African Journal of Rural Development, Vol. 4 (2): Apri-June 2019: pp. 185-202. ISSN 2415-2838

Can insects save humanity?

M. MAHLANGU*, R. FOLIGNI and M. MOZZON
Università Politecnica delle Marche, Department of Agricultural, Food and Environmental Sciences, Via Brecce Bianche 10, 60131, Ancona, Italy
***Corresponding author:** makhosimahlangu@yahoo.com

ABSTRACT
With an increase in the global population and the need to avail new arable land, there is a need to look for alternative farming systems that are sustainable. The production of protein from macro-farming units is becoming unsustainable. To add to this demeanor is the food waste debacle. The present review evaluates the insect industry holistically from the growth of the insects to harvesting and processing, to using insects in food waste reduction, to the production of bioactive ingredients from insects, to food safety issues regarding entomophagy, and to consumer acceptance of the insects. The authors highlight the potential of using insects as future food and feed component and evaluate the stronger sustainability of protein production through insect farming. Entomophagy is a global culinary trend dominant in Africa, America, and Asia. With increased migration, the use of insects has to be seriously evaluated in markets not readily accepting them. The use of insects in the feed also offers a potential for sustainable protein utilisation, considering that soybean protein and fishmeal are becoming difficult to use as a protein source due to costs and unsustainable production methods. The future for the insect industry looks positive from all fronts.

Keywords: Bioactive compounds, entomophagy, food waste, insects, novel food, Tenebrio molitor

RÉSUMÉ
Avec l'augmentation de la population mondiale et la nécessité de disposer de nouvelles terres arables, il est nécessaire de rechercher des systèmes agricoles alternatifs durables. La production de protéines à partir d'unités macro-agricoles devient insoutenable. Ajouter à ce comportement est la débâcle du gaspillage alimentaire. La présente revue évalue l'industrie des insectes de manière globale, de la croissance des insectes à la récolte et à la transformation, à leur utilisation dans la réduction des déchets alimentaires, dans la production d'ingrédients bioactifs, aux problèmes de sécurité alimentaire concernant l'entomophagie et à l'acceptation des insectes par les consommateurs. Les auteurs mettent en évidence le potentiel d'utilisation des insectes comme futurs composantes de l'alimentation humaine et animale et évaluent la durabilité plus forte de la production de protéines par l'élevage d'insectes. L'entomophagie est une tendance culinaire mondiale dominante en Afrique, en Amérique et en Asie. Avec une migration accrue, l'utilisation d'insectes doit être sérieusement évaluée sur les marchés qui ne les acceptent pas facilement. L'utilisation d'insectes dans l'alimentation animale offre également un potentiel d'utilisation durable des protéines, étant donné que les protéines de soja et la farine de poisson deviennent difficiles à utiliser comme source de protéines en raison des coûts et des méthodes de

Cite as: Mahlangu, M. Foligni, R. and Mozzon, M. 2019. Can insects save humanity? *African Journal of Rural Development* 4 (2): 185-202.

Received: 13 Febraury 2019
Accepted: 15 April 2019
Published: 30 June 2019

production non durables. L'avenir de l'industrie des insectes semble positif sur tous les fronts.

Mots-clés: Composés bioactifs, entomophagie, déchets alimentaires, insectes, nouvel aliment, Tenebrio molitor

INTRODUCTION

Trends towards 2050, predict a steady population increase to 9 billion people, forcing an increased food/feed output from available agro-ecosystems resulting in even greater pressure on the environment. Scarcities of agricultural land, water, forest, fishery, and biodiversity resources, as well as nutrients and non-renewable energy, are foreseen. Thus, transformation of organic by-products into edible insects could improve food availability (Pimentel and Pimentel, 2003; McLeod, 2011; Van Broekhoven *et al.,* 2015; Davis *et al.,* 2016). According to Davis *et al.* (2016), the United States agricultural sector consumes about 77% of all water used which presents insects as an alternative to conventional farming techniques There has been an increasing concern related to climate change, volatile food prices, growing food insecurity and greenhouse emissions from agriculture, with insects offering a solution to future sustainable food production systems, with low carbon footprints (Paloviita and Järvela, 2015). To achieve global food security, there has to be a paradigm shift to alternative diets which include an increase in insect consumption and a reduction in food waste. The planet has to be fed nutritionally sufficient diets but which should not be at the cost of the environment (Papargyropoulou *et al.,* 2014). The rapid growth of the human population may lead to consumption of traditional sources of animal proteins, such as poultry, beef, and pork, becoming unsustainable, hence a need to shift to other forms of protein sources such as insects (Caparros Megido *et al.,* 2014). Insects are a popular component of the diet of a third of the human population (Miglietta *et al.,* 2015). Insects are of paramount importance in the survival of humankind, playing vital roles as the main pollinators in plant reproduction. There are three fundamental characteristics of insect use, that is: (1) diversity of insect use in daily life, (2) the awareness and use of insects in places where human activity and the natural environment merge, and (3) the role of insects in socio-cultural communication (Nonaka, 2009).

Global warming is also impacting negatively on the production of animal protein, due to diminishing pastures and a broadening demand-supply gap for animal feed protein (Premalatha *et al.,* 2011). This has motivated experts to evaluate food production systems, with particular emphasis on protein production. Forest insects are numerous with the exact number of specie not quantified (Varelas and Langton, 2017). There are estimated to be about 10^8 (10 quintillion) individual insects alive at any given time in the world, with rapid reproduction rates and high fecundity (Durst and Shono, 2010; Schabel, 2010). Edible and non-edible insects are key forms of forest ecosystems. They function as pollinators, aerators of the soil through burrowing, decomposers of dead plants and animals producing valuable products such as honey and silk; being used in medical therapy such as maggot therapy; in biocontrol of harmful pest species and to improve soil fertility through waste bioconversion (Van Huis *et al.,* 2013). Insects are important food sources for residents of the forest such as reptiles, fish, birds and to some plants like the carnivorous Venus flytrap (Meyer-Rochow, 2010). Many forest invertebrates including molluscs, annelids, crustaceans, arachnids, and insects have been traditionally consumed by various communities (Schabel, 2010). As edible insects are rich sources of nutrients (e.g. proteins), they help improve food security in specific communities and also provide much-needed revenue (Durst and Shono, 2010).

Colonial invaders frequently dismissed entomophagy as a primitive or barbaric practice, implying superiority of their own culture and food, while they themselves relished other invertebrates such as molluscs as gourmet food (Schabel, 2010). In Western Europe, the consumption of insects is not readily accepted, often viewed with disgust and association with primitive societies (Caparros Megido *et al.,* 2014). Entomophagy is heavily influenced by cultural and religious practices and varies with an ethnic group, insect populations and location (Meyer-Rochow, 2010; van Huis *et al.,* 2013; Si and Turpin, 2015). In Africa, India, Persia, and Arabia, locusts have been consumed as an alternative protein source, with their preparations varying according to location, with methods such as boiling, frying and grinding to cake mixes, being prevalent (Ghaly and Alkoaik, 2009). How insects became human food cannot be determined with certainty. One suggestion is that the harvesting of wild honey led to honey collectors eating bee brood (eggs, honey, larvae and pupae in the hive) as a source of protein. This may have led to the sampling of other insect larvae and pupae. This may have overtime provided ritual, normal and emergency food sources (Meyer-Rochow, 2010).

Insects are consumed even when other forms of protein are available, with three-quarters of people eating insects as a snack and viewing them as being tasty (Yen *et al.,* 2010). The cost of insects is higher in parts of Central Africa as compared to alternative sources of animal protein like beef, with insects providing up to 50% of dietary proteins (Raubenheimer and Rothman, 2013; Dobermann *et al.,* 2017). People in Zambia consider the mopane worm (*Gonimbrasia belina*), the caterpillar of the saturniid moth, tasty as meat (Nonaka, 2009). The most common edible insects are the beetles and constitute about 31% of the total of all consumed insects (Figure 1).

The paper presents an updated review of the literature on the insect industry and discusses the future prospects of insect farming as a sustainable initiative as compared to conventional farming techniques.

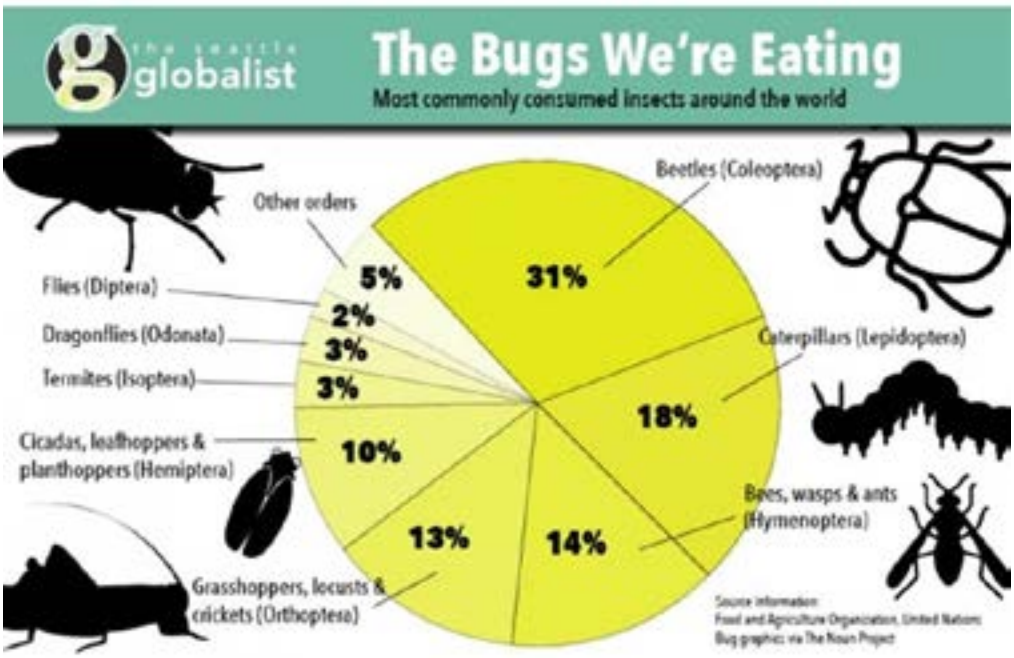


Figure 1. The most consumed insects globally

Consumption of insects. Insects are important in the diets of many nations (Mlcek *et al.,* 2014). Insects are consumed at various stages of growth with ants being consumed right across the lifecycle. Ants can be consumed as eggs, pupae and as adults. Silkworms are consumed at both the larval and the pupal stage. Aquatic insects such as water scavenger beetles, predaceous diving beetles, and dragonflies are eaten at the nymphal stage (Yen *et al.,* 2010). In some African countries, there are often restrictions on the consumption of insects with larvae being reserved for the dignitaries and the wealthy (Paoletti *et al.,* 2000; Meyer-Rochow, 2010).

Cultures where insects have been consumed traditionally often exhibit a greater food insect resilience than cultures in which the consumption of insects has had little or no effect, as traditional and local food cuisines (Meyer-Rochow, 2010). Entomophagy, although in its infancy in developed countries, could act as an alternative source of quality nutrients and proteins (Verkerk *et al.,* 2007). Insects form a regular part of diets as a side dish, snack or ingredient of composite dishes, whenever available during the year (Bukkens, 1997). Insects might aid in alleviating global hunger and malnutrition (Durst and Shono, 2010). In some developing countries with growing middle classes and upper classes, often individuals consume insects as a "Nostalgia food", often reminding them of earlier or their days on the countryside (Durst and Shono, 2010).

Americas and Africa have the highest number of insect species eaten as food (Meyer-Rochow, 2010). Approximately 470 species of insects are eaten in Africa, with the Central African region being the most important hotspot for having a culture of entomophagy. The common insects consumed are of the order *Coleoptera, Orthoptera,* and *Lepidoptera* (Kelemu *et al.,* 2015). Four main types of insects are consumed in Southern Africa that is termites, caterpillars, and stinkbugs (Nonaka, 2009). In Southern Africa, there are occasional swarms of red locusts, which cause severe crop damage. With no methods of deterring the swarms, the insects are collected for food and dried. They are sometimes sold in local markets. The dried locusts can be fried in a pan with oil, salt, herbs, and onions. Tomatoes are sometimes added and served with maize meal (Nonaka, 2009). The biggest problem with measuring the consumption of insects is that insects are seasonal and often observers of entomophagy are either curious or simply repulsive. This makes indigenous populations conceal their consumption of insects (Posey, 1987; DeFoliart, 1989; Bukkens, 1997; Nonaka, 2009).

At any given time the dynamics of interchange of culinary dishes between different ethnic groups often leads to some foods going out of fashion, with other foods being established and becoming fashionable. Cultures mostly affected by this dynamic culinary interchange include cultures involved in trade, cultures with external links and cultures which accommodate new ideas (Meyer-Rochow, 2010). The isolation and degree of openness of a culture affect the balance between newly arriving food items (or food preparation methods) and long-established practices threatened by new arrivals (Meyer-Rochow, 2010). Table 2 shows the global insect consumption per continent.

In Thailand, local people do not consume edible insects because of them being environmental-friendly or nutritious or being cheaper than other meat cuts like poultry and meat. Rather they consume insects because they taste good (Durst and Shono, 2010). Healthy insects must be caught alive and processed immediately. Usually, the wings, intestines, and exoskeleton are removed before cooking (Yen *et al.,* 2010). China, for instance, consumes 178 insect species with the preparation of edible insects including roasting, boiling, frying, stewing after frying, stewing and braising, with insects being consumed as eggs to adults. Consumption of insects is traced back to ancient times in China (Chen *et al.,* 2009; Feng *et al.,* 2018). In Thailand over 50 species of insects are consumed, with the most popular insects being bamboo worms, locusts, beetles, silkworm pupae, crickets, and red ants. Common cooking methods include roasting and frying (Yhoung-Aree *et al.,* 1997). Insects often have foul smells and to mask off the smell, numerous herbs can be used such as chilli, basil leaf, garlic and lemongrass (Yen *et al.,* 2010).

Insects provide animal protein, essential amino acids, and micronutrients to the population (Bukkens, 1997; Kouřimská and Adámková, 2016). Insects are highly nutritious containing high fat, protein, vitamins, fibre, and mineral content. The metamorphic stage, diet, and habitat in which it lives, of the insect, also affect the nutritional value of the insects (Bukkens, 1997; Schabel, 2010; Van Huis *et al.,* 2013; Kouřimská and Adámková, 2016). Mealworms (*Tenebrio molitor*) have been used as a protein source for domestic animals and for human consumption (Ravzanaadii *et al.,* 2012). Mealworms contain all the 20 amino acids and offer a good nutritional profile (Bukkens, 1997; Van Huis *et al.,* 2013; Miglietta *et al.,* 2015). The omega-3 and six fatty acids in mealworms are comparable with those of fish, being higher than in cattle and pigs (Bukkens, 1997; Van Huis *et al.,* 2013). Table 1 shows the nutrient composition between fishmeal, commercial meal and various insect meals. The vitamin, protein and mineral content of the mealworms is similar to that in fish and meat (Van Huis *et al.,* 2013).

One hundred grams of dried caterpillars contain 52.9 g of proteins, 15.4 g of fats, 16.9 g of carbohydrates and have an energy value of 430 kcal. They are also rich in minerals and vitamins (Meyer-Rochow, 2010). Caterpillars provide macrominerals such as chlorides, calcium, magnesium, phosphorus, potassium, sodium, and sulphur. They also contain trace minerals such as cobalt, copper, iron, iodine, fluorine, manganese, molybdenum, nickel, selenium, vanadium and zinc (Ramos-Elorduy, 2002; Vantomme *et al.,* 2004). Caterpillars are also rich in vitamins B_1, B_2 and B_6 whilst bee brood (pupae) is rich in vitamins A and D (Ramos-Elorduy *et al.,* 1997; Schabel, 2010).

The majority of edible insects are rich in calcium, potassium, iron, and magnesium (Ramos-Elorduy *et al.,* 1997). The consumption of bee combs with all their components including immature stages of the bees provides the ultimate food and health supplement in terms of calories and a balance of calories and a balance of proteins, carbohydrates, fats, vitamins, minerals and purported medicinal properties (Schabel, 2010). House crickets (*Acheta domesticu*s) were fed to rats and outperformed soy protein as a source of amino acids at all levels of intake (Finke *et al.,* 1989).

Production and processing of insects. Insects are mostly collected in the wild in most communities consuming them, and the industrial production of insects is carried out in countries such as Thailand. The quantity and species of edible insects collected in the wild depends on the season and location (Yen *et al.,* 2010). Edible insects can be a reflection of rich biodiversity and are regarded as cultural resources. They are a source of alternative food in remote or mountainous areas (Nonaka, 2009). The most commonly eaten insect forms are larvae and pupae, which require little or no processing before they are, consumed (Meyer-Rochow, 2010). Almost the entire insect can be processed into food (Meyer-Rochow, 2010). The capturing, processing, transportation and marketing of edible insects globally provides necessary income and livelihood to numerous people and societies. Processing of insects is usually locally based and often under-recognized with little documentation and traceability (Durst and Shono, 2010). In Southern Africa when the caterpillars emerge, the caterpillars are picked one by one by hand from trees and processed to dry (Nonaka, 2009). In Thailand, simple mass rearing techniques have been developed on a commercial scale for several edible insects species such as ants, crickets and bamboo caterpillars. This provides additional income for farmers (Yen *et al.,* 2010). In some African societies, forest bees and caterpillars often generate money which often exceeds common agricultural crops with both insects requiring far less labour compared to conventional farming systems (Munthali and Mughogho, 1992, Vantomme *et al.,* 2004). Mealworms contain a high amount of fat which could be used as a future commercial oil source (Ghosh *et al.,* 2017).

In New Guinea, the Sago palm (*Metroxylon sagu*) is a prime source of insects. People eat adult palm weevil and larvae (grubs). One or

Table 1. The nutrient composition of Fishmeal, commercial meal and various insect meals

	Unit	Fishmeal	BSF	Mealworm	Superworm	Housefly
Dry Weight	%	25	44	39	42	25
Crude Protein	%DW	75	42	53	47	50
Crude Fibre	%DW	1	7	12	9.3	6
Ash	%DW	14	21	3	2.4	10
Fat	%DW	10	35	39	42	12
Gross Energy	MJ/kgDW	22	22	27	25	23
Calcium	g/kgDW	26	76	23	25	5
Phosphorus	g/kgDW	22	9	8	6	16
Pottasium	g/kgDW	12	7	9	8	6
Sodium	g/kgDW	11	1.3	0.9	1.1	5
Magnesium	g/kgDW	3	4	2.3	1.2	3.4
Manganese	mg/kgDW	10	246	15	22	91
Zinc	mg/kgDW	99	108	144	83	119
Copper	mg/kgDW		6	21	15	27
Iron	mg/kgDW		1370	89	92	995

Table 2. Global insect consumption by continent

Continent	Number of species recorded	Percent of total	Number of consuming countries
Asia	349	20	29
Australia	152	9	14
Africa	524	30	26
Americas	679	39	23
Europe	41	2	11
Total	1745	100	103

two months before a feast, men cut sago palms, specifically for grub production and notch the logs so that the weevils can readily deposit their eggs. This allows grubs to convert the smaller quantities of starch into protein and fat, exploiting an efficient manner of yields from low-yield sago palms (Meyer-Rochow, 2010). There is a huge gap between scientific studies and indigenous gatherers of insects because most gatherers do not know sustainable levels of insect resource management. Overexploitation of insects creates pressure on natural resources due to high prices (Ramos-Elorduy, 2006).

Two principal harvesting techniques are employed in Africa in attaining edible caterpillars (*Imbrasia* spp. and *Anaphe* spp.). The first method involves hand-harvesting the caterpillars from the ground, from the branches, from the trunks and leaves of the trees. The second method involves cutting individual branches and the harvesting of the caterpillars. After being purged the caterpillars are washed and cooked and then preserved using sun-drying and smoking techniques (Meyer-Rochow, 2010). Smoked caterpillars can be stored for up to three months (Meyer-Rochow, 2010).

The potential of using insects on food waste. Food waste has global implications on the environmental, economic and social dynamics of modern society (Papargyropoulou *et al.,* 2014). The majority of food waste is created at the consumer level, with a total of about 33% of food lost across the entire food chains (Davis *et al.,* 2016). To resolve the food waste debacle, there needs to be the adoption of a sustainable production and consumption approach, and tackle food surplus and waste in the global food supply chain (Papargyropoulou *et al.,* 2014). Mealworms can be grown on organic waste (Van Broekhoven *et al.,* 2015). The advantages of growing mealworms include easy rearing, short life cycle, a good proportion of essential amino acids and a promising protein source (Ghaly and Alkoaik, 2009). Insects are effective in the degradation of food waste through ingestion and being less effective in the reduction of the volatile solid (VS) and carbon content (Pastor *et al.,* 2015). Various factors affect the production of larvae from vegetable waste, such as the quantity of vegetable waste produced; regularity of supply of vegetable waste; the type of vegetable waste; the quality of the vegetable waste and environmental conditions when waste is generated (Carruthers, 2014). In terms of waste management, mealworms can be used to convert waste into proteins. Waste can be viewed as a valuable resource, to produce the protein of the future (Toca, 2017). Vegetable waste is seasonal and coincides with the period over which the crop is harvested (Carruthers, 2014).

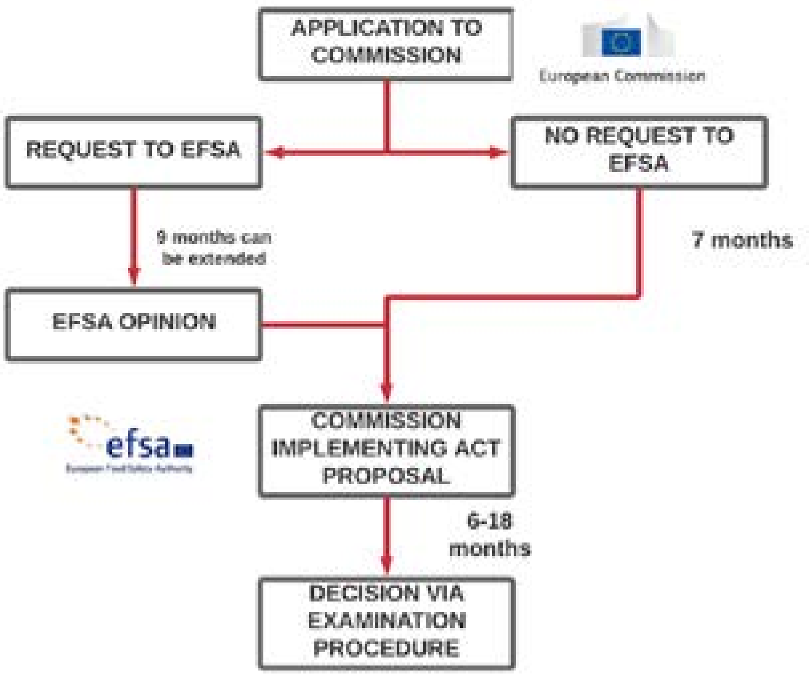
The forestry industry produces large quantities of organic waste which is often discarded. Forest biomass waste could be used as a new substrate for insect rearing (Varelas and Langton, 2017). This is especially so since edible insects contribute to all four categories of ecosystem services as outlined by the Millenium Ecosystem Services definition: regulating, provisioning, maintaining and cultural services (Payne and Van Itterbeeck, 2017).

Production of bioactive compounds from insects. The processing of products from oil, chitin and insect protein powder and the development of healthcare foods has been studied in China (Feng *et al.,* 2018). Insects are rich in high-quality proteins, bioactive compounds and other nutrients (Sun-Waterhouse *et al.,* 2016). Insects have the ability to sequester and produce allelochemicals and phytochemicals. Chemicals responsible for repellency and toxicity can be acquired through two different ways, i.e., automatic production of defence chemicals and the sequestration of phytochemicals directly from the plant providing the food. This provides the possibility of developing new novel drugs and pesticides (Blum, 1994; Uddin *et al.,* 2008; Elemo *et al.,* 2011; Marco *et al.,* 2013; Musundire, 2014; Shi *et al.,* 2014). Recent studies on the bioactive characterization of insects have been carried out. Shi *et al.* (2014) found four new norepinephrine derivatives from *Aspongopus chinensis*. The bioactive compounds were tested against renal protection in high-glucose-induced mesangial cells and COX-2 inhibition. *Aspongopus chinensis* is widely distributed in China and is used as a medicine for cancer, erectile dysfunction and pain. Eight new compounds were identified (Shi *et al.,* 2014). *Encosternum delegorguei* extracts display free radical scavenging characteristics and offer a potential source of natural antioxidants (Musundire, 2014).

Folk and traditional insect medicines (entomotherapy and entomoprophylaxis) have been used extensively around the world (Schabel, 2010). There are traditional claims from communities in Africa, who consume and assert the medicinal role of consuming the insects. Some assumed medicinal properties of these insects include aiding in digestive systems, acting as appetizers, enhancing sexual desires and cure of asthma and heart diseases (Musundire, 2014).

Insects also contain chitin as their building blocks, which is a biopolymer with interesting applications in agriculture, medicine, and industry (Costa-Neto, 2005). Chitin is sensed in the gastrointestinal tract and lungs, where it can activate the innate immune system through eosinophils and macrophages (Komi *et al.*, 2018).

Production of novel food products from insects. A novel food is described by the European Union as a food commodity which has not been consumed to any significant degree in the EU before 15 May 1997. This includes innovative food, newly developed food or food produced using new technologies, as well as food traditionally eaten outside of the EU, according to Novel Food Regulation (EU) 2015/2283 (Figure 2).



Humans are also utilizing a fraction of the full food potential of their environment, offering insects a potential in the food market (Meyer-Rochow, 2010).

There are numerous products being developed from insects which cannot be categorised into specific functional groups. Novel foods that have been recently developed include cocktail bitters made from crickets; burgers from bugs; cricket-tofu; seasonings like Sal de Gasuno in Mexico; insect nuggets and schnitzels; cricket enriched tomato sauce and mealworm oil (Engström, 2018). In developed countries, the consumption of edible insects offers novelty and a form of snack food. In countries such as Germany and the United States, various foods have been offered to adventurous eaters like maggot ice cream and seasoned larvae (Meyer-Rochow, 2010). The ultimate goal is to elevate certain edible insects to gourmet food status. If this is accomplished, demand will follow (Meyer-Rochow, 2010).

Oils and lipids from edible insects. The fat content of insects ranges between 10 to 50%, with edible insects being rich in fat, for species such as termites (Naughton *et al.,* 1986; DeFoliart, 1991). The fat content varies depending on the growth stage with the larva and pupa stages having higher fat contents compared to the adult stage (Chen *et al.,* 2009). There is a significant difference between the SFA 15:0, 16:0 and 18:0, between Coleoptera and Orthopetera due to differences in the stage of growth (Ng *et al.,* 2016). Insects have higher essential fatty acids compared to animal fats (Chen *et al.*, 2009). The fatty acid composition is highly dependent on the diet being fed (Stanley-Samuelson *et al.,* 1988). Lipids have a structural and biological function in the body and also assist in the transportation of essential fat-soluble vitamins (Feingold and Elias, 2014; Ng *et al.,* 2016). Insects contain a good lipid profile containing omega-3 fatty acids such as alpha-linolenic acid and eicosapentaenoic acid (Yang *et al.,* 2006). The most abundant MUFA, PUFA, and SFA in insects were C18:1 cis 9, C18:2 cis 9,12 and C16:0 (Osimani *et al.,* 2017). DHA is important for the growth and function of the nervous tissue. Reduced DHA is associated with impairments in behavioural and cognitive performance which are important in brain development. The role of DHA is in neurotransmission, neurogenesis, and protection against oxidative stress (Innis, 2007). DHA is also involved in retinal function (Jeffrey *et al.,* 2001; Viciano *et al.,* 2017). A few insects are able to produce biologically active compounds from dietary PUFAs (Stanley-Samuelson *et al.,* 1988).

Food safety issues with edible insects. While the nutritional, medicinal and numerous merits of entomophagy generally support the consumption of insects, one should not overlook food safety and sustainable harvesting of the insects (Schabel, 2010). Insects collected from the forests are generally considered clean and free of chemicals and also considered “health foods” in some societies. Some insects also have beneficial medicinal properties (Durst and Shono, 2010). Insects also obtain their nutrients mostly from flora and fauna in the forest and the insect may in some instance become poisonous because of the chemical composition of its food. Polyphagous insects such as *Zonocerus* spp. can sequester more than one phytochemical depending on the toxicity of the plant (Schabel, 2010). Some insects may produce toxic bioactive compounds. They may also contain residues of heavy metals and pesticides from the ecosystem (Kouřimská and Adámková, 2016).

The use of farmed insects as a novel protein source has raised the question of the safety of insects as human food and as animal feed by the European Union (E.U) Commission through a mandate to the European Food Safety Authority (EFSA) (Finke *et al.,* 2015). The possible presence of biological and chemical hazards in food and feed products derived from insects would depend on the production methods, what the insects are fed on (substrate), the lifecycle stage at which the insects are harvested, the insect species, as well as the methods used for further processing. Some researchers have found that insects are natural carriers of microorganisms with various microflora found in edible insects (Osimani *et al.,* 2017). Microorganisms found in edible insects include *Vibrio, Acinebacter, Streptomyces, Agrococcus, Aspergillus, Wallemia, Eurotium, Tetrapisispora, Loktanella, Escherichia, Pediococcus, Weissella, Athrobacter, Naxibacter, Rufibacter* and *Bacillus,* which can either be commensal or potentially pathogenic microorganisms (Osimani *et al.,* 2017). Insects can be dangerous and incidences of botulism have been recorded in Kenya and Namibia after consumption of termites kept in plastic bags for four days (Knightingale and Ayim, 1980; Schabel, 2010). High aflatoxin levels were documented in commercial lots of mopane worms (*Gonimbrasia belina*) in Botswana (Mpuchane *et al.,* 1996).

There have been documented allergic reactions to entomophagy such as malnourished individuals in Nigeria who consumed *Anaphe* spp. (Thaumetopoeidae) and were diagnosed with ataxic syndrome (Adamolekun, 1993). People in Mexico experienced headaches after consuming Eucheirasocialis (Pieridae) (Schabel, 2010). The allergy against locusts and grasshopper is more profound as compared to that of crickets. Cricket allergens are proteinaceous compounds mainly arginine kinase and hexamerin 1B (Pener, 2016). Some insects also require special capturing methods, preparation, storage and transportation methods to make them safe for consumption (Schabel, 2010).

National assessments have been conducted by other European Member States such as Belgium, France and the Netherlands (Finke *et al.,* 2015). At the other end of the edible insect spectrum, are insects which may cause serious health problems and sometimes leading to fatalities. Some poisonous insects may resemble edible insects. In some regions, the population may not be able to consume insects because of toxicity levels (Schabel, 2010). Misidentification of insects and consumption of poisonous species has been noted in societies in Thailand, after the consumption of insects such as the blister beetle (*Mylabris phalerata* Pall, Family Meloidae), which contains the toxic cantharidin substance (Yen *et al.,* 2010).

With the increasing number of consumers who are health conscious and sophisticated, there needs to be a method to standardise production methods to ensure nutritionally and safe quality insect foods (Durst and Shono, 2010). There is a need to reduce the adverse effects of pathogens from insects through transgenerational immune priming and the use of probiotics to ensure sustainable insect farming (Grau *et al.,* 2017).

Marketing and hindrances with the promotion of insects as a food and feed source. The demand for the development and commercialization of novel insect-based foods remains very low due to psychological and cultural barriers linked to eating insects, with Western societies less likely to accept insects as culinary dishes as compared to Eastern societies (Sun-Waterhouse *et al.,* 2016). The existing regulations in the European Union present hindrances and constitute legal barriers for the marketing of insects for food and feed (Finke *et al.,* 2015). Appropriate marketing of insects and their use in livestock feed can also improve the acceptance of insects as a food source, compared to unrealistic goals of using insects as an alternative protein source to meat (Shelomi, 2015). There are challenges with scaling up insect production whilst maintaining environmental benefits. The challenges are often related to unclear processing and storage methods; rearing practices and regulations involved in their safety when consumed by animals and humans (Dobermann *et al.,* 2017). The absence of large food cooperation's also hinders the growth of the insect food and feed industry (Han *et al.,* 2017).

People are intimidated by insects, with different remarks towards them such as being unhygienic, dirty, unhealthy and being disease transmitters. They do not like their appearance and are often intimidated by them, with women readily being disgusted by them (Van Huis *et al.,* 2013; Mlcek *et al.,* 2014; Kauppi, 2016).

Little is known about life cycles, management potential and population dynamics of many edible insects. There is also little knowledge on the impacts of overharvesting forest insects on the forest vegetation, ecosystems and other forest fauna. Globally various initiatives are used to destroy pests which often have high-quality animal protein of up to 75% to save crops with no more than 14% plant protein (Mlcek *et al.,* 2014). Forest managers have little appreciation for the potential of harvesting and managing insects sustainably. There is no scientific literature on manipulating harvest techniques and manipulating forest vegetation to sustain and maximise insect populations. Forest managers also consider insects as being destructive (Durst and Shono, 2010). A combination of recent scientific understanding of insect ecology with the knowledge of traditional management strategies will maximise benefits and minimise costs accrued by edible insects (Payne and Van Itterbeeck, 2017). Importantly, the absence of economic data could hinder the commercial development of edible insects (Meyer-Rochow, 2010).

To reduce the number of taboos related to insects, there has to be a scientific study on them. These include phobias and allergies towards certain insect species (Meyer-Rochow, 2009).

The future of the insect industry. Domestication of insects is limited to silkworms and bees (Meyer-Rochow, 2010). Fruit flies, mealworms, grasshoppers and crickets are being cultivated for use in consumer products. Various food products have captivated the public such as insect bars, insect candy, cricket flour and insect pasta (Cosgrove, 2017). World Edible Insect Day was initiated on the 23rd of October 2015 with the entrepreneurs in the insect being termed entopreneurs (Engström, 2018).

Hargol, which is a grasshopper farm, in Israel is currently working on improving production capacity, as demand is higher than supply (Cosgrove, 2017). In Mexico, certain insects such as escamoles, white agave worms, botija, axayacatl, vinitos and black wasp are in high demand (Ramos-Elorduy, 2006). Notable companies involved in protein-bars/ insect bars include: Exo (US); Chapul (US); Crickbar (Sweden); Jump Bars (Canada); Zoic Bar (UK); Instinct (Germany); Leader Zircca Bar (Finland); SEQ Foods (Netherlands); Swarm Protein (Germany); The Cricket Effect (Australia) and Jimini's (France) (Engström, 2018). In the production of protein-shakes/ nutrition supplements, the major producers are Bugeater Foods (US); CrikNutrition (Canada); Jurassic Snacks (US) and Sustainable Boost (US) (Engström, 2018). The major companies involved in the production of insect candy/ snacks/ crispbread include: Hotlix (USA); Snack Insects (Germany); Insecteo (France); Eat:em (Sweden); Wickled Cricket (Germany); Griinsect (Finland); Bugsnacks (Vietnam) and Wholi Foods (Denmark) (Engström, 2018).

Consumer food behavioural changes are influenced by political, economic, nutritional, safety, sustainability and availability factors (Carlucci *et al.,* 2015). Insect restaurants/ Insect Chefs/ Insect Catering are growing food trends with restaurants such as the Grub Kitchen (UK); Entomochef (Belgium); Don

Bugito (USA); Insect-o-shi (Netherlands); Bugs Café (Cambodia) and MasterBug (Italy), being involved in this gastronomic avenue (Engström, 2018).

As industrial livestock farming wrecks havoc on our environment and public health and our global population increases, we simply cannot continue to produce animal protein at our current rate. To satisfy the current meat consumer trends, there is a need to involve more industrious farming systems, which are often not environmentally sustainable (Miglietta *et al.,* 2015). This is not to say that we will not or should not be eating meat in the future, it just means that we will likely be getting our protein from a diversity of sources. The integration of insects into traditional protein diets will lead to a sustainable way of feeding the population (Premalatha *et al.,* 2011; Miglietta *et al.,* 2015). Modern food production systems have started incorporating insects as sources of protein due to a number of advantages, such as insects high fecundity, their very fast growth rates, the ability to absorb water from their food and their high efficiencies in converting phytomass into protein-rich animal biomass (Miglietta *et al.,* 2015).

Standardisation of mass-rearing techniques of mealworms is required to further develop the insect industry and make it a competitive industry against traditional protein industries (Kim *et al.,* 2016). The scientific identities and life cycle details of many forest insects are still not known. Activities such as forest degradation and clearing can affect the life cycle of insects. Insects account for the highest amount of diversity in forests but are the least studied of the biota (Meyer-Rochow, 2010). In communities in the Amazon basin, New Guinea and tropical Africa, there is the deliberate manipulation of the tree distribution to improve insect exploitation by increasing their availability and predictability. This is done through numerous methods such as deliberate tree cuttings, shifting cultivation, fire regimes, the manual introduction of insects and host tree preservation (Van Itterbeeck and van Huis, 2012).

Edible forest insects are closely related to the following fields: human nutrition (famine and ritual food); forestry; anthropology; agriculture; livestock rearing and traditional medicine. The individual disciplines are important in predicting the future of edible food insects (Meyer-Rochow, 2010). The creation of a wider market for food insects provides an economic incentive to conserve insects habitats (Durst and Shono, 2010). In the United States, the annual value of insects' services amounted to more than US$57 billion. Insects are food for wildlife, pollinate crops and support a pest control industry (Meyer-Rochow, 2010). In Mexico exporting from Apiculture have exceeded more than US$35 million per year (Ramos-Elorduy, 2006). The Democratic Republic of Congo exports five tonnes of dried caterpillars to France and three tonnes to Belgium (Meyer-Rochow, 2010). The price of edible insects is significantly higher as compared to traditional protein sources.

The consumption of insects in Europe and North America is highly unlikely. The possible solution will be to incorporate insect protein in supplements, processed food and animal feed. There needs to be an awareness on insect-eating with their potential contributions to the environment, livelihoods, and nutrition being fully relayed to the consumers (Durst and Shono, 2010; Kouřimská and Adámková, 2016). A number of impoverished people around the world could use harvesting, transporting and marketing of edible insects as a source of income and livelihood if the ecosystems are maintained at optimum production levels (Meyer-Rochow, 2010).

The future for edible insects looks bright considering that the industry has undergone more-sophisticated and far-reaching marketing, including advertising, attractive packaging and addressing food safety issues (Meyer-Rochow, 2010). Realizing the commercial potential of edible insects will rely on one of the following factors: adopting insect management techniques, expanding and intensification of edible insect harvests and a movement towards insect domestication and rearing (Meyer-Rochow, 2010). There is a need to develop "Edible Insects Exploitation and Trading Norms and Legislation" to reduce the gap between knowledge of the resources and their exploitation (Ramos-Elorduy, 2006). There is also a need to develop more contextual and precise terminologies and vocabularies for edible insects, in order for the scientific community to develop the industry further (Evans *et al.,* 2015).

Insects should be viewed as valuable food sources by the Western World either directly in the human diet or indirectly as an animal feed. Insects should not be viewed as pests that need to be destroyed (Meyer-Rochow, 2009). Despite the flush of publicity, it is highly unlikely that entomophagy will move into western mainstream cuisines. There is little evidence that suggests that caterpillars, pupae, grasshoppers, and grubs will be able to outcompete steaks and pork chops (Schabel, 2010).

The increase in migrations by nationalities from Asia, Central America and Africa may provide a platform for the growth of an edible insect sector, which may lure adventurous Western food enthusiasts. Europe has witnessed a surge in migrations from other continents in recent years (Schabel, 2010; Alscher, 2017). There has also been an increase in Ecotourism which combines nature appreciation with cultural dimensions, with some ecotourists trying edible insects to blend into societies naturally involved in entomophagy (Cerda *et al.,* 2005; Schabel, 2010). Cultural tastes and preferences can be changed with food such as lobsters and sushi to make it into the mainstream food industry (Bessa *et al.,* 2017).

The governments need to support the insect industry as lack of it, slows down research and development efforts. This affects areas such as youth development, consumer education, product development, and patent acquisition. A collaboration between industry and government will lead to the development of sophisticated food and feed products (Han *et al.,* 2017).

The benefits of entomophagy include poverty reduction through food security, income generation through the sale of insects, nutritional benefits, reduction of pesticide use and bio-conservation (Verbeke, 2015; Van Huis, 2017; Gamborg *et al., 2*018). There is a need for further scientific research to develop the insect industry (Mlcek *et al.,* 2014). In order to preserve the germplasm of alimentary ethnoentomobiodiversity and prevention of the erosion of the insect gene pool, there is a need to create reserve zones to protect and prohibit the collection of insects in these zones (Ramos-Elorduy, 2006; van Huis and Oonincx, 2017).

To determine the relative costs and benefits of agriculture that includes edible insects there is a need to conduct comparative life cycle analyses (LCAs) that compare the nutritional, environmental and economic outputs of grain-livestock systems and crop-insect agriculture (Payne and Van Itterbeeck, 2017).

CONCLUSION

Modern agricultural practices produce much food at unsustainable levels. With the current increase in the population, insects offer a new untapped industry. Insects can be used in various industries such as reducing food waste, sustainable agricultural production, production of bioactive compounds and also in entomophagy. Insect production although in its infancy could offer a modern new industry.

The use of insects in functional foods is a novel concept which requires further research on the type of substrates and industrial upscaling. There are various constraints towards the full potential of the insect industry, with such factors such as consumer acceptance, food safety concerns and the production of a viable industry. One thing remains certain with increased globalization and that is the six-legged insects will influence protein consumption by animals and humans in the future. Africa also needs to wake up from its slumber and control the production and processing of insects since they are the highest consumers.

ACKNOWLEDGEMENT

The authors acknowledege Universita Politecnica delle Marche (Italy) and EEZ-CSIC (Spain)

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Adamolekun, B. 1993. *Anaphe venata* entomophagy and seasonal ataxic syndrome in southwest Nigeria. *The Lancet* 341 (8845): 629.

Alscher, S. 2017. Knocking at the doors of "fortress Europe": Migration and border control in Southern Spain and Eastern Poland. UC San Diego Working Papers. pp.1-28.

Bessa, L. W., Pieterse, E., Sigge, G. and Hoffman, L. C. 2017. Insects as human food; from farm to fork. *Journal of the Science of Food and Agriculture.*

Blum, M. 1994. The limits of entomophagy: a discretionary gourmand in a world of toxic insects. *The Food Insects Newsletter* 7 (1):1-6.

Caparros Megido, R., Sablon, L., Geuens, M., Brostaux, Y., Alabi, T., Blecker, C., Drugmand, D., Haubruge, É. and Francis, F. 2014. Edible insects acceptance by Belgian consumers: promising attitude for entomophagy development. *Journal of Sensory Studies* 29 (1):14-20.

Carlucci, D., Nocella, G., De Devitiis, B., Viscecchia, R., Bimbo, F. and Nardone, G. 2015. Consumer purchasing behaviour towards fish and seafood products. Patterns and insights from a sample of international studies. *Appetite* 84: 212-227.

Carruthers, S. 2014. Production of fish feed from vegetable waste. *Practical Hydroponics and Greenhouses* 149: 18-22.

Cerda, H., Araujo, Y., Glew, R. and Paoletti, M. 2005. Palm worm (*Coleoptera,* Curculionidae: *Rhynchophorus palmarum*) a traditional food: examples from Alto Orinoco, Venezuela. pp.354-366. In: Ecological Implications of Minilivestocks, Paoletti, M.G. (Ed.), Science Publishers, Enfield

Chen, X., Feng, Y. and Chen, Z. . 2009. Common edible insects and their utilization in China. *Entomological Research* 39 (5):299-303.

Costa-Neto, E. M. 2005. Entomotherapy, or the medicinal use of insects. *Journal of Ethnobiology* 25 (1): 93-114.

Davis, S. C., Kauneckis, D., Kruse, N. A. K., Miller, E., Zimmer, M. and Dabelko, G. D. 2016. Closing the loop: integrative systems management of waste in food, energy, and water systems. *Journal of Environmental Studies and Sciences* 6 (1): 11-24.

DeFoliart, G. 1991. Insect fatty acids: similar to those of poultry and fish in their degree of unsaturation, but higher in the polyunsaturates. *The Food Insects Newsletter* 4 (1):1-4.

Dobermann, D., Swift, J. and Field, L. 2017. Opportunities and hurdles of edible insects for food and feed. *Nutrition Bulletin* 42 (4):293-308.

Durst, P.B. and Shono, K. 2010. Edible forest insects: exploring new horizons and traditional practices. pp. 1-4. In: Durst, P. B., Johnson, D.V., Leslie, R. L. and Shono, K. 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.

Elemo, B. O., Elemo, G. N., Makinde, M. and Erukainure, O. L. 2011. Chemical evaluation of African palm weevil, *Rhychophorus phoenicis*, larvae as a food source. *Journal of Insect Science* 11 (146):1-6.

Evans, J., Alemu, M.H., Flore, R., Frøst, M.B., Halloran, A., Jensen, A. B., Maciel-Vergara, G., Meyer-Rochow, V., Münke-Svendsen, C. and Olsen, S.B. 2015. 'Entomophagy': an evolving terminology in need of review. *Journal of Insects as Food and Feed* 1 (4): 293-305.

Feingold, K. R. and Elias, P. M. 2014. Role of lipids in the formation and maintenance of the cutaneous permeability barrier. *Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids* 1841 (3):280-294.

Feng, Y., Chen, X. M., Zhao, M., He, Z., Sun, L., Wang, C. Y. and Ding, W. F. 2018. Edible insects in China: Utilization and prospects. *Insect Science* 25 (2):184-198.

Finke, M. D., Rojo, S., Roos, N., van Huis, A. and Yen, A. L. 2015. The European Food Safety Authority scientific opinion on a risk profile related to production and consumption of insects as food and feed. *Journal of Insects as Food and Feed* 1 (4): 245-247.

Gamborg, C., Röcklinsberg, H. and Gjerris, M. 2018. Sustainable proteins? Values related to insects in food systems. pp. 199-211. In: Edible Insects in Sustainable Food Systems. Springer, Cham.

Ghaly, A. E. and Alkoaik, F. 2009. The yellow mealworm as a novel source of protein. *American Journal of Agricultural and Biological Sciences* 4 (4):319-331.

Grau, T., Vilcinskas, A. and Joop, G. 2017. Sustainable farming of the mealworm *Tenebrio molitor* for the production of food and feed. *Zeitschrift für Naturforschung C* 72 (9-10):337-349.

Han, R., Shin, J. T., Kim, J., Choi, Y. S. and Kim, Y. W. 2017. An overview of the South Korean edible insect food industry: challenges and future pricing/promotion strategies. *Entomological Research* 47 (3): 141-151.

Innis, S. M. 2007. Dietary (n-3) fatty acids and brain development. *The Journal of Nutrition* 137 (4):855-859.

Jeffrey, B. G., Weisinger, H. S., Neuringer, M. and Mitchell, D. C. 2001. The role of docosahexaenoic acid in retinal function. *Lipids* 36 (9):859-871.

Kauppi, H. 2016. Insect economy and marketing: How much and in what way could insects be shown in packaging? MSc. Thesis, Aalto University, Helsinki. 53pp.

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N. and Ekesi, S. 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. *Journal of Insects as Food and Feed* 1 (2):103-119.

Kim, S. Y., Kim, H. G., Lee, K. Y., Yoon, H. J., and Kim, N. J. 2016. Effects of agricultural byproducts, DDG and MSG, on the larval development of mealworms. *International Journal of Industrial Entomology* 32 (2): 69-79.

Knightingale, K. and Ayim, E. 1980. Outbreak of botulism in Kenya after ingestion of white ants. *British Medical Journal* 281 (6256):1682.

Komi, D. E. A., Sharma, L. and Cruz, C. S. D. 2018. Chitin and its effects on inflammatory and immune responses. *Clinical Reviews in Allergy and Immunology* 54 (2): 213-223.

Kouřimská, L. and Adámková, A. 2016. Nutritional and sensory quality of edible insects. *NFS Journal* 4: 22-26.

Marco, H. G., Šimek, P., Clark, K.D. and Gäde,

G. 2013. Novel adipokinetic hormones in the kissing bugs *Rhodnius prolixus, Triatoma infestans, Dipetalogaster maxima* and *Panstrongylus megistus*. *Peptides* 41:21-30.

McLeod, A. 2011. World livestock 2011-livestock in food security. Food and Agriculture Organization of the United Nations (FAO). FAO, Rome. 130pp.

Meyer-Rochow, V. 2010. Entomophagy and its impact on world cultures: the need for a multidisciplinary approach. pp.23-36. In: Forest insects as food: humans bite back. Durst, P. B. J., Dennis, V., Leslie, R. N. and Shono, K. (Eds.), RAP Publication, Bangkok, Thailand.

Meyer-Rochow, V. B. 2009. Food taboos: their origins and purposes. *Journal of Ethnobiology and Ethnomedicine* 5(1):18.

Miglietta, P. P., De Leo, F., Ruberti, M. and Massari, S. 2015. Mealworms for food: a water footprint perspective. *Water* 7(11):6190-6203.

Mlcek, J., Rop, O., Borkovcova, M. and Bednarova, M. 2014. A comprehensive look at the possibilities of edible insects as food in Europe–a review. *Polish Journal of Food and Nutrition Sciences* 64 (3):147-157.

Mpuchane, S., Taligoola, H. and Gashe, B. 1996. Fungi associated with *Imbrasia belina*, an edible caterpillar. *Botswana Notes and Records* 28 (1):193-197.

Musundire, R. 2014. Bio-active compounds composition in edible stinkbugs consumed in South-Eastern districts of Zimbabwe. *International Journal of Biology* 6 (3): 36-45.

Naughton, J. M., O'Dea, K. and Sinclair, A. J. 1986. Animal foods in traditional Australian aboriginal diets: polyunsaturated and low in fat. *Lipids* 21 (11): 684-690.

Ng, K., B. Stoll, S., Chacko, M., Saenz de, P., Lauridsen, C., Gray, M., Squires, E. J,. Marini, J., Zamora, I. J. and Olutoye,O.O. 2016. Vitamin E in new-generation lipid emulsions protects against parenteral nutrition–associated liver disease in parenteral nutrition–fed preterm pi*gs. Journal of Parenteral and Enteral Nutrition* 40 (5): 656-671.

Nonaka, K. 2009. Feasting on insects. *Entomological Research* 39 (5): 304-312.

Osimani, A., Garofalo, C., Milanović, V... Taccari, M., Cardinali, F., Aquilanti, L., Pasquini, M., Mozzon, M., Raffaelli, N. and Ruschioni, S. 2017. Insight into the proximate composition and microbial diversity of edible insects marketed in the European Union. *European Food Research and Technology* 243 (7):1157-1171.

Paloviita, A. and Järvelä, M. 2015. Climate change and food security: three case studies on uncertainty. pp. 35-47. In: Climate change adaptation and food supply chain management. Routledge.

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N. and bin Ujang, Z. 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production* 76:106-115.

Pastor, B., Velasquez, Y., Gobbi, P. and Rojo, S. 2015. Conversion of organic wastes into fly larval biomass: bottlenecks and challenges. *Journal of Insects as Food and Feed* 1(3):179-193.

Payne, C. L. and Van Itterbeeck, J. 2017. Ecosystem services from edible insects in agricultural systems: a review. *Insects* 8 (1): 1-24.

Pener, M. P. 2016. Allergy to crickets: a review. *Journal of Orthoptera Research* 25 (2):91-95.

Pimentel, D. and Pimentel, M. 2003. Sustainability of meat-based and plant-based diets and the environment. The *American Journal of Clinical Nutrition* 78 (3): 660S-663S.

Premalatha, M., Abbasi, T., Abbasi, T. and Abbasi, S. 2011. Energy-efficient food production to reduce global warming and ecodegradation: The use of edible insects.

Renewable and Sustainable Energy Reviews 15 (9):4357-4360.

Ramos-Elorduy, J. 2006. Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. *Journal of Ethnobiology and Ethnomedicine* 2 (1): 51-60.

Raubenheimer, D. and Rothman, J. M. 2013. Nutritional ecology of entomophagy in humans and other primates. *Annual Review of Entomology* 58:141-160.

Schabel, H. G. 2010. Forest insects as food: a global review. pp. 37-64. In: Durst, P. B. J., Dennis, V., Leslie, R. N. and Shono, K. (Eds.), Forest Insects as Food: Human bite back. RAP Publisher, Bangkok, Thailand.

Shelomi, M. 2015. Why we still don't eat insects: Assessing entomophagy promotion through a diffusion of innovations framework. *Trends in Food Science and Technology* 45 (2):311-318.

Shi, Y.-N., Tu, Z. C., Wang, X.L., Yan, Y.M., Fang, P., Zuo, Z. L., Hou, B., Yang,T. H. and Cheng, Y. X. 2014. Bioactive compounds from the insect *Aspongopus chinensis*. *Bioorganic and Medicinal Chemistry Letters* 24 (22):5164-5169.

Si, A. and Turpin, M. 2015. The importance of insects in Australian Aboriginal society: a dictionary survey. *Ethnobiology Lette*rs 6 (1):175-182.

Stanley-Samuelson, D. W., Jurenka, R. A., Cripps, C., Blomquist, G. J. and de Renobales, M. 1988. Fatty acids in insects: composition, metabolism, and biological significance. *Archives of Insect Biochemistry and Physiology* 9 (1):1-33.

Sun-Waterhouse, D., Waterhouse, G. I., You, L., Zhang, J., Liu, Y., Ma, L., Gao, J. and Dong, Y. 2016. Transforming insect biomass into consumer wellness foods: a review. *Food Research International* 89:129-151.

Toca, A. 2017. Rethinking waste streams: using food waste to rear mealworms. pp. 32-41. (Unpublished doctoral dissertation), KTH Royal Institute of Technology, Stockholm, Sweden

Uddin, S. N., Akond, M., Mubassara, S. and Yesmin, M. N. 2008. Antioxidant and antibacterial activities of *Trema cannabina*. *Middle-East Journal of Scientific Research* 3 (2): 105-108.

van Broekhoven, S., Oonincx, D. G., van Huis, A. and van Loon, J. J. 2015. Growth performance and feed conversion efficiency of three edible mealworm species (*Coleoptera*: Tenebrionidae) on diets composed of organic by-products. *Journal of Insect Physiology* 73:1-10.

van Huis, A. 2017. Edible insects. *Journal of Insects as Food and Fee*d 3 (2): 67-68.

van Huis, A. and Oonincx, D. G. 2017. The environmental sustainability of insects as food and feed. A review. *Agronomy for Sustainable Development* 37 (5): 43.

van Huis, A., van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P. 2013. Edible insects: future prospects for food and feed security. No. 171. Food and Agriculture Organization of the United Nations. 201pp. FAO, Rome, Italy

van Itterbeeck, J. and van Huis, A. 2012. Environmental manipulation for edible insect procurement: a historical perspective. *Journal of Ethnobiology and Ethnomedici*ne 8 (1): 1-7.

Varelas, V. and Langton, M. 2017. Forest biomass waste as a potential innovative source for rearing edible insects for food and feed–A review. *Innovative Food Science and Emerging Technologies* 41:193-205.

Verbeke, W. 2015. Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. *Food Quality and Preference* 39: 147-155.

Viciano, E., Monroig, Ó., Barata, C., Peña, C. and Navarro, J. C. 2017. Antioxidant activity and lipid peroxidation in *Artemia nauplii* enriched with DHA-rich oil emulsion and the effect of adding an external antioxidant based on hydroxytyrosol. *Aquaculture Research* 48 (3):1006-1019.

Yang, L. F., Siriamornpun, S. and Li, D. 2006. Polyunsaturated fatty acid content of edible insects in Thailand. *Journal of Food Lipids* 13 (3): 277-285.

Yen, A., Hanboonsong, Y. and van Arnold, H. 2010. The role of edible insects in human recreation and tourism. The Management of Insects in Recreation and Tourism. pp.169-185.