addressing the first three UN's Sustainable Development Goals (no poverty, zero hunger, and good health and well-being). Edible insects production also helps in mitigating the negative effects of climate change and improve biodiversity both of which positively contributes to food security. Even with all these benefits, several challenges are encountered in the promotion of edible insects farming and consumption in developing and developed countries. Top in the list of these obstacles is the issue of food safety where, especially western consumers willing to consume edible insects and/or edible insects-derived foods are wary of the microbiological and chemical health risk they could pose. Based on the current literature, there is clearly a need to balance the food safety concerns and the nutritional benefits of edible insects. There is a necessity to promote food safety and hygiene practices in the entire edible insect value chain including during wild harvesting in order to ensure that this highly nutritious food that requires little resources to produce is availed to the consumers in a state that does not pose any health risks. Lack of regulations on edible insects value chain which lacks in many countries, especially developing countries is also another problem that requires urgent attention as addressing this issue is likely to boost consumer confidence and ease trade of this commodity between countries.

## 1. Introduction

The practice of insect consumption as a type food, often referred to as entomophagy has gained a lot of interest in both developed and developing countries in recent times. Entomophagy is not a new habit as it has been practiced for years by many cultures worldwide as a means of providing unique, delicious and nutritious food to the consuming populations [1]. The use of insects as food is most widespread in developing countries, mainly in tropical and subtropical climatic environments where they are often consumed by the rural poor, especially in Africa and Asia [2]. The perception of insect consumption as 'poor man's food' in some developing countries which led to their depressed consumption [3] is slowly changing with time. The current increasing acceptance of insect consumption in one form or another, not only in developing but also in developed countries [4] is mainly influenced by consumer awareness of the nutritional benefits linked to these kinds of foods [5]. However, even with the increasing recognition and importance of edible insects in human nutrition, there are food safety concerns raised (including but not limited to microbiological and chemical hazards) especially in developed countries that deter some prospective consumers from incorporating or even thinking of including them in their diets [6].

Food insecurity in the face of climate change is a reality that calls for mitigating strategies to be urgently developed and implemented to ensure adequate quality and safe food availability at all times. The world population is rapidly increasing and it is estimated that by year

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2050, the world population will have hit the nine billion mark [7] with demand for food increasing by 60% [8]. Feeding this huge population is going to be a huge challenge due to increasingly limited resources such as agriculturally cultivable land. This, without a doubt calls for alternative innovative ways of ensuring that adequate, quality, safe and nutritious foods are available and accessible to all at all times. Setting aside more land for food crop growing and animal rearing cannot be considered as a mitigation strategy since land clearing for agriculture may contribute to climate change and loss of biodiversity [9], worsening the food availability situation worldwide.

Besides their nutritional benefits, edible insects are also promoted by various organizations and governments as one way of taming climate change, conferring an environmental benefit of reduced greenhouse gas emissions [10] as they have been associated with feeding on waste organic matter [11]. As an alternative source of protein compared to domestic animals-based foods, edible insects have additional benefits that include use of less rearing land, a high rate of reproduction and high feed conversion efficiency [12]. Ramos-Elorduy [13] reported a higher efficiency of conversion of ingested food in edible insects (e.g. 53-73% in *Tenebrio molitor* L.) compared to livestock (10-12%) and chicken (38-43%). Authors such as Van Huis and Oonincx [14] have also confirmed that edible insects have better feed conversion efficiency. The authors reported that yellow mealworms can convert up to 45% dietary protein to edible body mass while black soldier fly larvae can convert up to 55% of dietary protein to edible body mass. Van Huis and Oonincx [14] reported that this feed conversion efficiency was significantly higher than that observed with chicken (converted 33% of dietary protein to edible body mass). This suggests that with limited input resources, insects rearing would be a better venture of contributing to food and nutritional security. Even more interestingly, Heckmann et al. [15] and Van Huis et al. [7] have reported that unlike in cattle and, pork and chicken where only 40 and 55% of mass is ingested and digested by humans, as high as 80% of mass of many edible insects is utilized suggesting a significant reduction in food loss.

To the rural poor in the developing countries, consumption and trading in edible insects, especially street-vending, contributes to economic empowerment (especially of women) and improved livelihood [16] directly contributing to the attainment of the UN's first two Sustainable Development Goals (SDGs) – no poverty and zero hunger respectively. In order to meet the present chronic food and nutrition security challenges, including hidden hunger, we need to explore various ways to ensure that we are food secure today and in future.

One of the recent approaches is promoting utilization of edible insects in our diverse diets [17]. Besides gathering the edible insects from their natural habitat, there is increasing adoption of recent innovative technologies involving mass rearing [7] in some developed countries (e.g. Holland, Denmark and Belgium) and developing countries such as Kenya, Thailand and Vietnam. At least 150 edible insect species are consumed in Thailand where they form an important part of the diet [18]. With an estimated number of people standing at, at least two billion traditionally depending on insect-based diets [7], and the number of potential consumers likely to go up thanks to continuing acceptance of this food type, insect rearing and utilization in food-based diets looks positive now and in foreseeable future. In fact the UN recommends entomophagy as a possible solution to the limited world food supply [7].

## 2. Benefits of edible insects wild harvesting and/or domestication

### 2.1. Edible insects as a source of nutrients in human diet

The world is currently facing a challenge of fulfilling the first three UN's SDGs of 'no poverty', 'zero hunger' and 'good health and well-being' which are interrelated, by year 2030 which is only 11 years away from now. Of greatest concern is under-nutrition (micronutrient deficiency), over-nutrition (obesity) and protein-energy malnutrition which have a direct effect on the health of people. According to Kohler et al. [19] three options exists to ensure zero hunger and malnutrition; supplementation (short-term mitigation strategy), food fortification (medium-term mitigation strategy) and dietary diversification (long-term mitigation strategy). Out of these three, the most economically feasible, environmentally friendly and most sustainable option is dietary diversification [19] which can take numerous approaches including inclusion of varied food types, some of which are underutilized or under exploited in the diet. One such food type is edible insects which are loaded with nutrients but are poorly exploited and underutilized in human diets and nutrition globally.

Several insect species have from time immemorial been used by different cultures in many countries worldwide as a source of food, especially during times of other food type shortages, and when these insects are readily available in nature for harvesting/collecting. It is estimated that close to 2000 species of insects are edible in a variety of forms. According to Van Huis et al. [7], the most commonly consumed insect types include beetles (31%); caterpillars (18%); ants, wasps and bees (14%); locusts, crickets and grasshoppers (13%); scale insects, leafhoppers, true bugs, cicadas and planthoppers (10%); dragonflies (3%); termites (3%) and flies (2%). In Europe, the most farmed insect types are mealworm larvae (*Tenebrio molitor*) and crickets (*Acheta domesticus*) as they are considered the most promising in food and feed industries [20]. Their contribution to food and nutritional security has been recognized thanks to a wide range of nutrients they contain that confer numerous health benefits to consumers according to Murefu et al. [21]. It is probably for this reason that most of the scientific literature on edible insects concentrates more on the nutritional aspect than any other facet of this increasingly interesting subject among the entomophagists in an effort directed at advocating the addition of insects to food menus.

Edible insects can be eaten raw or in processed form (roasted, toasted, fried, boiled, extruded, e.t.c.) [22,23]. Their nutritional composition normally depends on insect type, stage of development, diet reared on, processing method used and edible insect species sex [24,25], among other factors. Typically, edible insects are regarded as highly nutritious foods that are an excellent source of energy, fats, proteins and minerals [13].

A lot of attention and effort are placed on edible insects on their potential to addressing food and nutrition security as they are a good source of protein which can be obtained in relatively short period of time due to their short life-cycles compared to conventional livestock-based sources. Generally, the main nutrient in edible insects is protein which depending on insect type, range from 35 to 61% for Isoptera e.g. termite and Orthoptera e.g. grasshopper and cricket respectively [24]. A more recent study carried out in Thailand investigating protein, amino acid and mineral composition of Bombay locust, scarab beetle, house cricket, and mulberry silkworm found that these insects contained a high protein content of 27-54g per 100g of edible portion [19]. Insects generally provide more than 50% of dietary protein in some Central African countries where their market value is considered higher than most of animal-derived protein sources [26]. Those edible insects currently being contemplated for consumption in the developed world such as crickets and mealworms have a fresh weight protein content in the range of 19–22 g/100g [27] which has been shown to be comparable to traditional animal protein sources [28]. With an average fresh weight protein content of 60 g/100g [6], edible insects are reported to provide more protein to human diet compared to excellent plant-based sources such as soybean protein. In fact research carried out by Finke et al. [29] assessing protein quality of different insect meals fed to rats suggested that they were of equal or better quality compared to soy protein. Based on these findings, it is potentially likely that insects-derived proteins are of a higher biological value than those obtained from plant sources and are thus more nutritionally useful in the human diet. As 67-98% of edible insects' proteins is highly digestible, many of them can be categorized as high value protein sources as their essential amino acid score varies from 46 to 96% [13]. With the recent reports of animal-based protein sources such as processed meats being linked to the rise of non-communicable illnesses such as cancer [30], more interest in rearing and consumption of edible insects is likely to be seen as both as an alternative source of protein and as a way of reducing and/or preventing the prevalence of these diseases.

Fat, which is the second highest component of edible insects has a wide range of variation dependent on insect type. On average, across all edible insects types, the fat content ranges from 13 to 33% for Orthoptera (e.g. crickets and grasshoppers) and Coleoptera (e.g. beetles and grubs (insect larvae)) respectively [24]. Worth noting though is that the larvae stages of insects such as caterpillars generally contain the highest fat content compared to adult stages [31]. The fatty acid profile of edible insects, which is more polyunsaturated, is reported to be proportionate to that of fish and poultry [32] which suggest that insects can provide healthier fats to human diets compared to the well known traditional sources that include fatty fish. In this regard, edible insects can be deemed to be better sources of energy when compared to, for example, beef and pork which contain more of monosaturated fatty acids than polyunsaturated fatty acids when it comes to the prevention of coronary heart diseases. It has also been reported that, generally, depending on species, insects accumulates significantly lower cholesterol levels compared to foods of animal origin [33] and could also, according to Sabolová et al [34] contain plant sterols thus making them a better healthier choice food source.

Insects are a good source of many minerals. According to Rumpold and Schluter [24], most edible insects have high levels of phosphorous that meet adults' dietary requirements. The authors and Kohler et al. [19] also reported that several insect types provide significant amount of magnesium, especially crickets, locusts and grasshoppers. Insects are also generally regarded as good sources of manganese, copper, selenium, zinc, iron and calcium. In fact edible insects have been shown to contain more calcium, zinc and iron than chicken, pork and beef [35] which means that entomophagy can be considered as an alternative source of minerals to beat 'hidden hunger' prevalent in most developing countries [36] where prevalence of persons at risk of zinc deficiency, for instance, stands at 17% [36] while those at risk of iron deficiency stands at 25% [37]. The low levels of sodium in edible insects means that this food type can be readily and conveniently incorporated in low sodium diets for high sodium sensitive individuals [24]. Insects are generally rich in a wide range of vitamins including riboflavin, biotin and pantothenic acid. Grasshoppers, locusts, beetles and crickets are particularly rich in folic acid. Although other type of vitamins occurs in relatively low amounts, it is hypothesized that vitamins concentration in edible insects can be influenced by and/or controlled through feed manipulation [38].

### 2.2. Edible insects as a means of improving human gut microbiota

Due to their high chitin content which accounts for at least 10% of the whole dried insects, insects can be a good source of fiber in human diet [6]. Chitin is a type of carbohydrate polymer that forms the exoskeleton of most arthropods including insects. Recently, chitin has been linked to improved human gut microbiology where it has been reported to improve gastrointestinal health due to its prebiotic potential [39]. By promoting proliferation of naturally occurring microbiota in the gut, chitin as a prebiotic, indirectly helps prevent incidences of microbial foodborne illnesses and food digestion difficulties [39]. Growth in the human gut of pathogenic microorganisms such as *Salmonella typhimurium*, enteropathogenic *Escherichia coli* and *Vibrio cholera* among others have been shown to be reduced by chitin and its derivatives [40] while at the same time encouraging multiplication and thriving of useful intestinal bacterial species such as *Bifidobacteria* and *Lactobacillus* [41]. In two recent separate studies, chitin is believed to promote growth of gut microbiota; Stull et al. [42] reported that presence of cricket chitin increased the multiplication of *Bifidobacterium animalis* by 5.7 times while Selenius et al. [39] showed enhancement in the growth of *Lactobacillus rhamnosus* GG and inhibition of *Escherichia coli* TG by chitin.

### 2.3. Edible insects as a source of livelihood

For some communities in different parts of the world, wild insects gathering, preparation and/or processing, and sale, mainly as street-vended foods [43] forms part of their livelihood [44]. Use and trading in edible insects has always been a principal form of livelihood diversification means among many rural communities that practice entomophagy in developing countries, possibly because it is a resource that occur naturally and very little or no technical knowhow is required in terms of gathering and preparing them for consumption or sale. In regions where entomophagy is practiced, whenever there is food scarcity, edible insects are the main fallback livelihood [45] buffering against unpredictable seasonal shortages of food [46]. The practice of gathering insects from the wild is commonly practiced by women and children especially under rural set-ups that besides improving diets, also act as a means through which the practitioners earn a living in form of a cash income for other basic needs such as purchase of other types of food, education and farm inputs among others [47]. In some regions such as Thailand, edible insects have been reported to fetch better prices than conventional animal protein sources such as poultry, beef, pork and fish [48].

It is likely that the low entry requirements to engage in insect harvesting, processing and trade have fueled the active roles played by women and children in the edible insect sector in developing countries [27]. Insects harvesting, and recently farming can provide jobs and entrepreneurial opportunities both in developed and developing countries helping in improving the living standards particularly of the latter. About 92% of insects consumed are wild-harvested with very few insect types being farmed, even in Asian nations where insects eating as a culture is generally accepted [49,50]. Increasing demand of insects as food has recently seen a shift from wild-harvesting to mass domestication of e.g. crickets that provide valuable income to farmers [51,52]. Nevertheless, since edible insects mass farming technology is reasonably new, there is limited knowledge on factors that would influence the yield and quality of the harvest. Acquiring insights of such determinants would be valuable as it would contribute in the development of insect-derived food products [53]. It is envisaged that in not too distant future, the edible insect value chain will significantly develop and improve thanks to scientific understanding of their domestication and innovative business ideas geared towards insect food and feed products diversification. In Thailand for example, insect farming, specifically cricket rearing is a documented livelihood strategy that has been shown to significantly improve the living standards of the rural farmers in the country as an alternative source of income as well as enhancing social and human capital [54]. Promoting incorporation of insects in human diets may mean encouraging people to start farming them in order to improve the supply [27] and to reduce the threat of extinction due to overexploitation that may occur through continuous natural harvesting from the wild. This, together with the ever growing acceptance of insects as food can only mean that their demand will continue increasing.

### 2.4. Environmental benefits of rearing edible insects

The already limited resources such as land and water are facing pressure from feeding the ever increasing global population which requires an increase in food production to sustain it. Increasing population comes with more demand for food which may create environmental problems particularly because of less land available for growing crops and rearing animals for food. According to Van Huis et al. [7], if there are no changes in agricultural production, there is a likelihood of increased glasshouse gas emissions and environmental degradations which can lead to detrimental consequences in terms of food security, especially food availability. The current high demand for animal proteins requires that livestock is reared in large numbers over diminishing land resource which is not possible and therefore, alternative substitutes for animal proteins needs to be embraced to overcome this problem [55].

Rearing edible insects compared to rearing livestock has been shown to have an insignificant environmental footprint [56] making it a better choice for caring of the environment while providing the nutritional benefits. Although the conventional sources of proteins (e.g. livestock and fish) are economically feasible due to their high productivity, they are not without their downside as they contribute to enormous environmental costs [57] including: contamination of both surface and ground water with manure that may be carrying pathogenic microorganisms and chemical contaminants such as heavy metals [58], emission of greenhouse and ammonia gases and possible deforestation as a result of increased feed requirements [27].

A more sustainable approach to feeding the increasing population that is not detrimental to the environment and biodiversity needs to be adopted [59] to ensure food security. One approach to achieving this includes rearing and utilization of edible insects in human diet. According to Van Huis et al. [7], rearing of edible insects confers several benefits to the environment which include; utilization of organic waste streams reducing environmental pollution while waste value-adding, emission of low greenhouse gases (livestock keeping is accountable for 18% of greenhouse gas emissions) [27,60], less water requirement (e.g. mealworms are reported to be hardier than livestock in terms of water requirements), high feed conversion efficiency (e.g. crickets are more efficient in converting feed to 'meat' as poultry (twice as efficient), pigs (four times as efficient) and cattle (twelve times as efficient)). Rearing and consumption of insects has also been shown to significantly reduce the use of pesticide [61] thus reducing the negative environmental impact and the likely presence of pesticide residues in foods. Direct consumption of insects which are agricultural pests can also help reduce usage of pesticides in agriculture significantly reducing the potential of pesticide residues in plant-derived foods and environmental pollution with chemicals. According to Dobermann [52], entomophagy has been shown to be an effective strategy of controlling crop insect pests e.g. the successful control of locust in 1978 as a result of government promotion of insect consumption in Thailand.

## 3. Edible insects consumption challenges and food safety concerns

### *3.1. Edible insects consumer acceptability*

Despite numerous benefits of edible insects consumption, consumer acceptance still remains one of the obstacles to their utilization as a protein food source especially in the developed countries where insects are viewed in disgust by majority of the population [62,63]. This is not much of a surprise because a recent study carried out in Germany trying to comprehend consumer attitudes towards consumption of edible insects reported neophobia and disgust as the main deterrent factors contributing to low uptake of this food type among the prospective consumers [64]. In fact Europeans generally associate consumption of edible insects with poor countries [7,63] although in some countries such as Austria, Belgium, Holland and France, farming and consumption of edible insects is somehow tolerated [27]. Studies carried out in some European countries revealed that only a limited number of people are likely to eat insects as alternative for meat (6.3% females and 12.8% males), and only 19% were ready to swap meat for insects as a protein source [63,65]. Although modest neophobia was observed among participant in a Belgian edible insects consumer acceptance survey [66], the study revealed that people were willing to consume insects in the future. A more recent and similar study in the same country seems to confirm the slight but insignificant growing acceptance of entomophagy among Belgian consumers [67] where potential consumers seemed to prefer foods processed with edible insects as an ingredient other than eating whole insects. Orsi et al. [64] also noted that utilization of edible insects as food ingredients other than sale of whole edible insects would offer a better opportunity to promote entomophagy in German markets. It is generally agreeable, based on these recent studies that entomophagy practice has a potential of being successfully promoted in the developed countries. It would also be interesting to understand the feelings about this practice among prospective consumers in the developing countries where many communities within this population consume edible insects, and where such consumer studies are limited. In most European countries however, use of insects as an ingredient in the manufacture of animal feed is generally accepted [68].

To some extent, the influence of western culture in developing countries has somewhat depressed or stagnated the consumption of edible insects especially among the middle and upper class earners, as well as the urbanites where consumers have been viewed as poor and practicing primitive activities [63,69]. Recently, food preference in developing countries has been observed to shift more towards westernized diets and with many people moving and living in urban centres, diminished consumption of conventional foods including edible insects has been observed [70]. Lack of embracing entomophagy by the west and negative portrayal of the practice by some media in both developing and developed countries has contributed to sluggish uptake of insect consumption which may lead to nutritional problems, particularly in societies that depended on them for food and nutritional security [63].

Limited literature is available in regard to factors influencing consumer acceptance and willingness to consume edible insects. According to Verbeke [63] and Gere [71], some of the factors influencing consumer consumption of edible insects include convenience, interest in the environment and food neophobia. Dobermann et al. [52] observed that people are less likely to consume insects the more they are disinterested in taking care of the environment and the more neophobic they are. This observation is supported by findings of Sogari et al. [72] who reported a negative correlation between neophobia and consumer willingness to practice entomophagy in an Italian study. Interestingly, the authors also reported that women were less likely to consume edibles insects than their male counterparts, a finding that is worth further investigation to find out whether gender really plays a role in entomophagy.

In order to encourage insects eating and farming, strategies needs to be devised geared towards value addition into products that are more attractive and that people can easily relate with. Change in form and/or product development where edible insects form part of a food product ingredient may offer an avenue through which perceptions are changed, and insects are consumed 'indirectly'. Megido [66] observed that people are more willing to consume edible insects when presented in other food forms e.g. cookies, energy bars, burgers and sandwich spreads among others. This should be encouraged especially among the food manufacturers alongside educating the consumers on the nutritional benefits of consuming edible insects. Change in negative perception (thus increasing consumer willingness to eat insects) about entomophagy as a result of enlightening consumers about the benefits of consuming insects has been observed in Italy and Denmark and the same approach ought to be replicated to other countries or communities to achieve the same goal.

### *3.2. Potential hazards associated with edible insects*

As the consumption of edible insects gains momentum worldwide, food safety issues in their regard continue becoming a concern particularly in the developed world after recognition of insects as food that has seen a slight increase in their consumption [73]. Due to lack of and/or limited knowledge of edible insects food safety in many countries, this will continue being a barrier for promoting edible insects farming and consumption in some niches. According to Van der Fels-Klerx [74], food safety concerns in regard to edible insects needs to be addressed particularly in western countries in order to encourage and promote their use in human diets. Knowledge of risks in regard to rearing and use of insects in food production including utilization as food ingredients is not well known [75]. Besides the nutritional benefits associated with edible insects, they may carry exogenous and endogenous risk factors to human health as is in the case of animal and plant-based foods. Potential food safety hazards that may be associated with edible insects may be grouped into three categories; chemical, biological and allergens [21]. According to European Food Safety Authority (EFSA) [76], prevalence and concentration of contaminants in insects and insect-derived foods is majorly influenced by insects production method, insect species, insect stage of harvest and substrate used (including sources) in the rearing process. The principle route of exposure of food safety hazards in edible insects to humans, according to Van der Fels-Klerx [74], is the feed substrate on which they are reared. This in essence means that to improve the food safety aspect of edible insects, these factors, and especially correct choice of quality hazard free feed substrate needs to be assessed and controlled which is only possible under controlled production other than wild harvesting. Poma et al. [77] opines that ensuring edible insects food safety can promote consumer acceptance of them as substitute food source helping change the perception of western consumers.

#### *3.2.1. Allergens*

An adverse immune response to food, which is caused by substances called allergens (type of antigens), is referred to as a food allergy [78] which can result to a serious illness and sometimes death. Food allergy is an emerging public health problem whose management along the food value chain continues to pose great challenge to the industry and professional health care practitioners worldwide. A wide range of foods can cause allergic reactions to sensitive people and, potentially, any protein containing food can evoke an allergic reaction in responsive persons [79]. Since the greatest component in edible insects is proteins, it is possible that some insects and insect-derived foods are potential allergen sources; in fact according to Murefu et al. [21], some types of proteins present in edible insects including arginine kinase are considered allergens. The fact that insects are also related to crustaceans, the potential for them to cause food related allergies is suggested [20]. Apart from aginine kinase, other common allergens linked to edible insects include α-amylase and tropomyosine. It is estimated that between 1.0 to 3.2%, and 0.1 to 5.7% of European adult and children respectively have food allergies [80]. A study carried out in Belgium revealed that 19% of persons were sensitized by skin prick tests prepared with grilled *A. domesticus* and *T. molitor* insect samples [20] suggesting that a large population could be at risk of developing allergic reactions upon consumption of certain edible insects types.

Edible insects are considered novel food [81]. With these kind foods, it is important to determine their potential hazards and risks including their allergenicity. Most of the research in regard to insect allergy focusses on inhalation insect allergy and insect venom allergy with little effort directed towards allergenicity in terms of food safety [82]. With edible insects offering an attractive alternative and sustainable means of meeting the protein demand for the increasing population [62], there is a potential for their increased consumption in future with the possibility of increasing insect food allergy prevalence. An understanding through research, of the potential for insects and insect-based food to cause adverse health effects to consumers in regard to allergenicity is therefore important.

Reports on adverse effects to consumers upon insects consumption is limited; however, recent studies indicate that 18% of fatal reactions to foods in China were as a result of insects consumption [83], while 7.6% of insects consumers in Laos exhibited allergic reactions [84]. It is not clear why most insect food allergies reported in the scientific literature is from developed countries [11] as opposed to developing countries where they are largely consumed. One of the possible explanations to this scenario is lack of research in insects' food allergies in the developing countries. According to de Gier and Verhoeckx [82], insect food allergy has been reported for mealworm, silkworm, sago worms, caterpillars, grasshopper, locust, bee, cicada, *Bruchus lentis* and *Clanis bilineata*. Edible insects allergic reactions have also been documented elsewhere; locusts and grasshoppers in India [85], mopane cartapillars (*Imbrasia belina*) in Africa [86] and silkworm pupa in China [87]. The most commonly consumed insect type in China is silkworm pupa and it is estimated that at least one thousand of the consumers experience allergic reactions with at least fifty of these consumers requiring emergency hospitalization [87]. The only insect-derived food additive implicated in triggering an allergic reaction so far is carmine (used as food dye) which is obtained from female cochineal insects (*Dactylopius coccus*) [82]. It is possible that with increasing research in entomophagy, more insect types will be implicated in insect food allergies, and therefore, mitigation strategies need to be considered and put in place to safeguard consumer health including proper products labeling to inform potential consumers of foods containing edible insects or edible insects ingredients.

#### *3.2.2. Pesticide residues*

Wild harvested edible insects are of particularly great importance when it comes to presence of pesticide residues in insect-derived foods and ingredients. This is because the kind of material they feed on is not controlled (they can freely move or migrate from one place to another) and sometimes they may feed on pesticide-sprayed vegetation or crops which may, potentially lead to accumulation of the residue in their bodies. Consumers relying on wild harvested edible insects are particularly at risk of pesticide food poisoning. In Thailand for example, pesticide contaminated insects (after a disinfection procedure) were sold in the market endangering lives of entomophagists [88]. In Kuwait [89], potentially hazardous locust contaminated with chlorinated and organophosphorus pesticides residues were reported in the market after spraying of crops to control the pest. In this study, as high as 49.2 μg/kg and 740.6 μg/kg of chlorinated and organophosphorus pesticide respectively were quantified in insects samples analyzed. Other authors reporting presence of pesticide residues in edible insects include Gao et al. [90], Charlton et al. [91], EFSA [76], Houbraken et al. [92], Van der Spiegel [93] and Poma et al. [77]. However, with the current promotion of edible insect farming where their feeding is controlled, it is possible to produce pesticide residue-free edible insects.

#### *3.2.3. Mycotoxins*

Mycotoxins, which are regarded as the most important food contaminants in relation to their negative impact on public health and food security are secondary metabolites produced by many phytopathogenic and food spoilage moulds of mainly *Fusarium, Aspergillus* and *Penicillium* genera [94]. Mycotoxins may be present in the feed substrate on which edible insects are reared. Limited studies have been carried out to determine occurrence and extent of contamination of edible insects and edible insect-derived foods with mycotoxins. According to FAO [11], mycotoxins detected and quantified in edible insects may originate from contamination of feed substrate by the three genera of moulds mentioned above as well as production in insects gut. This observation demonstrates that edible insects can be of potential food safety concern particularly because of the acute and chronic effects these toxins can have on both human and animal health. A few authors have reported presence of mycotoxins with varying concentrations in edible insects [74,95–98].

Out of all the mycotoxins detected and/or quantified in edible insects, perhaps the toxins of the greatest health concern are aflatoxins which readily occur in tropical developing countries ironically associated with greater consumption of edible insects. Aflatoxins are proven carcinogens, which are also linked to stunted growth in human [99,100]. Moulds implicated in the production of aflatoxin have been isolated from fresh edible insects as well as from dried ones possibly as a result of unhygienic processing conditions such as exposure to an open environment e.g. during sun drying and open display during selling as a street food [101,102]. A recent study by Kachapulula et al. [103] investigating aflatoxin contamination of dried insects and fish in Zambia showed that for certain edible insects (moth *Gynanisa maja*, moth *Gonimbrasia zambesina* and termite *Macrotermes falciger*), the concentration exceeded the country's regulatory limit of 10 μg/kg. This clearly shows that edible insects could contribute to aflatoxicoses development if appropriate measures are not taken in their value-chain management, especially when they are consumed as ready-to-eat street vended foods.

### 3.2.4. Antinutrients

Antinutrients, also referred to as antinutritional factors are naturally occurring substances in foods that inhibit nutrients (both macro- and micronutrients) intake, digestion, absorption and utilization [104]. These substances, which are more common and occur in higher concentration in plant-based foods than in animal-based foods may also produce other adverse health effects to consumers depending on type and concentration in foods. Different types of antinutrients have been detected and quantified in a variety of edible insect types. Ekop et al. [105] detected and quantified four types of antinutrients (tannin, oxalate, hydrocyanide and phytate) in four insect species in Nigeria. Some of the insect types from which phytates and tannins have been detected include long-horned beetle, grasshoppers, termites, meal bugs and termites [97,106]. In Nigeria, a heat resistant thiaminase enzyme naturally present in the pupa of African silkworm (*Anaphe* spp.) has been implicated in seasonal ataxic syndrome [107]. "Seasonal ataxia is a clinical syndrome of acute cerebellar ataxia which follows ingestion of roasted larvae of *Anaphe venata*, an alternative protein source consumed in western Nigeria" [106]. Other antinutrients detected and quantified in edible insects include saponins and alkaloids [108]. In this regard, there is a need to understand what antinutrients are present in which insects type in order to devise ways of either eliminating them before consumption, avoid consumption of the implicated insect types or seek an alternative insect type for consumption.

### 3.2.5. Heavy metals

Heavy metals, usually considered systemic toxicants include lead, mercury, arsenic and cadmium (among others) are metallic elements capable of inducing toxicity at low levels of exposure [109]. Contamination of foods by heavy metals is known to cause adverse health effects, both acute and chronic in humans and animals [110]. There is currently finite knowledge on the safety of edible insects in regard to heavy metals. Possible heavy metals accumulation in edible insects which has been shown to depend on many factors including insect species, growth phase and feed substrate has been documented [76]. Whereas essential heavy metals have not been shown to accumulate in edible insects, non-essential heavy metals such as cadmium, lead, mercury and arsenic have been shown to accumulate in insects, the extent of which is dependent on metal element, insect species and its growth stage [74,111]. Some of the heavy metals that have been detected and/or quantified in some edible insects include cadmium, lead and mercury [112–114]. Two heavy metals of greatest concern are cadmium and arsenic because of their potential to accumulate in black soldier fly and in yellow mealworm larvae respectively which are two main insect types which are of great interest for use as food and feed particularly in western countries [74]. Recently, Kohler et al. [19] detected mercury, lead, cadmium and arsenic albeit in low concentration in four edible insect types (mulberry silkworm, scarab beetle, house cricket and Bombay locust) consumed in Thailand. These few reports suggests the likelihood for edible insects, particularly the wild collected to contribute to unsafe edible insects food safety burden, a challenge that would perhaps be possible to mitigate by controlled edible insects production, processing and storage.

### 3.2.6. Pathogenic microorganisms

Studies about microbial contamination of edible insects are limited in the scientific literature but it is a growing area of interest and research. The data available on this aspect seems to suggest that both spoilage and pathogenic microorganisms can be inherent and that the extent of contamination depends on many factors including insect type, whether wild collected or domesticated, processing and handling procedures used in their preparation, and hygiene practices among others [24]. It is well recognized that several pathogenic bacterial genera including *Escherichia, Staphylococcus* and *Bacillus* can infect both humans and invertebrates (including insects) [23] presenting health risks to edible insects consumers even in instances where there is no contamination of foods from other sources. This is particularly so because insects can be carriers of pathogenic microbes, and with some communities in developing countries consuming them raw, this presents a direct health risk to the consumers. The fact that most of the edible insects in the developing countries are collected from the wild, an environment that may be unhygienic is likely to further complicate this issue. Pathogenic microorganisms often associated in outbreak of foodborne diseases have been isolated in many edible insect types. Reports of microbial foodborne infections and intoxications originating from entomophagy have been reported in scientific literature [115] demonstrating the need for promoting effective good hygiene practices in the entire edible insect food value chain to protect the health of the entomophagists.

Some recent studies carried out in regard to microbial risks associated with edible insects have reported potential presence of pathogenic microorganisms in these foods [116–118]. A study determining the diversity of microbiota present in edible insects processed and sold from Thailand revealed presence of many potentially human pathogenic bacterial genera including *Vibrio, Streptococcus, Staphylococcus*, *Clostridium* and *Bacillus* [117]. A more recent study characterizing microbes in raw edible grasshopper (*Ruspolia differens*) obtained from the wild in Uganda [119] also pointed to the possibility of edible insects harboring potentially dangerous genera of bacteria. In this case, the authors reported presence of *Campylobacter, Bacillus, Staphylococcus, Neisseria, Pseudomonas* and *Clostridium* genera. These researches suggest the likelihood for both raw and processed ready-to-eat insects in contributing to microbial foodborne illnesses to the insects consumers. Edible insect food safety in regard to pathogenic microorganisms seems to be of more significant concern to developing countries especially those in Africa and Asia where the consumers mainly rely on wild harvesting [120]. This is in comparison to edible insects obtained through domestication mainly practiced in developed countries where rearing is controlled minimizing or eliminating the potential contamination by microbiological hazards [24]. The most common pathogenic bacterial species that have been isolated from edible insects in the current literature belong to the genera *Staphylococcus, Micrococuss, Bacillus, Salmonella, Shigella* and *Clostridium* [96,119,121,122]. There is need to ensure hygienic edible insects production procedures, processing, preservation and handling to reduce the risks of spreading microbial foodborne illnesses. Holding all factors constant, it is expected that wild harvested edible insects, particularly those consumed raw would pose significant risks to consumers compared to those farmed, as in the latter, production control measures are undertaken.

### 3.2.7. Parasites

The role of edible insects in transmitting parasitic foodborne diseases has barely been investigated although there exists a potential of some edible insects to contribute to unsafe foods in this regard. The likelihood of wild harvested insects in transmitting parasitic diseases to human is higher than that of farmed insects because wild collected insects are not confined and their feeding habits are not controlled unlike in the case of farm reared insects. According to Chai et al. [123], analysis of some insects and human autopsies in regions where entomophagy is practiced implies the potential of foodborne transmission of parasites by some edible insects. *Dicrocoelium dendriticum* is a zoonotic parasite that is readily transmitted to humans through consumption of edible insects such as ants [79]. Foodborne and waterborne parasites including *Entamoeba histolytica, Giardia lamblia* and *Toxoplasma* spp. have been isolated in insects such as cockroaches [79]. It is worth noting however, that this was observed in wild harvested insects and that there is currently lack of data linking farm reared insects to foodborne parasite transmission. In this regard, it is of paramount importance to investigate the potential of farmed insects in the development of parasitic foodborne diseases in human, particularly in those edible insects that are consumed raw. This is useful because of the currently heightened interest in insects farming in both developing and developed countries which has a potential of spreading the risks should there be any in this regard.

## 4. Edible insects nutrients digestibility and bioavailability

Nutrient digestibility refers to a way of evaluating the extent of digestion or availability of nutrients, usually macronutrients while nutrient bioavailability refers to the fraction of the nutrients absorbed from the consumed food and utilized for normal body functions [124]. Edible insects nutrients digestibility and bioavailability is of paramount importance in the utilization of this food commodity. It would be of no nutritional benefit to the consumers if a given edible insect type contained high levels of nutrients on laboratory analysis but which are not readily available to the body for health and wellbeing promotion. Often, reported nutritional composition upon laboratory analysis of either raw or processed edible insects may not provide full information on what, which and how much of the nutrients are available to the body [125]. Scientific literature in the aspect of edible insects nutrient digestibility and bioavailability is scanty and currently an area of increased interest among some entomophagists promoting inclusion of edible insects in human diets. Several factors have been reported to influence nutrients digestibility and bioavailability in human foods. These factors that include edible insect type [126], processing method [125], antinutritional factors [108,127] and chitin levels [128] need to be further studied in the context of edible insects to better understand how they influence digestibility and bioavailability of nutrients in regards to human consumption.

Processing of edible insects in one way or another such as roasting, steaming, frying, drying and boiling is usually encouraged to improve safety, palatability and keeping quality [129]. However, these processing methods which are rarely controlled where edible insects are largely traditionally consumed may negatively influence nutrient digestibility and bioavailability although the findings are sometimes contradictory [130]. Findings reported slightly over a decade ago showed reduced true dry matter, ash, zinc and crude protein digestibility in mopane worms [131]. Recently in mealworms, according to Caparros Megido et al. [132], protein digestibility was reported to significantly increase on boiling and oven cooking methods. Poelaert et al. [133], in a study investigating protein value of two insects subjected to various heat treatments using growing rats and the protein digestibility-corrected amino acid score revealed high protein digestibility in both raw (84-92%) and heated (84-90%) as well as amino acid profile that met dietary requirements for human. In a more recent study by Manditsera et al. [130], where the authors were determining the effect of domestic cooking methods on protein digestibility and mineral bioaccessibility of wild harvested adult edible insects (*Eulepida mashona* (beetle) and *Henicus whellani* (cricket)), the findings revealed reduced protein digestibility upon processing. The authors in this case opined that this could have happened due to modification of proteins and mineral interactions with the rest of the edible insect food matrix. In this study, boiling led to significant reduction of minerals compared to roasting indicating preference of the latter processing method as a sure way of guaranteeing mineral bioavailability to edible insects consumers. It is however worth noting that the mechanisms underlying the possible improvement of edible insects protein digestibility and/or bioavailability through various types of processing methods is not well understood like it is for e.g. beef and other types of animal proteins. It is therefore important for scientists, particularly edible insects scientists to explore this gray area of entomophagy.

From these few reports, it is evident that more research is required to remove the contractions on the factors influencing edible insects nutrient digestibility and bioavailability. It is also vital that more studies are carried out to design or develop ways of improving edible insects nutrient digestibility and bioavailability as this food type is viewed as one of the best sustainable ways of curbing food insecurity and hidden hunger, particularly in regions where entomophagy is largely practiced. It should not be assumed that high edible insects nutrients profile on laboratory analysis translates to bioavailability and utilization for normal body functions. Such an assumption may impact negatively on human health where levels of, for example, protein and minerals may not be sufficient (due to low digestibility and bioavailability) to meet dietary requirements leading to malnutrition or hidden hunger in edible insects consumers.

## 5. Shelf-life of edible insects

Edible insects can be consumed raw or processed using various methods such as sun drying, boiling, roasting and frying. Processing of edible insects that involves some form of heat treatment is an important aspect that is meant to serve various purposes such as destruction of potential microbial pathogens, improve palatability and delay or prevent spoilage thus extending the product shelf-life. The extent to which these benefits are achieved depends mainly on the type of the processing method. Shelf-life refers to the time a food maintains its acceptable quality and remains safe to consume [134]. One of the challenges limiting continued inclusion of edible insects in diets all year round is the fact that the wildly harvested insects are seasonal and have limited shelf-life, thus readily spoils. The postharvest shelf-life of freshly harvested edible insects is usually very short, for example, that of edible grasshopper (*Ruspolia nitidula*) is 1–2 days [135]). In this regard, there is a need to device ways of prolonging the storage stability to prevent edible insects food losses. It is opined that the challenge of seasonality can be overcome if more stable edible insects products are produced [135] which necessitate shelf-life studies. There is currently limited scientific literature on shelf-life studies of edible insects, processed or otherwise, and edible insects-derived foods. The reason behind this scenario is not clear but it may be probably because most edible insects researchers have tended to concentrate more on the rearing, nutritional profiling and health benefits associated with this food type as well as incorporating edible insects as an ingredient in conventional foods to increase consumer acceptability while neglecting most of the other aspects including shelf-life studies.

A study carried out in Nigeria determining the shelf-life of two common edible insect species (*Macrotermes bellicosus* and *Rhynchophorus phoenicis*) as one of the components revealed a significant reduction in both macro- and micronutrients after storage for 3 months [114]. In this study however, it is not clear under what conditions the storage was carried out, thus, it is difficult to explain this finding. In a study carried out in Uganda, Ssepuuya et al. [135] demonstrated the effectiveness of hurdle technology in extending the shelf-life of sauteed ready-to-eat edible grasshopper (*Ruspolia nitidula*). In this study, the authors reported an increase in shelf-life of *R. nitidula* up to 22 weeks when the vacuum packaged product was stored under chilled and ambient temperature conditions. Borremans et al. [136] demonstrated that the appeal of edible insects can be increased by enhancing their shelf-life and by doing so, the authors showed that marination could increase the storage stability of mealworm larvae (*Tenebrio molitor*) for at least 7 days. Kamau et al. [137] demonstrated that a shelf-life of 7 months at 25°C is achievable if black soldier fly larvae (*Hermetia illucens*) and edible house cricket (*Acheta domesticus*) powders were dried to approximately 5% moisture content and packaged in 80 μm thick polyethylene bags.

More research is required in the determination and understanding of shelf-life of both raw and processed edible insects in order to develop and implement ways of extending storage stability of the products while ensuring product safety at the same time. From the limited studies in this aspect, it is apparent that hurdle technology has the potential of enhancing edible insects shelf-life and safety just like it has been proven to work in other food categories. Hurdle technology is a technique that employs a combination of preservation methods meant to extend the shelf-life of food while ensuring safety at the same time by preventing growth of pathogenic microorganisms [138]. In the adoption of this technology, in the context of developing countries which are mainly in the tropics and where most entomophagy is practiced, emphasis should be given to technologies that can enhance the keeping quality at ambient temperature as methods requiring electricity such as refrigeration and freezing among others are expensive, unaffordable and unsustainable to most people.

## 6. Edible insects regulations

Safety policies and regulations in regard to edible insects should be of paramount importance in governments of both developing and developed countries to ensure a reduced or risk free supply of this food type to the consumers from farm-to-fork. The consumption patterns by many consumers has significantly changed in recent times due to their increasing understanding of their rights to quality and safe foods, and this would no doubt apply to edible insects and foods derived from them, especially to the western consumers who particularly seem to be wary to practice entomophagy. There is lack of regulations touching on edible insects production, processing and sale in developing countries where entomophagy is generally traditionally practiced [52] leading to no barriers imposed to their utilization. The case is however different in western countries where majority of them are either in the process of developing, reviewing and/or implementing their regulations. For example, recently EFSA required that all insect-based foods meant for human consumption be regarded as novel foods. Novel foods are mainly considered those that do not have a history of consumption by humans in the country/region in question. The European Commission (EC) defines novel food as “Food that had not been consumed to a significant degree by humans in the EU before 15 May 1997, when the first regulation on novel food came into force.”

Regulation (EU) No 2015/2283 sometimes referred to as the new Novel Food Regulation whose main purpose is to safeguard consumers health by ensuring food safety provides guidelines that must be adhered to for all novel foods intended for sale within the European Union (EU) market. Through this regulation, the EU consumers are availed a wide range of safe, unique and innovative food choices including those from third world countries. According to OJEU [139], novel foods should only be approved if they meet the laid down regulations which include being safe for consumption, not misleading to consumers by being clearly labeled, and not differing in a way that their use would be nutritionally disadvantageous to the consumer if they are meant to replace other foods.

A wide range of foods are currently considered novel foods based on Regulation (EU) No 2015/2283 and are included in the Union list of authorized Novel Foods [139]. Edible insects which may include whole insects, parts of whole edible insects including ingredients derived from them such as meals/flours, as well as ingredients other than those derived from whole edible insects or their parts such as insects extracts are considered novel foods [140]. However, according to Merten-Lentz and Commandeur [141], by November 2018, none of the edible insects had been included in the Union novel food list. This is possibly due to the stringent requirements of applications for authorization of a novel food backed up by substantial scientific research data in support of the safety of the novel food which may take time to gather and provide evidence to EFSA. This, however, is bound to change in the very near future as more data is obtained in support of edible insects as novel foods. In addition to this regulation, some EU member countries have their own legislation regulations through their food safety agencies/authorities in regard to edible insect trade for consumption as human food e.g. the UK, Holland, Denmark, Austria and Belgium [142].

Lack of (the case of developing countries) and strict regulations (the case of western countries) can obviously be viewed as a barrier to utilization of edible insects which can be counter-productive in the promotion of edible insects as sustainable means of combating food insecurity. Edible insects produced in developing countries may pose food safety concerns to western countries consumers as a result of nonexistent or relaxed production, processing and handling rules [142]. Due to this reason, it would be difficult for developing countries edible insects farmers to a earn a living through export of this commodity due to food safety concerns from well-regulated western markets even if there were ready markets in these regions. Stringent regulations in developed countries are also the reason there is insignificant growth and commercialization of edible insects and foods derived from them in Europe [143]. In light of these observations, there is an urgent need for the development and implementation of harmonized edible insects food safety regulations particularly in the developing countries in order to promote safe utilization of this commodity from farm-to-fork.

## 7. Conclusion

The current research evidence shows that edible insects can play a significant role in addressing food and nutrition insecurities and this should be encouraged. Scientific evidence shows that edible insects' nutritional quality is equivalent and sometimes exceeds that of animal-based foods. This and the fact that edible insects have a faster growth rate, high food conversion efficiency and requires less resources to rear compared to livestock should make them a more attractive quality food source especially to the rural poor in the developing countries.

In countries or communities where entomophagy is practiced, edible insects may be generally recognized as safe (GRAS) foods, but this is not the case in most developed countries where most consumers are wary of their safety, thus hesitant to include them in their diets. The scientific literature on edible insects food safety aspects is limited. There is therefore a need for more research geared towards understanding the risks involved in their consumption to safeguard consumer health.

In light of this, entomophagy needs to be promoted and encouraged globally, but there needs to be a balance between consumer food safety concerns, and the nutritional and health benefits of this food type. Development and implementation of edible insects legislation regulations in both the developing and developed countries should be encouraged as this, in the long run, apart from ensuring safety, can also aid trade in this commodity among countries. Emphasis should also be put on future research looking at up-scaling edible insects production and commercialization.

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## Declaration of competing interest

None.

## References

[1] J. Ramos-Elorduy, Anthropo-entomophagy: cultures, evolution and sustainability,

Entomol. Res. 39 (2009) 271–288.
[2] R.T. Gahukar, Entomophagy and human food security, Int. J. Trop. Insect Sci. 31 (2011) 129–144.
[3] J. Tao, Y.O. Li, Edible insects as a means to address global malnutrition and food insecurity issues, Food Qual. Saf. 2 (2018) 17–26.
[4] J. Stoops, S. Crauwels, M. Waud, J. Claes, B. Lievens, Microbial community assessment of mealworm larvae (*Tenebrio molitor*) and grasshoppers (*Locusta migratoria migratorioides*) sold for human consumption, Food Microbiol. 35 (2015) 122–127.
[5] J.J. Schouteten, H. De Steur, S. De Pelsmaeker, S. Lagast, J.G. Juvinal, I. De Bourdeaudhuij, Emotional and sensory profiling of insect-, plant- and meat-based burgers under blind, expected and informed conditions, Food Qual. Prefer. 52 (2016) 27–31.
[6] S. Belluco, C. Losasso, M. Aggioletti, C.C. Alonzi, M.G. Paoletti, A. Ricci, Edible insects in a food safety and nutritional perspective: a critical review, Compr. Rev. Food Sci. Food Saf. 12 (2013) 296–313.
[7] A. van Huis, J. Van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, P. Vantomme, Edible Insects: Future Prospects for Food and Feed Security. FAO Forestry Paper 171, Food and Agriculture Organization of the United Nations, 2013, pp. 1–187.
[8] N. Alexandratos, J. Bruinsma, World Agriculture Towards 2030/2050: The 2012 Revision, FAO, Rome, Italy, 2012 ESA Working Paper No. 12-03.
[9] J.A. Foley, R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, Global consequences of land use, Science 309 (570) (2015) 574.
[10] D.G. Oonincx, J. van Itterbeeck, M.J. Heetkamp, H. van den Brand, J.J. van Loon, A. van Huis, An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption, PLoS One 5 (2010) 1–7.
[11] FAO, A. van Huis, J. van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, P. Vantomme (Eds.), Edible Insects. Future Prospects for Food and Feed Security, 2013 Rome, 2013. Available at: http://www.fao.org/docrep/018/i3253e/i3253e00.htm Accessed 10th August, 2019.
[12] H.C. Klunder, J. Wolkers-Rooijackers, J.M. Korpela, M.J.R. Nout, Microbiological aspects of processing and storage of edible insects, Food Control 26 (2012) 628–631.
[13] J. Ramos-Elorduy, J.M. Moreno, E. Prado, M. Perez, Nutritional value of edible insects from the State of Oaxaca, Mexico, J. Food Compos. Anal. 10 (1997) 142–157.
[14] A. Van Huis, D.G.A.B. Oonincx, The environmental sustainability of insects as food and feed. A review, Agron. Sustain. Dev. 37 (2017) 1–14.
[15] L.H. Heckmann, J.L. Andersen, N. Gianotten, M. Calis, C.H. Fischer, H. Calis, Sustainable mealworm production for feed and food, in: A. Halloran, R. Flore, P. Vantomme, N. Roos (Eds.), Edible Insects in Sustainable Food Systems, Springer International Publishing, Cham, 2018, pp. 321–328.
[16] N. Roos, A. van Huis, Consuming insects: are there health benefits? J. Insects Food Feed 3 (2017) 225–229.
[17] S.K. Srivastava, N. Babu, H. Pandey, Traditional insect bioprospecting-as human food and medicine, Indian J. Tradit. Knowl. 8 (2009) 485–494.
[18] J. Yhoung-Aree, Edible insects in Thailand: nutritional values and health concerns, Forest Insects as Food: Humans Bite Back. Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19–21 February 2008, 2010.
[19] R. Kohler, R. Kariuki, L. Lambert, H.K. Biesalski, Protein, amino acid and mineral composition of some edible insects from Thailand, J. Asia Pac. Entomol. 22 (2019) 372–378.
[20] F. Francis, V. Doyen, F. Debaugnies, G. Mazzucchellic, R. Caparrosa, T. Alabia, C. Bleckerd, E. Haubrugea, F. Corazza, Limited cross reactivity among arginine kinase allergens from mealworm and cricket edible insects, Food Chem. 276 (2019) 714–718.
[21] T.R. Murefu, L. Macheka, R. Musundire, F.A. Manditsera, Safety of wild harvested and reared edible insects: a review, Food Control 101 (2019) 209–224.
[22] D. Sun-Waterhouse, G.I.N. Waterhouse, L. You, J. Zhang, Y. Liu, L. Ma, Transforming insect biomass into consumer wellness foods: a review, Food Res. Int. 89 (2016) 129–151.
[23] N.T. Grabowski, G. Klein, Microbiology of cooked and dried edible Mediterranean field crickets (*Gryllus bimaculatus*) and superworms (*Zophobasatratus*) submitted to four different heating treatments, Food Sci. Technol. Int. 23 (2017) 17–23.
[24] B.A. Rumpold, O.K. Schluter, Nutritional composition and safety aspects of edible insects, Mol. Nutr. Food Res. 57 (2013) 802–823.
[25] M. Kulma, L. Kouřimská, V. Plachý, M. Božik, A. Adamkova, V. Vrabec, Effect of sex on the nutritional value of house cricket, *Acheta domestica* L. Food Chem. 272 (2019) 267–272.
[26] D. Raubenheimer, J.M. Rothman, Nutritional ecology of entomophagy in humans and other primates, Annu. Rev. Entomol. 58 (2011) 141–160.
[27] A. van Huis, Edible insects contributing to food security? Agric. Food Sec. 4 (2015) 1–9.
[28] L. Yi, C.M.M. Lakemond, L.M.C. Sagis, V. Eisner-Schadler, A. van Huis, M.A.J.S. van Boekel, Extraction and characterization of protein fractions from five insect species, Food Chem. 141 (2013) 3341–3348.
[29] M.D. Finke, G. Defoliart, N.J. Benevenga, Use of a four parameter logistic model to evaluate the quality of the protein from three insect species when fed to rats, J. Nutr. 119 (1989) 864–871.
[30] B. Magalhaes, B. Peleteiro, N. Lunet, Dietary patterns and colorectal cancer: systematic review and meta-analysis, Eur. J. Cancer Prev. 21 (2012) 15–23.
[31] S. Bukkens, Insects in the human diet: nutritional aspects, in: M.G. Paoletti (Ed.), Ecological Implications of Minilivestock: Potential of Insects, Rodents, Frogs and Snails, Science Publisher, Enfield, NH, 2005, pp. 545–577.
[32] G. DeFoliart, Insect fatty acids: similar to those of poultry and fish in their degree of unsaturation, but higher in the polyunsaturates, Food Insects Newsl. 4 (1991) 1–4.
[33] K.S. Ritter, Cholesterol and insects, Food Insects Newsl. 3 (1990).
[34] M. Sabolová, A. Adámková, L. Kouřimská, D. Chrpová, J. Pánek, Minor lipophilic compounds in edible insects, Potravinarstvo Slovak J. Food Sci. 10 (2016) 400–406.
[35] S. Sirimungkararat, W. Saksirirat, T. Nopparat, A. Natongkham, P.B. Durst, D.V. Johnson, R.N. Leslie, K. Shono (Eds.), Forest Insects as Food: Humans Bite Back, FAO, Bangkok, Thailand, 2010, pp. 189–200.
[36] R.S. Gibson, Dietary-induced zinc deficiency in low income countries: challenges and solutions, Nutr. Today 50 (2015) 49–55.
[37] E. McLean, M. Cogswell, I. Egli, D. Wojdyla, B. de Benoist, Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005, Public Health Nutr. 12 (2009) 444–454.
[38] M. Pennino, E.S. Dierenfeld, J.L. Behler, Retinol, alpha-tocopherol and proximate nutrient composition of invertebrates used as feed, Int. Zoo Yearb. 30 (1991) 143–149.
[39] O. Selenius, J. Korpela, S. Salminen, C.G. Gallego, Effect of chitin and chitooligosaccharide on *in vitro* growth of *Lactobacillus rhamnosus* GG and *Escherichia coli* TG, Appl. Food Biotechnol. 5 (2018) 163–172.
[40] J.C. Fernandes, F.K. Tavaria, J.C. Soares, Ó.S. Ramos, M. JoãoMonteiro, M.E. Pintado, M.F. Xavier, Antimicrobial effects of chitosans and chitooligosaccharides upon *Staphylococcus aureus* and *Escherichia coli* in food model systems, Food Microbiol. 25 (2008) 922–928.
[41] T. Steer, H. Carpenter, K. Tuohy, G.R. Gibson, Perspectives on the role of the human gut microbiota and its modulation by pro-and prebiotics, Nutr. Res. Rev. 2000 (13) (2000) 229–254.
[42] V.J. Stull, E. Finer, R.S. Bergmans, H.P. Febvre, C. Longhurst, D.K. Manter, J.A. Patz, T.L. Weir, Impact of edible cricket consumption on gut microbiota in healthy adults, a double-blind, randomized crossover trial, Sci. Rep. 8 (2018) 1–13.
[43] J. Yhoung-aree, P. Puwastein, G.A. Attig, Edible insects in Thailand: an unconventional source of protein? Ecol. Food Nutr. 36 (1997) 133–149.
[44] S. Kelemu, S. Niassy, B. Torto, K. Fiaboe, H. Affognon, H. Tonnang, N.K. Maniania, S. Ekesi, African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security, J. Insects Food Feed 1 (2015) 103–119.
[45] R.T. Gahukar, Edible insects farming: efficiency and impact on family livelihood, food security, and environment compared with livestock and crops, Insects as Sustainable Food Ingredients. Production, Processing and Food Applications, 2016, pp. 85–111.
[46] D.L. Dufour, Insects as food: a case study from the northwest Amazon, Am. Anthropol. 89 (2) (1987) 383.
[47] R.A. Hope, P.G.H. Frost, A. Gardiner, J. Ghazoul, Experimental analysis of adoption of domestic mopane worm farming technology in Zimbabwe, Dev. South. Afr. 26 (2009) 29–46.
[48] E.N. Chidumayo, K.J. Mbata, Shifting cultivation, edible caterpillars and livelihoods in the Kopa area of northern Zambia, For. Trees Livelihoods 12 (2002) 175–193.
[49] A.L. Yen, Insects as food and feed in the Asia Pacific region: current perspectives and future directions, J. Insects Food Feed 1 (2015) 33–55.
[50] Y. Feng, X.M. Chen, M. Zhao, Z. He, L. Sun, C.Y. Wang, W.F. Ding, Edible insects in China: utilization and prospects, Insect Sci. (2017) 1–15.
[51] Y. Hanboonsong, Edible insects and associated food habits in Thailand, Forest Insects as Food: Humans Bite Back. Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19–21 February 2008, Chiang Mai, Thailand, 2010.
[52] D. Dobermann, J.A. Swift, L.M. Field, Opportunities and hurdles of edible insects for food and feed, BNF Nutr. Bull. 42 (2017) 293–308.
[53] G. Maciel-Vergaraa, V.I.D. Ros, Viruses of insects reared for food and feed, J. Invertebr. Pathol. 147 (2017) 60–75.
[54] A. Halloran, N. Roos, Y. Hanboonsongt, Cricket farming as a livelihood strategy in Thailand, Geogr. J. 183 (2017) 112–124.
[55] J.A. Foley, N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, C. O'Connell, D.K. Ray, P.C. West, C. Balzer, E.M. Bennett, S.R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockström, J. Sheehan, S. Siebert, D. Tilman, D.P.M. Zaks, Solutions for a cultivated planet, Nature 478 (2011) 337–342.
[56] A.L. Yen, Edible insects: traditional knowledge or western phobia? Entomol. Res. 39 (2009) 289–298.
[57] N. Fiala, Meeting the demand: an estimation of potential future greenhouse gas emissions from meat production, Ecol. Econ. 67 (2008) 412–419.
[58] P.S. Thorne, Environmental health impacts of concentrated animal feeding operations: anticipating hazards: searching for solutions, Environ. Health Perspect. 115 (2007) 296–297.
[59] J. Sachs, Rethinking macroeconomics: knitting together global society, Broker 10 (2010) 1–3.
[60] J. Sachs, The Age of Sustainable Development, Columbia University Press, New York City, NY, 2015.
[61] R. Cerritos, Z. Cano-Santana, Harvesting grasshoppers *Sphenarium purpurascens* in Mexico for human consumption: a comparison with insecticidal control for managing pest outbreaks, Crop Prot. 27 (2008) 473–480.
[62] J. Mlcek, O. Rop, M. Borkovcova, M. Bednarova, A comprehensive look at the possibilities of edible insects as food in Europe-a review, Pol. J. Food Nutr. Sci. 64 (2014) 147–157.

[63] W. Verbeke, Profiling consumers who are ready to adopt insects as a meat substitute in a Western society, Food Qual. Prefer. 39 (2015) 147–155.
[64] L. Orsi, L.L. Voege, S. Stranieri, Eating edible insects as sustainable food? Exploring the determinants of consumer acceptance in Germany, Food Res. Int. 125 (2019) 108573.
[65] C. Hartmann, M. Siegrist, Insects as food: perception and acceptance. Findings from current research, Ernahrungs-Umschau 64 (2017) 44–50.
[66] R.C. Megido, L. Sablon, M. Geuens, Y. Brostaux, T. Alabi, C. Blecker, D. Drugmand, E. Haubruge, F. Francis, Edible insects acceptance by Belgian consumers: promising attitude for entomophagy development, J. Sens. Stud. 29 (2018) 14–20.
[67] L.V. Thielen, S. Vermuyten, B. Storms, B. Rumpold, L.V. Campenhout, Consumer acceptance of foods containing edible insects in Belgium two years after their introduction to the market, J. Insects Food Feed 5 (2018) 35–44.
[68] W. Verbeke, T. Spranghers, P. De Clercq, Insects in animal feed: acceptance and its determinants among farmers, agriculture sector stakeholders and citizens, Anim. Feed Sci. 204 (2015) 72–87.
[69] H. Looy, F. Dunkel, J. Wood, How then shall we eat? Insect eating attitudes and sustainable foodways, Agric. Hum. Values 31 (2014) 131–141.
[70] V. Raschke, B. Cheema, Colonisation, the New World Order, and the eradication of traditional food habits in East Africa: historical perspective on the nutrition transition, Public Health Nutr. 11 (2008) 662–674.
[71] A. Gere, G. Szekely, S. Kovacs, Readiness to adopt insects in Hungary: a case study, Food Qual. Prefer. 59 (2017) 81–86.
[72] G. Sogari, G. Menozzi, C. Mora, The food neophobia scale and young adults' intention to eat insect products, Int. J. Consum. Stud. 43 (2018) 68–76.
[73] H. Tranter, Insects Creeping into English Diets: Introducing Entomophagy to School Children in a Provincial Town, MSc Thesis University of East Anglia, 2013 3853497.
[74] H.J. van der Fels-Klerx, L. Camenzuli, S. Belluco, N. Meijer, A. Ricci, Food safety issues related to uses of insects for feeds and foods, Compr. Rev. Food Sci. Food Saf. 17 (2018) 1172–1183.
[75] O. Schluter, B. Rumpold, T. Holzhauser, A. Roth, R.F. Vogel, W. Quasigroch, Safety aspects of the production of foods and food ingredients from insects, Mol. Nutr. Food Res. 61 (2016) 1–14.
[76] EFSA, Risk profile of insects as food and feed, EFSA J. 13 (2015) 4257.
[77] G. Poma, M. Cuykx, E. Amato, C. Calaprice, J.F. Focant, A. Covaci, Evaluation of hazardous chemicals in edible insects and insect-based food intended for human consumption, Food Chem. Toxicol. 100 (2017) 70–79.
[78] S.G. Johansson, T. Bieber, R. Dahl, P.S. Friedmann, B.Q. Lanier, R.F. Lockey, Revised nomenclature for allergy for global use: report of the Nomenclature Review Committee of the World Allergy Organization, October 2003, J. Allergy Clin. Immunol. 113 (2004) 832–836.
[79] J. Boye, A.O. Danquah, C. Thang, X. Zhao, Food allergens, Clin. Rev. Allergy Immunol. 3 (2012) 798–819.
[80] B.I. Nwaru, et al., Prevalence of common food allergies in Europe: a systematic review and meta-analysis, Allergy 69 (2014) 992–1007.
[81] J.C. Ribeiro, L.M. Cunha, M. Sousa-Pinto, J. Fonseca, Allergic risks of consuming edible insects: a systematic review, Mol. Nutr. Food Res. 62 (2018) 1–12.
[82] S. de Gier, K. Verhoeckx, Insect (food) allergy and allergens, Mol. Immunol. 100 (2018) 82–106.
[83] K. Ji, et al., Anaphylactic shock and lethal anaphylaxis caused by food consumption in China, Trends Food Sci. Technol. 20 (2009) 227–231.
[84] H. Barennes, M. Phimmasane, C. Rajaonarivo, Insect consumption to address undernutrition, a national survey on the prevalence of insect consumption among adults and vendors in Laos, PLoS One 10 (2015) 1–16.
[85] J. Chakravorty, S. Ghosh, V.B. Meyer-Rochow, Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North East India), J. Ethnobiol. Ethnomed. 7 (2011) 1–5.
[86] S.J. Kung, B. Fenemore, P.C. Potter, Anaphylaxis to mopane worms (*Imbrasia belina*), Ann. Allergy Asthma Immunol. 106 (2011) 538–540.
[87] K.M. Ji, Z.K. Zhan, J.J. Chen, Z.G. Lieu, Anaphylactic shock caused by silkworm pupa consumption in China, Allergy 63 (2008) 1407–1408.
[88] G.R. DeFoliart, Insect as food: why the western attitude is important, Annu. Rev. Entomol. 44 (1999) 21–50.
[89] T. Saeed, F. Dagga, M. Saraf, Analysis of residual pesticides present in edible locusts captured in Kuwait, Arab. Gulf J. Sci. Res. 11 (1993) 1–5.
[90] Y. Gao, H. Wang, F. Qin, P. Xu, X. Lv, J. Li, B. Guo, Enantiomerization and enantioselective bioaccumulation of metalaxyl in *Tenebrio molitor* larvae, Chirality 26 (2014) 88–94.
[91] A.J. Charlton, M. Dickinson, M.E. Wakefield, E. Fitches, M. Kenis, R. Han, Exploring the chemical safety of fly larvae as a source of protein for animal feed, J. Insects Food Feed 1 (2015) 7–16.
[92] M. Houbraken, T. Spranghers, P. De Clercq, M. Cooreman-algoed, T. Couchement, G. Clercq, Pesticide contamination of *Tenebrio molitor* (Coleoptera: Tenebrionidae) for human consumption, Food Chem. 201 (2016) 264–269.
[93] M. Van Der Spiegel, M. Van Der Spiegel, Safety of foods based on insects, in: V. Prakash, O. Martín-Belloso, L. Keener, S. Astley, S. Braun, H. McMahon (Eds.), Regulating Safety of Traditional and Ethnic Foods, Academic Press (Elsevier Inc), 2016, pp. 205–216.
[94] J.E. Smith, C.W. Lewis, J.G. Anderson, G.L. Solomons, Mycotoxins in Human Nutrition and Health, EEC, Luxembourg, 1994, p. 22.
[95] M.F. Simpanya, J. Allotey, S.F. Mpuchane, A mycological investigation of phane, an edible caterpillar of an emperor moth, *Imbrasia belina*, J. Food Prot. 63 (2000) 137–140.
[96] W. Braide, S. Oranusi, L.I. Udegbunam, O. Oguoma, C. Akobondu, R.N. Nwaoguikpe, Microbiological quality of an edible caterpillar of an emperor moth, *Bunaea alcinoe*, J. Ecol. Nat. Environ. 3 (2011) 176–180.
[97] R. Musundire, I.M. Osuga, X. Cheseto, J. Irungu, B. Torto, Aflatoxin contamination detected in nutrient and anti-oxidant rich edible stink bug stored in recycled grain containers, PLoS One 11 (2016) 1–16.
[98] E. Wynants, S. Crauwels, B. Lievens, S. Luca, J. Claes, A. Borremans, Effect of post-harvest starvation and rinsing on the microbial numbers and the bacterial community composition of mealworm larvae (*Tenebrio molitor*), Innovative Food Sci. Emerg. Technol. 42 (2017) 8–15.
[99] Y. Gong, A. Hounsa, S. Egal, P.C. Turner, A.E. Sutcliffe, A.J. Hall, K. Cardwell, C.P. Wild, Post-weaning exposure to aflatoxin results in impaired child growth: a longitudinal study in Benin, West Africa, Environ. Health Perspect 112 (2004) 1334–1338.
[100] Y. Liu, C.H. Chang, G.M. Marsh, F. Wu, Population attributable risk of aflatoxin-related liver cancer: systematic review and meta-analysis, Eur. J. Cancer 48 (2012) 2125–2136.
[101] S. Mpuchane, H.K. Taligoola, B.A. Gashe, Fungi associated with *Imbrasia belina*, an edible caterpillar, Botsw. Notes Rec. 28 (1996) 193–197.
[102] K.J. Mbata, E.N. Chidumayo, Traditional values of caterpillars (Insecta: Lepidoptera) among the Bisa people of Zambia, Int. J. Trop. Insect Sci. 23 (2003) 341–354.
[103] P.W. Kachapulula, J. Akello, R. Bandyopadhyay, P.J. Cotty, Aflatoxin contamination of dried insects and fish in Zambia, J. Food Prot. 81 (2018) 1508–1518.
[104] K.E. Akande, U.D. Doma, H. Agu, H.M. Adamu, Major antinutrients found in plant protein sources: their effect on nutrition, Pak. J. Nutr. 9 (2010) 827–832.
[105] E.A. Ekop, A.I. Udoh, P.E. Akpan, Proximate and anti-nutrient composition of four edible insects in Akwa Ibom State, Nigeria, World J. Appl. Sci. Technol. 2 (2010) 224–231.
[106] S.A. Adeduntan, Nutritional and antinutritional characteristics of some insects foraging in Akure forest reserve Ondo state, Nigeria, J. Food Technol. 3 (2005) 563–567.
[107] T. Nishimune, Y. Watanabe, H. Okazaki, H. Akai, Thiamin is decomposed due to *Anaphe* spp. Entomophagy in seasonal ataxia patients in Nigeria, J. Nutr. 130 (2000) 1625–1628.
[108] R. Musundire, C.J. Zvidzai, C. Chidewe, B.K. Samende, F.A. Manditsera, Nutrient and anti-nutrient composition of *Henicus whellani* (Orthoptera: Stenopelmatidae), an edible ground cricket, in south-eastern Zimbabwe, Int. J. Trop. Insect Sci. 34 (2014) 223–231.
[109] A.T. Arif Tasleem Jan, M. Azam, K. Siddiqui, A. Ali, I. Inho Choi, Q.M.Z. Haq, Heavy metals and human health: mechanistic insight into toxicity and counter defense system of antioxidants, Int. J. Mol. Sci. 16 (2015) 29592–29630.
[110] C. D'Souza, R. Peretiatko, The nexus between industrialization and environment: a case study of Indian enterprises, Environ. Manag. Health 13 (2000) 80–97.
[111] S. Diener, C. Zurbrügg, K. Tockner, Bioaccumulation of heavy metals in the black soldier fly, *Hermetia illucens* and effects on its life cycle, J. Insects Food Feed 1 (2015) 261–270.
[112] Z.S. Zhang, X.G. Lu, Q.C. Wang, D.M. Zheng, Mercury, cadmium and lead biogeochemistry in the soil–plant–insect system in huludao city, Bull. Environ. Contam. Toxicol. 83 (2009) 255–259.
[113] A.D. Banjo, O.A. Lawal, B.T. Fasunwon, G.O. Alimi, Alkali and heavy metal contaminants of some selected edible arthropods in south western Nigeria, Am. Eurasian J. Toxicol. Sci. 2 (2010) 25–29.
[114] A.D. Banjo, S.A. Aina, A.R. Salau, Shelf-life and heavy metals study of two common edible insects in Ijebu division, Southwestern Nigeria, J. Biol. Life Sci. 4 (2013) 18–23.
[115] H.G. Schabel, Forest Insects as Food: Humans Bite Back, FAO, Bangkok, Thailand, 2010, pp. 37–64.
[116] C. Garofalo, A. Osimani, V. Milanovic, M. Taccari, F. Cardinali, L. Aquilanti, The microbiota of marketed processed edible insects as revealed by high-throughput sequencing, Food Microbiol. 62 (2017) 15–22.
[117] A. Osimani, C. Garofalo, V. Milanovic, M. Taccari, F. Cardinali, L. Aquilanti, Insight into the proximate composition and microbial diversity of edible insects marketed in the European Union, Eur. Food Res. Technol. 243 (2017) 1157–1171.
[118] D. Vandeweyer, S. Crauwels, B. Lievens, L. Van Campenhout, Metagenetic analysis of the bacterial communities of edible insects from diverse production cycles at industrial rearing companies, Int. J. Food Microbiol. 261 (2017) 11–18.
[119] G. Ssepuuya, E. Wynants, C. Verreth, S. Crauwels, B. Lievens, J. Claes, D. Nakimbugwe, L. Van Campenhout, Microbial characterisation of the edible grasshopper *Ruspolia differens* in raw condition after wild-harvesting in Uganda, Food Microbiol. 77 (2019) 106–117.
[120] G.R. Defoliart, Edible insects as minilivestock, Biodivers. Conserv. 4 (1995) 306–321.
[121] E.N. Amadi, D.B. Kiin-kabari, Nutritional composition and microbiology of some edible insects commonly eaten in Africa, hurdles and future prospects: a critical review, J. Food Microbiol. Saf. Hyg. 1 (2016) 1–7.
[122] M. Mezes, Food safety aspects of insects: a review, Acta Aliment. 47 (2018) 513–522.
[123] J.Y. Chai, E.H. Shin, S.H. Lee, H.J. Rim, Foodborne intestinal flukes in Southeast Asia, Korean J. Parasitol. 47 (2009) S69–S102 Suppl..
[124] P.J. Aggett, Population reference intakes and micronutrient bioavailability: a European perspective, Am. J. Clin. Nutr. 91 (suppl) (2010) 1433S–1437S, https://doi.org/10.3945/ajcn.2010.28674C.
[125] E. Fernandez-Garcia, I. Carvajal-Lerida, A. Perez-Galvez, *In vitro* bioaccessibility assessment as a prediction tool of nutritional efficiency, Nutr. Res. 29 (2009) 751–760.
[126] G.O. Latunde-Dada, W. Yang, M. Vera Aviles, *In vitro* iron availability from insects

and sirloin beef, J. Agric. Food Chem. 64 (2016) 8420–8424.
[127] R. Musundire, J.C. Zvidzai, C. Chidewe, Bio-active compounds composition in edible stinkbugs consumed in South-eastern districts of Zimbabwe, Int. J. Biol. 6 (2014) 36–45.
[128] S. Marono, G. Piccolo, R. Loponte, C. Di Meo, Y.A. Attia, A. Nizza, F. Bovera, *In vitro* crude protein digestibility of *Tenebrio molitor* and *Hermetia illucens* insect meals and its correlation with chemical composition traits, Ital. J. Anim. Sci. 14 (2015) 338–343.
[129] J.P. Williams, J.R. Williams, A. Kirabo, D. Chester, M. Peterson, Nutrient content and health benefit of insects, in: A.T. Dossey, J.A. Morales-Ramos, M. Guadalupe Rojas (Eds.), Insects as Sustainable Food: Production, Processing and Food Appplication, Elsevier, Amsterdam, 2016, pp. 61–84.
[130] F.A. Manditsera, P.A. Luning, V. Fogliano, C.M.M. Lakemond, Effect of domestic cooking methods on protein digestibility and mineral bioaccessibility of wild harvested adult edible insects, Food Res. Int. 121 (2019) 404–411.
[131] O.R. Madibela, T.K. Seitiso, T.F. Thema, M. Letso, Effect of traditional processing methods on chemical composition and in vitro true dry matter digestibility of the Mophane worm (*Imbrasia belina*), J. Arid Environ. 68 (2007) 492–500.
[132] R. Caparros Megido, C. Poelaert, M. Ernens, M. Liotta, C. Blecker, S. Danthine, F. Francis, Effect of household cooking techniques on the microbiological load and the nutritional quality of mealworms (*Tenebrio molitor* L. 1758), Food Res. Int. 106 (2018) 503–508.
[133] C. Poelaert, F. Francis, T. Alabi, R. Caparros Megido, B. Crahay, J. Bindelle, Y. Beckers, Protein value of two insects, subjected to various heat treatments, using growing rats and the protein digestibility-corrected amino acid score, J. Insects Food Feed 4 (2018) 77–87.
[134] B. Fu, T.P. Labuza, Shelf-life prediction: theory and application, Food Control 4 (1993) 125–133.
[135] G. Ssepuuya, R.O. Aringo, I.M. Mukisa, D. Nakimbugwe, Effect of processing, packaging and storage-temperature based hurdles on the shelf stability of sautéed ready-to-eat *Ruspolia nitidula*, J. Insects Food Feed 2 (2016) 245–253.
[136] A. Borremans, S. Lenaerts, S. Crauwels, B. Lievens, L. Van Campenhout, Marination and fermentation of yellow mealworm larvae (*Tenebrio molitor*), Food Control 92 (2018) 47–52.
[137] E. Kamau, C. Mutungi, J. Kinyuru, S. Imathiu, C. Tanga, H. Affognon, S. Ekesi, D. Nakimbugwe, K.K.M. Fiaboe, Moisture adsorption properties and shelf-life estimation of dried and pulverised edible house cricket *Acheta domesticus* (L.) and black soldier fly larvae *Hermetia illucens* (L.), Food Res. Int. 106 (2018) 420–427.
[138] S. Singh, R. Shalini, Effect of hurdle technology in food preservation: a review, Crit. Rev. Food Sci. Nutr. 56 (2016) 641–649.
[139] OJEU, Regulation (EU) No 2015/2283 of the European Parliament and the council of 25 November 2015 on novel foods, amending Regulation (EU) No 1169/2011 of the European Parliament and of the Council and repealing Regulation (EC) No 258/97 of the European Parliament and of the Council and Commission Regulation (EC) No 1852/2001, Off. J. Eur. Union L (2015) 327/1.
[140] IPIFF, EU Novel Food Legislation. The International Platform of Insects for Food and Feed, http://ipiff.org/insects-novel-food-eu-legislation/, (2019) Accessed 20/09/19.
[141] K. Merten-Lentz, C. Commandeur, Edible Insects in the EU: The Long Road to Legalization, https://www.foodnavigator.com/Article/2018/11/07/Edible-insects-in-the-EU-the-long-road-to-legalisation, (2018) Accessed on 20/09/19.
[142] S. Mancinia, R. Moruzzoa, F. Ricciolia, G. Paci, European consumers' readiness to adopt insects as food. A review, Food Res. Int. 122 (2019) 661–678.
[143] M. Shelomi, Why we still don't eat insects: assessing entomophagy promotion through a diffusion of innovations framework, Trends Food Sci. Technol. 45 (2015) 311–318.