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Edible Insects as the New Frontier in Nutrition for Sustainable Development

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Abstract

Edible insects have been part of the daily eating experience for people in many tropical countries, for thousands of years. The idea of looking at insects as food has been introduced also in more regions, being this habit spurred by a demand of growing immigrant communities in cities of the western hemisphere. Entomologists have described more than two thousand edible species, arguing that growing insects has more advantages besides improving nutrition and diets. For example, insects can be reared on organic substrates thus reducing environmental contamination, while adding value to waste generated during a production cycle. They emit less GHGs and ammonia (NH_3). They are high feed converters and require much less water than domesticated livestock species. They have few, or no animal welfare issues and pose minimal risks of transmitting zoonotic diseases. This work aimed at reviewing the status of edible insects in selected regions around the world, assessing their potential for human consumption and sustainability. Their employment for urban agriculture was considered also as a feasible market niche to supply consumers with an additional source of fresh, locally grown food. In addition to this, marketing strategies to overcome some consumers' resistance to eating insects, or foods containing insects were discussed.

Keywords: Agriculture; Education; Entomophagy; Foods; Nutrition; Sustainable Development

Abbreviations: CAFOs: confined animal farming operations; LCA: lives cycle assessment; FAO: Food and Agriculture Organization; PAPs: Processed Animal Proteins

Introduction

Insects have played a significant role in people's diet around the world for millennia [1,2] and entomophagy, the habit of eating insects, is still being practiced by about two billion people [3] across nations' boundaries and cultures. Despite an antagonistic role that some of these arthropods play as foes of agricultural crops, or for parasitizing farm animals and humans [4], insects have become species of interest for their potential in providing high-protein food for human and livestock [5,6]. Present challenges for increasing agricultural outputs to satisfy the food needs of a growing human population have made insects attractive to investors and entrepreneurs who envision developing further this specific segment of the agroindustry [7-9]. However, a pervasive reluctance toward consuming insects, or insect products in most countries of the industrial, western hemisphere remains contrary toward accepting insects for consumption [10] More resistive challenges about this issue are dealing with the safety of insects' consumption [11] and an overall perception of "grossness" for entomophagy [12], including neophobia [13].

A maximization of crops yields achieved with an industrialization of agriculture, through supportive policies, governmental subsidies, genetic engineering (GE) and more advanced technologies, has proved to be lucrative for the agroindustry yet, unsustainable for mitigating inequalities about food access and distribution [14]. Top-down agendas to produce more food for a growing population continue to be promoted by many governments through generous financial support to achieve further intensification of agriculture. To fulfill increasing food needs worldwide and make insect farming a potentially viable resource to satisfy such demand, Belluco and his collaborators [11] conceded that an extension of insect foods shelf-life constituted a legitimate need to be pursued. It is important to understand that besides food, insects also provide a variety of products and ecological services that possess distinctive, economic values (Table 1). Insects' products and services are beneficial to multifunctional farming systems, making persuasive the case for enhancing insect conservation efforts in agriculture, while relaxing approaches directed toward their eradication

[15,16]. According to van Huis and others [9], an employment of insects as food yields a significant number of advantages, as these:

➢ Require much less water than cattle, pigs, chickens, and other domestic animals.

➢ Have no animal welfare issues that may obstruct insect farming.

➢ Pose a limited risk of transmitting zoonotic diseases.

➢ Possess a high feed-conversion efficiency ratio (FCR).

➢ Can be farmed on organic substrates/biomass thus, reducing environmental contamination, while adding value to waste generated during a production cycle [6].

➢ Emit a limited amount of GHGs and relatively little ammonia [17].

Table 1: Insect products and their use. Adapted from [8]

Product	Source	Product Use
Cochineal (carmine)	This is a dye produced by scale insects *(Dactylopius coccus)* and it is used in the food, textile, and pharma industries. Chile, Ecuador, Peru, Bolivia are producers.	Starbuck Coffee Co. Strawberry Frapuccino). Danone strawberry yogurt, Campari aperitif. Brazil, Germany, USA, France buy carmine.Brazil, Germany, USA, France buy carmine.
Lerp	This is a sugary secretion produced by the larvae of psyllid, molting insects (Hemiptera) and exoskeleton (cones). It is produced in Australia, Africa, Japan.	Nutritious food source for birds and more animals (including humans). It is thought to be the biblical "Manna". Mopane bread in Africa.
Silkworm waste & powder	Silk has been produced since ancient times in China and India. The pupae of *(Bombyx mori L.)* are delicacy food in southeast Asia.	Silkworm waste used to feed chickens and silkworm powder is medicine to treat diabetes in Korea.
Honeydew for honeybees	Honeydew produced by scale insect *(Marchalina hellenica)* in Greece and Turkey.	This is an important source of food for honeybees, which produce pine honey.
Edible oils	The melon bug *(Coridius/Aspongopus vidutus)* is endemic in Sudan, mainly in the western areas of Kordofan and Darfur.	The melon bug is a pest yet, its culinary uses are appreciated in Sudan. The extractable oil is stable and antibacterial.

Table 2: Insect species that can be grown as food and feed. Modified after [16]

Scientific name	Common name
Hermetia illucens	Black soldier fly
Musca domestica	**Common housefly**
Tenebrio molitor	**Mealworm**
Zophobas atratus	Giant mealworm
Alphitobius diaperinus	Lesser mealworm
Galleria mellonella	**Greater wax moth**
Achroia grisella	Lesser wax moth
Bombyx mori	**Silkworm**
Acheta domesticus	**House cricket**
Grylloides sigillatus	Tropical house cricket or banded crocket
Locusta migratoria migratorioides	African migratory locust
Schistocerca americana	American grasshopper

Note: In bold are insect species that can be easily raised for didactic purposes.

However, concerns related to whether, or not insects are safe to eat persist in industrialized countries, making legal consents and approvals of production protocols from governments, to regulate insect farming, processing, and marketing, compelling needs [11].

The purpose of this work consisted in evaluating the feasibility for employing edible insects in the human diet as a new venue to enhance food security, healthy nutrition, and sustainability. Despite challenges about developing appropriate marketing approaches to make insects as food acceptable to more consumers, there is a need to enhance conservation strategies, to avert fast, degradative changes to ecosystems, as these may soon lead insect species to extinction [15,18]. This paper accomplished a critical review of edible insects with the goal of ensuring quality foods for a growing human population, while counteracting malnutrition triggered by chronic food insecurity crises. A presentation of its benefits was included together with some drawbacks that in some contexts, continue to limit its acceptability.

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Agriculture and Insects as Food in Urban Settings

Although entomophagy is not a novel idea, its legitimacy for benefits it may bring to agriculture has been amplified by the many externalized costs affecting industrial farming [13]. The Union of Concerned Scientists (2008) [19] described these in three different categories: environmental costs (soil and biodiversity losses leading to an exhaustion of soil fertility), health costs (caused by water pollution due excessive uses of pesticides, antibiotics in animal farms and processed foods), and social costs (economic damage caused by factory farms and other businesses to small, family farms), often causing an abandonment of rural communities. An unconditional support for monocultures continues to be predicated by governments and the agroindustry as the "successful" model for food production, despite its massive consumption of oil, fertilizers, and pesticides, mostly oil derivatives, that are directly implicated in affecting environmental, animal, and human health [20]. Altieri and Nicholls [21] pointed out that 2.3 billion Kg. of pesticides continue to be used every year worldwide to maintain the health of crops and livestock. Premalatha and team [22] argued that agriculture continues to spend enormous amounts of money for these toxic inputs, to protect food crops that contain about a 14% protein, to control insect pests (another food source), that has a higher content of the same group of nutrients.

On the other hand, agroecology, which is a scientific, alternative approach to agriculture has proved to be productive and regenerative, without exhausting the resource base needed to maintain food productivity. It builds on agrobiodiversity [23], and a variety of resource-conservation aspects of traditional, local, small-scale agriculture, while drawing on modern ecological knowledge and methods [24]. Within an agroecological farming framework, insects become important, allied organisms of biologically diverse, agroecosystems. Their role is not only related to food (e.g.: honey, propolis and royal jelly from eusocial bees), but also towards important ecological services they provide, like crops pollination [16], or biological control against herbivorous insect species [25]. Also, numerous insect taxa like beetles for example, play an important role in nutrients cycling within soils, thus contributing to regenerate fertility, increase agrobiodiversity below ground, while controlling erosion and suppressing directly, or indirectly, soil-borne diseases [26]. In addition to this, agroecology serves as a powerful vehicle to produce food anywhere, including urban environments. Many studies have demonstrated how productive agriculture can be when it is practiced in cities, making urban agroecology a pivotal component of sustainable food systems [21,27,28]. Because of their limited need for space, insects farming could be feasible in cities, while offering excellent venues for producing local, quality foods for large segments of urban populations.

Public Health, Edible Insects and Food Security

Industrial agriculture has become a vulnerable enterprise, due to its enormous dependence on off-farm inputs (energy from oil, pesticides, fertilizers, germplasm, financial resources). Simplistic assumptions that these resources have become indispensable to maximize yields to ensure the profitability of farming, maintain an unsustainable food production regime in agriculture [29]. Regretfully, the concerns expressed by agroecologists about industrial agriculture having distanced itself more and more from ecosystems, have not been considered too seriously, to veer farming toward sustainability [30]. Thus, an unconditional confidence in the industrial approach to food production has weakened agriculture from withstanding pest infestations, diseases, climate change and most recently, infectious pandemics. For example, viruses have shown how closely intertwined we humans are to all living species. Organismal homeostasis may not be maintained without achieving a homeostasis of farming systems, ecosystems, and planetary health. As a systemic approach to agriculture, agroecology has demonstrated that ecological farming supports health from human beings to the ecosphere. Instead, vertically integrated monocultures and confined animal farming operations (CAFOs) that dominate most agrarian landscapes, become hazardous to health and strip environments of their regenerative capabilities to recover from extractive farming practices [13]. These are designed and maintained on the assumption of being capable of producing affordable foods in abundance however, their impacts on the environment (soil erosion, GHGs emissions, pollution, energy) and public health problems caused by water and air quality deteriorations, remain enormous. In intensive agrarian landscapes microbes and insects are farmers' nightmares because if pathogenic, they may compromise crops, animals' health, impacting gravely, yields and economy. To avoid these and similar risks, factory farms use massive amounts of agrichemicals and antibiotics, as part of their management, spurring an evolution of new strains, that will require more powerful antibiotics, to keep the number of disease-causing microbes and parasites at bay [31]. Concerns have emerged since the outbreak of the Covid-19 pandemic, suggesting the possibility that an emergence of this and similar infections like SARS, H_5N_1, Nipah, Mers, may have originated from human encroachment into wildlife areas, suggesting the possibility of spillover of novel infectious disease agents from wildlife to humans, through CAFOs [32]. This idea is supported by facts indicating that microorganisms (including viruses) are ubiquitous and can be shared among species. An expansion of farms destroys wild animals' habitats, causing their displacement and/or forcing their adaptation to human environments, which include huge livestock populations. This forced coexistence amplified by biodiversity losses facilitates microbial exchanges across species (e.g.: bat-cow-farmer) and

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when by chance one of these is pathogenic to humans, an infection may escalate into a serious outbreak.

Modern, fast transportation systems can spread germs broadly and, in a short time, a pandemic disease may occur. For these reasons, farms' size and scale of production should be limited by the carrying capacity of ecosystems and blend more harmoniously with landscapes and remaining natural habitats. Therefore, the industrial mode of food production should be revisited and restructured with a more robust ecological emphasis. Enabling ecosystems' conversion into factory farms and a further intensification of agriculture poses multiple risks and may increase the scale and occurrence of future pandemics. A recent study by Dickel [33] pointed out that infections caused by coronavirus SARS-CoV-2, Covid-19 through edible insects are unlikely to occur. Hence, insects as food could provide a safe and sustainable alternative to industrially grown meat, fish, and other mass-produced, farm-animal products.

Social, Educational and Health Benefits of Edible Insects

Eating edible insects continues to be a valued practice in supplementing the diet of hundreds of millions of people in tropical regions of undeveloped countries [34]. Its social benefits sustain local markets and economies with insects as local, renewable resources, thus contributing to an enhancement of food security [9] and sustainability. The 2005 World Summit on Social Development envisioned, sustainability as a balance among social, economic, and environmental domains, implying that food security should be pursued without damaging irreversibly, any component of the model [35] Despite its limitations, the three-prongs approach to sustainability remains a sound framework to also assess the sustainability of food production systems [36], including those that are raising insects. Insects are keystones, biotic components of ecosystems yet their unlimited harvests can exhaust and irreversibly affect the regenerative capability of insect populations to thrive. Alternatively, a sustainable harvest can yield environmental benefits, that also reduce the needs for spraying insecticides on cultivated fields [19]. However, harvesting insects from the wild cannot suffice to satisfy the needs for food and livestock feed [37] making edible insects call for more collaborations between food producers and wildlife conservationists so that the scale of production may be expanded to optimal levels, where insect foods are in high demand. From an educational viewpoint, and when employed within an ecological conservation framework as suggested by [38], the study of insects as a food topic can become a distinctive connector across disciplines, for a multitude of curricula in sustainability. Whether or not biology departments offer specific courses in entomology, small-scale cultivation of insects is common practice for maintaining live vertebrate species (reptiles, amphibians, fish), used in research projects, or for didactic purposes. Maintaining insect colonies is quite inexpensive and very effective to offer also work experience to students majoring in the biological sciences and/or related academic programs (Table 2).

The role of schools and universities in supporting entomology and entomophagy has potential to become effective in drawing students' interests from more study programs, while expanding their learning. Such a versatility of curricula in striving for a multidisciplinary learning demonstrates the power of education for sustainable development a step further, with implications for enhancing multiculturalism in education, well-being, and planetary health [39] Some universities have been conducting a variety of studies where insects are proposed as novel foods to students, showing a growing interest in entomophagy among youth [40-42] These studies have implications for an employment of edible insects in education with transformative learning effects, while enhancing an overall preparedness to an achievement of food, health, and nutrition for sustainable development, in 21st century society.

Costs, Market Niches for Insect Foods, and Sustainable Diets

The production of insects on a large scale has potential to yield sustainable, protein-rich foods, when compared to livestock production raised in CAFOs. This claim is verified by many lives cycle assessment (LCA) studies for selected, edible insect species [43-45]. These indicated that insects as foods release less greenhouse gases (CO_2, CH_4, NH_3, N_2O) into the atmosphere, when compared to the same emissions released for producing meat and dairy foods [9]. The energy needs to produce insects are similar however, or even higher than the energy, which is typically consumed to raise livestock species, especially during their transformation into dehydrated products, like flour [17]. Another notable advantage deals with the fact that insects' thermoregulation physiology is not dependent on the caloric intake of their diet, thus, maximizing the metabolizable energy from their ration, for their growth and development. For this reason, insects' FCR, or feed conversion ratio (kg. of feed/kg. of weight gain) is low when compared to that of farm animals, contributing to a minimal environmental impact when raising insects as food [46]. Moreover, insects can be grown on substrates like wastes, or by-products derived from the food industry, for which there is no economic value, nor use [6]. Space requirements are limited as well as water needs when compared to the same resources for raising conventional, farm animals thus, making insects farming potentially competitive in the 21st century agroindustry [43] More production costs included in an insect raising enterprise consist in storage, transportation, waste production management and/or use yet, these may be reduced if production operates within a circular economy. All life cycle assessments for insect species that were reviewed by Halloran and his collaborators [46] concluded that insects can serve as a more sustainable source of protein than farm-animals however, it

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is necessary to reckon with the fact that all these studies are not free from drawbacks. Therefore, Venderweyer [17] recommended maintaining momentum with further research about LCAs due to upscaling and increasing automation, as these are occurring rapidly, in the insects' production sector. In sum, the costs of producing insects for human consumption may vary significantly, among countries. For example, in many African and Asian nations where entomophagy is well established, the availability of insects remains linked to insects' life histories [47] Thus, termites, crickets, or weevil larvae become available at certain times of the year (Figure 1a-1e). Gatherers and consumers are aware of the seasonality of these foods where entomophagy has become established [12]. The market economy in these world regions is local, as insects are collected from the wild for the sustenance of gatherers' families, making only limited surpluses available for sale, in nearby, community markets. At these vending sites, according to the author's experience, insects are sold as street foods/snacks that have been deep-fried, boiled, or smoked, whereas the only processing may have consisted in wings removal by winnowing, the final food product [47].

Figure 1: a). The author holding a giant red-winged grasshopper (*Tropidacris cristata*) during the dry season, in Chiriquí, Panama, b). Termite nest (*Nasutitermes spp*.) on a young tree in Las Minas, Herrera, Panama, c). Stingless hon honeybees eliponines) at guard of their nest entrance, d). Nest entrance under the bracket fungus, in a tree's trunk, e). Author observing an empty Hon honeycomb stingless honeybees in Chepo, Herrera, Panama.

Eating Insects and Safety Concerns

Edible insects provide suitable nutritional alternatives to conventional meat and fish sources, contributing also to reducing malnutrition caused by food scarcity, in food insecure countries [48,7]. The feasibility of insects farming can be attributed also to its limited environmental impact, when compared to the same caused for raising farm animals, making this practice a highly efficient form of agriculture. The Food and Agriculture Organization of the United Nations (FAO) evaluated many insects (approximately, 1.900 species), edible and safe to eat, when these are processed correctly, before being consumed [6]. The appropriateness of processing insect products demands compliance with protocols, and these are like those guaranteeing the safety and quality of foods derived from more typical farm animals [33,49]. Since 2015 the European Union has been moving expeditiously to assess insect foods safety, as these are becoming more and more available because of trade agreements with producers abroad. The Netherlands is leading the European insect food market and it has been offering insect products since 2014 [11]. In North America the largest insect farm is near Toronto, Canada. It produces cricket and mealworm flours and whole-roasted snacks from these two species (https://entomofarms.com/). Many others (24 farms all

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together) are operative in the rest of the country and in the U.S. Insects' cultivation on a large scale requires safe feed sources (vegetables, fruits, or grains), to produce high quality, safe foods. Appropriate space, energy and water resources are also necessary production inputs. Organic waste may be used as food for insects raised for human consumption. However, researchers remain uncertain whether insects grown on these diets accumulate mycotoxins. In human nutrition, the most common risks posed by foods are nutrient malabsorption, growth alteration, chemical and microbiological contamination, leading to allergenic risks [51]. However, Ng'ang'a and his coworkers [49], found no risks involved in consuming grasshoppers (*Ruspolia differens*) when deep frying, smoking, boiling, which are typical preparation procedures with these insects for consumption in Tanzania, and other countries in Africa, are accomplished. However, these treatments eliminate pathogenic bacteria but not their endospores. Therefore, special attention should be paid when edible insects are processed, making this preparation phase a priority task for improving further processing technologies, when marketing ready-to-eat insects. An accumulation of heavy metals constitutes another matter of concern for some cultivated species of insects, which demands appropriate regulations and quality control protocols. From a food safety viewpoint management in raising insects, harvesting and post-harvest technologies remain keystone processes to guarantee food safety and quality [50].

Along this trajectory Borsari [51], reported that the European Union (EU) has been enacting specific policies to assess the safety of insect-derived foods since 2015 with Regulation (EU) 2015/2283 and in 2017 with Regulation (EU) 2017/893, which legalize the usage of insects as processed animal proteins (PAPs) in fish-farming facilities. Also, among European countries, The Netherlands has already been offering insect products as foods to its consumers for years, while spearheading the European market of insects as food [11]. Finally, to make the mass production of insects attractive and acceptable to consumers in the industrialized world, and more competitive about other animal derived foods such as meat or fish, it is necessary to continue researching rearing, harvesting practices, as well as, post-harvest processing technologies, including the automation for extracting proteins, fatty acids, and micronutrients [34]. While there is much interest in exploring further consumers' perceptions and attitudes about insects as food, there are also practicalities such as how to cook with insects, with sample recipes and degustation sampling that can be done at fairs, conferences, and more public events. A review by Belluco [10] confirmed that it is feasible for humans to eat some insect species if these are properly processed and prepared.

Conclusion and Recommendations

It should not be an overstatement to consider insect foods, or entomophagy as a new frontier in food production and human nutrition since robust trophic links between insects and people have been established since prehistoric times [1,52]. Insects' abundance and the low risk of collecting them, make these invertebrates a consistent source of food that women have been using to feed their families for millennia. It is a fact that early hunter-gatherers and their hominin ancestors foraged for insects (more women than men), shaping with this behavior the path of human evolution [53]. Insects and insect containing products opened a new horizon to distinctive foods that are important for human nutrition and feasible to grow, defying diverse environmental conditions [54]. To this day insects continue to be consumed worldwide and although they are not usually considered food in western societies, understanding that edible insects are a part of the human legacy, is fostering conversations about what is good to eat, both in prehistoric diets and for the future of food [53]. Consuming edible insects as novelty food, or snack food is beginning to get traction around the world, contributing to human nutritional requirements that are comparable to those derived from conventional, farm animal species. Insect foods are high in proteins, mono- and polyunsaturated fatty acids, vitamins, and minerals [55]. When compared to growing domestic animals, insects' growth rates and yield potential, versatility and reduced carbon footprint make them feasible to increase the needed food variety in humans' diet, and to satisfy their foreseeable, increasing demand occurring at present and future times [7]. Despite this, a recent report about consumers' response to insects as food from Australia indicated that there is reluctance to employ insects in people's diet, due to strong emotional constraints sustained by neophobia and disgust, that persist despite a recognition of the environmental and nutritional benefits of eating insects [56].

Despite present acceptability challenges, insects continue to be a worthy food resource for humanity [57]. They provide ecological services that benefit plant communities [16], whereas below the soil insects facilitate a decomposition of organic matter, enhancing humification and thus, improving soil porosity [26]. Whether or not insects as food will become established across culinary cultures and gastronomies remains challenging to ascertain, as market demand is mostly controlled by consumers' appreciation, or dislike for insect foods. Nonetheless, conservation efforts to protect insects from extirpation remain an imperative task that should be embraced on a planetary scale, to avoid their demise, as food systems benefit from insects' abundance and diversity. The global food system cannot be ecologically sustained any longer for increasing demands of meat and dairy foods. To this end, the 'planetary diet' has been suggested as a necessary trajectory to preserve Earth, while guaranteeing adequate, healthy food if we humans shift our diet to a more plant-based one [58]. However, this ambitious proposal did not include insects as sustainable substitutes for an uncontrollable consumption of meat and dairy products!

Strategies and approaches for enhancing an acceptance of insect foods and effective agendas about their conservation are

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proposed herein and these should focus on:

➢ Shifting the present food production paradigm predicated by industrial agriculture toward agroecology to reduce dependence from massive amounts of biocides, energy and resources that make current food systems highly centralized, unsustainable, and vulnerable to pandemics.

➢ Educating food producers to understand the health benefits of converting farming systems to sustainable agroecosystems, where farms' size and scale of production are decided by the carrying capacity of landscapes, rather than expected corporate returns.

➢ Cooperating across borders with scientific communities to amplify ongoing efforts for insect conservation and recovery from extirpation [59].

➢ Facilitating the reconnection of consumers with nature and food systems through a systemic transformation of education, from pre-school to graduate studies, which includes the study of entomology and entomophagy in all curricula.

➢ Amplifying connectivity levels among agriculture, ecosystems, and education to enhance sustainable development, with entomophagy as priority focus to achieve SDG#2 (zero hunger), worldwide [60].

➢ Developing specific research agendas on the calculations and assessments of ecological footprints for food [61] with emphasis on insects and value-added insect products.

We all depend on a continuous supply of food yet, most consumers remain oblivious of its origin and challenges to produce it and distribute it, through supply chains that although logistically efficient, possess the highest carbon footprint. The latter is inflated by transportation costs caused by a centralization of the food system. Entomophagy demonstrates to have potential to increase food security, while reducing malnutrition [12]. Its more limited need for resources, compared to farm-animals agriculture makes insects cultivation feasible for both rural and urban environments. An expansion of insect food production in cities can respond effectively, to increasing food demands with nutritious products that are produced and consumed locally. A decentralization of the food system will be necessary for moving toward sustainability in production agriculture [62] determining benefits that will lessen risks of zoonotic disease outbreaks and pandemics. Sogari and his collaborators [56] conceded that sustainability and climate change issues related to food production enhance awareness among youth for making entomophagy acceptable, envisioning higher acceptance, if the food industry in Australia will be innovative and creative to enhance positive sensory experiences about insects as food. The ultimate, new frontier for entomophagy retains its wider acceptability by society and only through a broader inclusion of insects as food agriculture will have moved a pivotal step further in its pursuit of sustainable development.

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References

1. DeFoliart GR (1999) Insects as Food: Why the Western Attitude is Important. Annual Review of Entomology 44: 21-50.
2. Morris B (2006) Insects as food among hunter-gatherers. Anthropology Today 24(1): 6-8.
3. Raubenheimer D, Rothman JM, Pontzer H, Simpson SJ (2014) Macronutrient contributions of insects to the diets of hunter–gatherers: A geometric analysis. Journal of Human Evolution 71: 70-76.
4. Eggleton P (2020) The State of the World's Insects. Annual Review of Environment and Resources 45(8): 1-22.
5. Glover D, Sexton A (2015) Edible Insect and the Future of Food: A Foresight Scenario Exercise on Entomophagy and Global Food Security. Institute of Development Studies (IDS).
6. Fowles TM, Nansen C (2020) Insect-Based Bioconversion: Value from Food Waste. In: Närvänen E, Mesiranta N, Mattila M, Heikkinen A (eds) Food Waste Management Pp:321-346
7. Belluco S, Losasso C, Maggioletti M, Alonzi C, Ricci A, et al. (2015) Edible insects: a food security solution or a food safety concern. Animal Frontiers 5(2): 25-30.
8. Gahukar RT (2011) Entomophagy and human food security. International Journal of Tropical Insect Science, 31(3): 129-144.
9. Glover D, Sexton A (2016) Edible Insects and the Future of Food. Policy Briefing Issue 114, Institute of Development Studies (IDS).
10. van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, et al. (2013) Edible Insects Future Prospects for Food and Feed Security. Rome: Food and Agriculture Organization of the United Nations (FAO).
11. Belluco S, Losasso C, Maggioletti M, Alonzi CC, Paoletti MG, et al. (2013) Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review. Comprehensive Reviews in Food Science and Food Safety 12: 296-313.
12. Collins CM, Vaskou P, Kountouris Y (2019) Insect Food Products in the Western World: Assessing the Potential of a New 'Green' Market. Annals of the Entomological Society of America 112(6): 518-528.
13. Kewuyemi YO, Kesa H, Chinma CE, Adebo OA (2020) Fermented Edible Insects for Promoting Food Security in Africa. Insects 11(5): 283.
14. Borsari B (2011) Agroecology as a needed paradigm shift to ensure food security in a global market economy. International Journal of Agricultural Resources, Government & Ecology 9(1/2): 1-14.
15. Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacond C, et al. (2020) Scientists' warning to humanity on insect extinctions. Biological Conservation 242: 1-12.
16. Nicholls CI, Altieri MA (2012) Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. Agronomy for Sustainable Development 33: 257-274.
17. Vandeweyer D (2018) Microbiological Quality of Raw Edible Insects and Impact of Processing and Preservation. Ph.D. dissertation, KU Leuven, Belgium pp:177.

How to cite this article: Bruno B. Edible Insects as the New Frontier in Nutrition for Sustainable Development. Nutri Food Sci Int J. 2023. 12(1): 555828. DOI: 10.19080/NFSIJ.2023.12.555828

18. Wagner DL (2020) Insect Declines in the Anthropocene. Annual Review of Entomology 65(23): 1-24.

19. Union of Concerned Scientists (2008) The Hidden Costs of Industrial Agriculture.

20. Borsari B, Espinosa J, Hassán J (2014) Agroecology and a vision for sustainable agriculture in spite of global climate change. Investigación y Pensamiento Crítico 2(5): 63-79.

21. Altieri MA, Nicholls CI (2018) Urban Agroecology: designing biodiverse, productive and resilient city farms. Agro Sur 46(2): 49-60

22. Premalatha M, Abbasi T, Abbasi T, Abbasi SA (2011) Energy-efficient food production to reduce global warming and ecodegradation: the use of edible insects. Renewable Sustainable Energy Review 15(9): 4357-4360.

23. Borsari B (2022b) Agrobiodiversity as Necessary Standard for the Design and Management of Sustainable Farming Systems. Planta Tropika Journal of Agroscience 10(1):93-101.

24. Gliessman SR, Méndez EV, Izzo VM, Engels EW, Gerlicz A (2023) Agroecology. Leading the Transformation to a Just and Sustainable Food System. 4th Ed. CRC Press, Boca Raton FL pp:442.

25. Pickett CH, Bugg RL (1998) Enhancing biological control: habitat management to promote natural enemies of agricultural pests. University of California Berkeley and Los Angeles CA pp:422.

26. Lavelle P, Spain A, Blouin M, Brown G, Deacaëns T, et al. (2016) Ecosystem Engineers in a Self- organized Soil: A Review of Concepts and Future Research Questions. Soil Science, 181(3/4): 91-109.

27. Sanyé-Mengual E, Gasperi D, Michelon N, Orsini F, Ponchia G, et al. (2018) Eco-Efficiency Assessment and Food Security Potential of Home Gardening: A Case Study in Padua, Italy. Sustainability 10: 2124.

28. Stewart R, Korthl M, Langer L, Rafferty S, Rebelo Da Silva N, et al. (2013) What are the impacts of urban agriculture programs on food security in low and middle-income countries? Environmental Evidence 2: 1-7.

29. Borsari B (2022a) From Agroecology to Food Systems Sustainability: An Evolutionary Path Shifting Toward Sustainable Agriculture and Development. In: Leal Filho W, Azul AM, Doni F, Salvia AL (eds) Handbook of Sustainability Science in the Future. Springer, Cham.

30. Altieri MA, Nicholls CI (2020) Agroecology and the emergence of post COVID-19 agriculture. Agriculture & Human Values.

31. Fox MW (1997) Eating with conscience. The bioethics of food. NewSage Press, Troutdale OR pp:192.

32. Wallace R (2016) Big Farms Make Big Flu: Dispatches on Infectious Disease, Agribusiness, and the Nature of Science. Monthly Review Press.

33. Dickel M, Eilenberg J, Falcao Salles J, Jensen AB, Lecocq A, et al. (2020) Edible insects unlikely to contribute to transmission of coronavirus SARS-CoV-2. Journal of Insects as Food and Feed.

34. FAO (2010) Forest insects as food: humans bite back. Proceedings of a workshop on Asia-Pacific resources and their potential for development. Durst PB, Johnson DV, Leslie RN, Shono K (eds) 19-21 February 2008, Chiang Mai, Thailand pp: 228.

35. UN General Assembly (2005) 2005 World Summit Outcome. A/Res/60/1 (October) p: 1-38.

36. Adams WM (2006) The Future of Sustainability: Re-thinking Environment and Development in the Twenty-First Century. Report of the IUCN Renowned Thinkers Meeting.

37. van Huis A, Oonincx DGAB (2017) The environmental sustainability of insects as food and feed. A review. Agronomy for Sustainable Development 37: 1-43.

38. Borsari B (2016) Sustainability Education as a Curriculum Emphasis. Academic Exchange Quarterly (Winter) 20(4): 31-37.

39. Borsari B, Vidrine MF (2022) Planetary Health Begins on Campus: Enhancing Students' Well-Being and Health Through Prairie Habitat Restoration. In: Leal Filho W (eds) Handbook of Human and Planetary Health. Climate Change Management. Springer, Cham.

40. Taşpınar O, Türkmen S (2020) The Effects of Healthy Nutrition Perception and Food Neophobia on Behavioral Intentions towards Edible Insect Products. International Journal of Society Research OPUS 15:1-22.

41. Orkusz A, Wolańska W, Harasym J, Piwowar A, Kapelko M (2010) Consumers' Attitudes Facing Entomophagy: Polish Case Perspectives. International Journal of Environmental Research and Public Health 17: 2427.

42. Yüksel E, Canhilal R (2018) A Survey of Public Opinion about Entomophagy in Erciyes University. International Journal of Agriculture and Wildlife Science (IJAWS) 4(2): 203-208.

43. Oonincx DGAB, de Boer IJM (2012) Environmental Impact of the Production of Mealworms as a Protein Source for Humans-A Life Cycle Assessment. PLoS ONE 7(12): e51145.

44. Smetana S, Palanisamy M, Mathys A, Heinz V (2016) Sustainability of insect use for feed and food: Life Cycle Assessment perspective. Journal of Cleaner Production 137: 741-751.

45. Halloran A, Hanboonsong Y, Roos N, Bruun S (2017) Life cycle assessment of cricket farming in north-eastern Thailand. Journal of Cleaner Production 156: 83-94.

46. Halloran A, Roos N, Eilenberg J, Cerutti A, Bruun S (2016) Life cycle assessment of edible insects for food protein: A review. Agronomy for Sustainable Development 36: 1-57.

47. Borsari B (2020) Eat Green, Eat Bugs: A Most Sustainable Lifestyle for your Wallet and our Planet. University of Minnesota, Local Foods College Webinars, February 4.

48. Feng S (2018) Tenebrio molitor L, entomophagy, and processing into ready to use therapeutic ingredients: a review. Journal of Nutritional Health & Food Engineering 8(3): 280-285.

49. Ng'ang'a J, Imathiu S, Fombong F, Ayieko M, Vaden Broec J, et al. (2018) Microbial quality of edible grasshoppers Ruspolia differens (Orthoptera: Tettigoniidae): From wild harvesting to fork in the Kagera Region, Tanzania. Journal of Food Safety.

50. Testa M, Stillo M, Maffei G, Andriolo V, Gardois P, et al. (2016) Ugly but tasty: A systematic review of possible human and animal health risks related to entomophagy. Critical Reviews in Food Science and Nutrition 57: 1-17

51. Borsari B (2023) Bread from bugs and the significance of employing insect foods in the human diet. Pp. 95-101. In: Kevany K, Prosperi P (eds) Routledge Handbook of Sustainable Diets. London and New York.

52. Ramos Elorduy J (2009) Anthropo-entomophagy: Cultures, evolution and sustainability. Entomological Research 39(5): 271-288.

53. Lesnik JJ (2018) Edible insects and human evolution. University Press of Florida, Gainesville FL pp: 184.

54. Vermeulen S, Park T, Khoury CK, Mockshell J, Béné C, et al. (2019) Changing diets and transforming food systems. CCAFS Working Paper no. 282. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

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55. Takov DI, Zubrik M, Contarini M (2021) Insects as a food source-potential and perspectives. Polish J Ent 90(2): 48-62.

56. Sogari G, Bogueva D, Marinova D (2019) Australian consumers' response to insects as food. Agriculture 9: 108.

57. Tiencheu B, Womeni HM (2017) Entomophagy: Insects as Food. In: Shields VDC (ed) Insect Physiology and Ecology. In Tech, Open, Agricultural and Biological Sciences.

58. Willett W, Rockström J, Loken B, Springmann M, et al. (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet 393: 447-492.

59. Harvey JA, Heinen R, Armbrecht I et al. (2020) International scientists formulate a roadmap for insect conservation and recovery. Nature Ecology & Evolution 4: 174-176.

60. Borsari B (2022c) Entomophagy and the Nexus Between Human and Planetary Health. In: Leal Filho W (eds) Handbook of Human and Planetary Health. Climate Change Management. Springer, Cham.

61. Świąder M, Szewranski S, Kazak JK, van Hoof J, Lin D, et al. (2018) Application of Ecological Footprint Accounting as a Part of an Integrated Assessment of Environmental Carrying Capacity: A Case Study of the Footprint of Food of a Large City. Resources 7(52): 2-18.

62. Borsari B, Kunnas J (2019) Agriculture Production and Consumption. In: Leal Filho W, Azul A, Brandli L, Özuyar P, Wall T (eds) Responsible Consumption and Production. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham

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