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Review Article

Entomophagy: A sustainable food alternative to save planet

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ABSTRACT

Climate change not only fringes rising average temperatures but shifting wildlife populations, rising seas, extreme weather events and other impacts. These changes are due to addition of greenhouse gases to the atmosphere due to impact of human activities. One of the important human activities which are a major contributor of greenhouse gas is Animal Agriculture. Meat consumption is responsible for releasing greenhouse gases such as methane, CO_2, and nitrous oxide. Livestock production accounts for 14.5% of all anthropogenic greenhouse gas emissions, with beef having the highest footprint due to large amounts of methane that an average cow produces. Agriculture accounts for 92% of the freshwater footprint of humanity; almost 35% relates to animal farming. The production of meat is directly and indirectly related to the loss of forests in South America, Amazon Rainforest and other areas of Brazil, Argentina and Paraguay. And many species face extinction or are under threat due to the destruction of natural environments. Sustainable alternative to going meat-free is entomophagy or insect farming which produces about 100 times less greenhouse gases per kg of mass organism gain. Edible insects like grasshoppers, crickets and mealworms are rich in protein and contain significantly higher sources of minerals such as iron, zinc, copper, and magnesium than beef. Regardless of its environmental benefits, entomophagy comes with its unique set of challenges.

1. Introduction

Experts predict that by 2050, the global population will increase to around nine billion individuals.[1,2] In order to satisfy the increasing need for food, food production must undergo a twofold increase.[1] Confronted with these challenges, there's a pressing need to reassess food production, making the adoption of sustainable and efficient food sources absolutely essential.[3,4] As per Chaalala, alternative protein sources are projected to capture up to one-third of the protein market by 2054.[5] In 2009, the FAO released a report advocating for insects as a sustainable nutritional option due to the escalating challenges posed by accelerated climate change, environmental degradation, and dwindling resources. As a result, it's conceivable that insects could become a primary source of nutrition for much of the global population in the future, a practice known as entomophagy. This shift could significantly promote more sustainable consumption habits, thereby contributing to the preservation of our planet's future. Unlike meat consumption, which emits greenhouse gases like methane, CO2, and nitrous oxide, insects have a smaller environmental footprint. While they require less land, water, and feed per unit compared to traditional livestock, their nutritional value is equivalent to crop products. Additionally, insects generate less waste, and their excrement, known as frass, serves as an effective fertilizer and soil enhancer. One of the major advantages

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of cultivating edible insects for human consumption is their ability to thrive on food waste.

Entomophagy: The concept of entomophagy, or the consumption of insects, is not new to contemporary society, as it has historical roots in past human cultures.[6] Currently, around 2.5 billion individuals worldwide incorporate over 1900 species of insects into their diets as a fundamental component.[7] Its traditional practice was started about 7000 years ago.[8,9] Beetles and ants' larvae are palatable food in African tribes.[10] while in Australia and Thailand; crispy fried locusts are appealing to many people.[11] A recent number of 2111 of edible insect species along with entomophilous regions was published by Jongema.[12] Maximum number/percentage of edible species is included in Coleoptera followed by Lepidoptera, Hymenoptera, Orthoptera, Hemiptera, Isoptera and Diptera. Taking into account the high nutritional value and resource efficiency in rearing insects, they are a more sustainable alternative to conventionally produced animal protein.[1,2,13–15]

Figure 1: Entomophagy or insect-eating.[16]

1.1. Key drivers in Entomophagy

a) Feed Conversion Ratio: The focus on proper food consumption is becoming more important, considering both the quality and quantity aspects. Achieving high output with minimal input is crucial for sustainably producing top-quality food, especially protein sources. When comparing the Feed Conversion Ratios (FCRs) of various animals like pork, chicken, beef, and insects, it guides us towards producing healthier meat sources compared to traditional ones. The subsequent FCRs per kilogram of feed input are: pork (5 kg), chicken (2.5 kg), and beef (10 kg).[17] The typical edible portion percentages for various meats are as follows: pork (55%), chicken (58%), beef (40%), and crickets (80%).[18] All indications indicate that crickets have a FCR efficiency twice that of chicken, four times that of pork, and twelve times that of beef. The higher FCR ratio of crickets compared to livestock suggests their poikilothermic nature and significantly reduced use of metabolic energy during their developmental stages.[19]

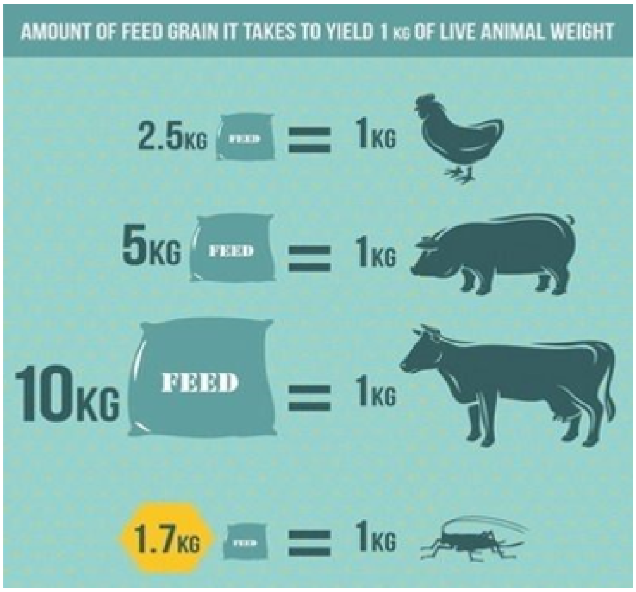

Figure 2: Feed conversion ratio.[20]

a) Footprints of Water and Land: Approximately 1.8 billion individuals reside in various regions facing inadequate access to water, and by 2025, around two-thirds of the global population will lack access to freshwater sources.[21] An estimate suggests that roughly 70% of the total water usage is attributed to livestock farming and agricultural activities.[22] A water footprint represents the volume of fresh water used to produce a particular product. Due to their cold-blooded nature, insects have a significantly higher Food Conversion Efficiency (FCE) compared to other types of livestock and poultry. Mealworms, for example, require a much smaller water footprint (less than 2 liters per kilogram) compared to other livestock (2200 liters per kilogram) and can be raised on organic waste.[23–25] The availability of arable land is a key consideration for agricultural activities. There is a direct correlation between the availability of agricultural land and the practice of livestock farming.[26] Calculated and estimated data on land usage by Locusta migratoria and Tenebrio molitor indicate the minimal land requirements for commercial insect farming.[27]

a) Greenhouse Gases Emission: Greenhouse gases emission is considered as noxious in creating global warming[30] The agricultural sector and livestock farms are notorious for emitting carbon dioxide (14.8 kg), as well as being major contributors to the global emissions of methane (31%) and nitrous oxide (65%). These emissions primarily originate from the use of fertilizers on feed crops and from manure.[31–33] Insects like termites, cockroaches, and scarab

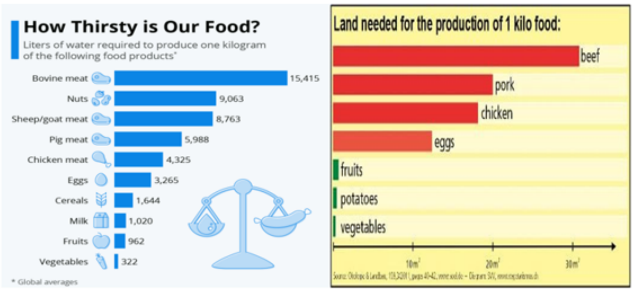

Figure 3: Footprints of water and land.[28,29]

beetles also contribute to greenhouse gas (GHG) emissions because of the presence of bacteria within them.[34] Yet, when comparing commercially farmed edible species such as Tenebrio molitor (mealworm), Locusta migratoria (locust), and Acheta domesticus (house cricket), there is favorable evidence indicating lower greenhouse gas (GHG) emissions.[35] When compared to other sources, livestock is the primary contributor to ammonia production, accounting for approximately two-thirds of total emissions.[31] An evaluation of the lifecycle of marketable crickets in Thailand showed a smaller environmental footprint compared to that of broiler chickens.[36] Insects utilize organic waste as an additional component of their diet, enhancing the sustainability of their farming practices.[37,38]

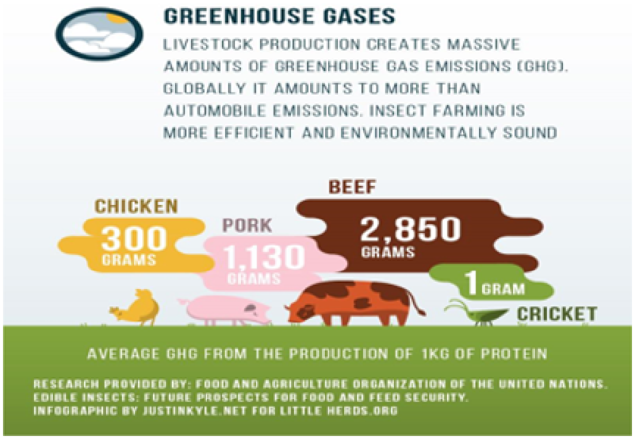

Figure 4: Sustainability of insects.[39]

Food Neophobia: Food neophobia refers to a person's inclination to refuse unfamiliar or novel foods.[13,40] Therefore, assessing the degree of food neophobia is a common practice in most studies exploring consumers' willingness to accept insects as food.[15,41–44]. Based on current research, there is an inverse relationship between consumers' food neophobia and their likelihood to consume insects, whether as a standalone food or as an ingredient in dishes.[41] Food neophobia, along with factors such as perceived health advantages, convenience, gender, past eating habits, and sensitivity to disgust, greatly influences the willingness of consumers in Western countries to consume insects.[15,45]. Research shows that empirical analysis is a more effective predictor than other significant variables, including subjective and objective knowledge.[46]

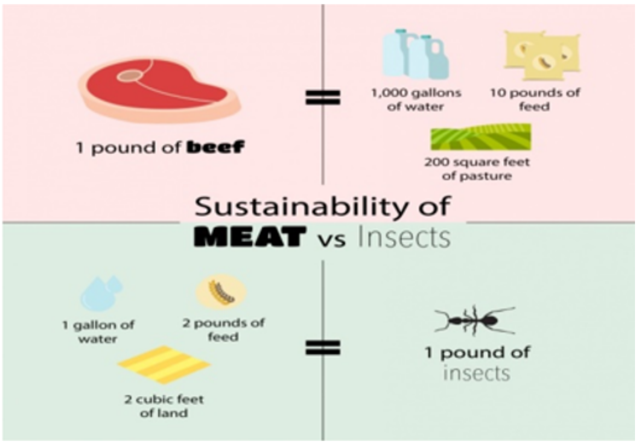

Figure 5: Sustainability of insects.[39,47,48]

2. Major Groups of Edible Insects

1. Lepidoptera - caterpillar, silkworm
2. Hymenoptera - bee, wasp
3. Orthoptera - locust, cricket, grasshopper
4. Hemiptera - true bugs, cicadas, leafhoppers, plant hoppers, scale insects
5. Isoptera - termites
6. Opisthopora

Table 1: Nutritional content of insects compared withother high-protein foods[19]

Insect or food item	Protein (g/kg)	Fat (g/kg)	Calories (kcal/kg)	Thiamine (mg/kg)	Riboflavin (mg/kg)
Black soldier fly	175	140	1994	7.7	16.2
House fly	197	19	918	13.3	77.2
House cricket	205	68	1402	0.4	34.1
Super worm	197	177	2423	0.6	7.5
Meal worm	187	134	2056	2.4	8.1
Giant mealworm	184	168	2252	1.2	16.1
Wax worm	141	249	2747	2.3	7.3
Silk worm	93	14	674	2.3	9.4
Beef	256	187	2776	0.5	1.8
Powder milk	165	268	4982	2.6	14.8

Utraceutical Benefits: Insects offer a diverse array of health benefits, with their medicinal properties varying based on factors such as their environment, diet, and life stage. Termites, for example, are packed with protein, essential amino acids like tryptophan, and various micronutrients, including iron. Incorporating termites into daily meals could boost iron levels and potentially combat anemia, particularly in developing regions.[49] Termites are employed in the treatment of numerous ailments such as asthma, sinusitis, hoarseness, influenza, bronchitis, and whooping cough, as outlined in Table 2. Additionally, they are utilized in addressing malnutrition among individuals.

Table 2: Termite species used in traditional medicine.[50]

Species/family	Treated disease	Country
Hodotermes mossambicus	Child malnutrition	Zambia (Africa)
Macrotermes bellicosus	Suture wounds	Somalia (Africa)
Macrotermes nigeriensis	Wounds	Nigeria (Africa)
Macrotermes exiguous	Asthma, flu etc	Brazil
Odontotermes feae	Ulcer, Rheumatics	India
Pseudacanthotermes spinger	Antifungal properties	Brazil

3. Cultivation and Processing of Edible Insects

One of the main reasons for considering insects as food is their efficient conversion of feed into protein mass and their rapid production compared to traditional protein sources like animals and plants. Figure 5 explains the crucial role of insect rearing in this process. The economic feasibility plays a significant role in determining the viability of insect farming, making it essential to find cost-effective methods for feeding and rearing edible insects, a topic widely discussed in the literature. Insect feed production poses less competition with human food production compared to animal feed production. Animal feed can include supplements like fish meal, bone meal, blood, and various plant proteins from sources such as sunflower, soybean, and cotton seedcake.[51–53]

During the rainy seasons in many parts of Western and Eastern Africa, termites are gathered as they come out of holes in the ground. This typically happens between April and October in Western Kenya. Insects are commonly eaten whole or can be processed into granular or paste forms.[54] The insects are typically cooked by boiling them briefly, then drying them in the sun before frying them in their own fat. Some people prefer to dip crickets in hot water for a minute, then sun-dry and grind them for use in various dishes like porridge, cookies, and sweet treats. Alternatively, they can be deep-fried until crispy and enjoyed whole, with the deep-fried version being particularly popular due to its delightful aroma and flavour.[55] Numerous research studies have indicated that how insects are prepared significantly influences people's willingness to consume them. However, so far, there has been little investigation into consumer expectations and preferences regarding various aspects of insect preparation, particularly in sub-Saharan Africa. Figure 6 displays the processing flowchart for insects.[56]

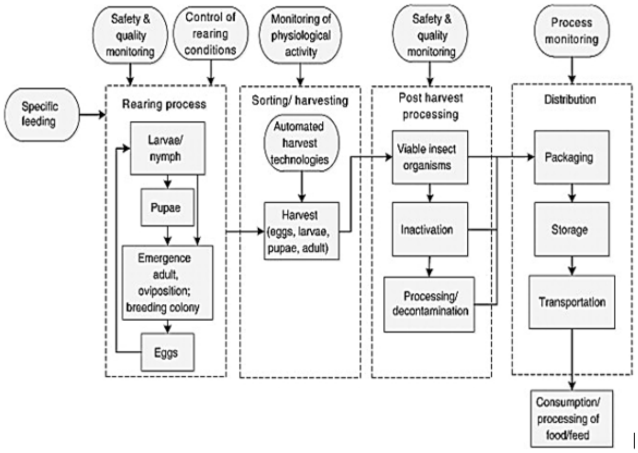

Figure 6: Main steps from cultivation to processing toprovide consumer through safety protocols and procedures.[53]

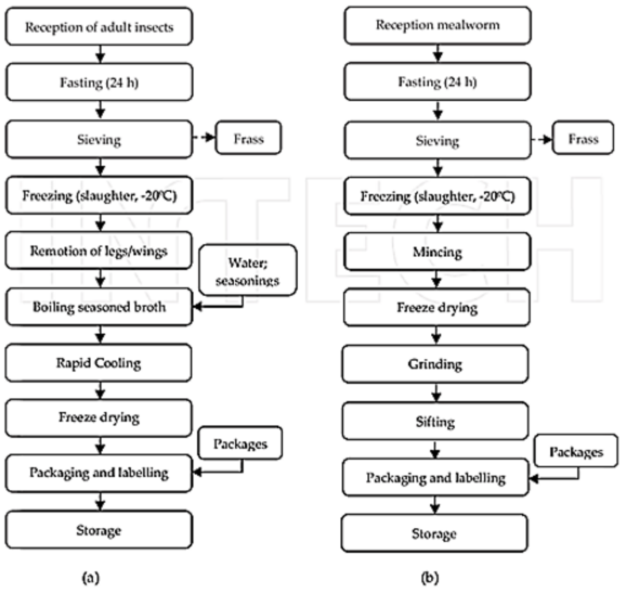

Figure 7: Processing flowchart of **(a)** cricket/grasshopperdry snacks and **(b)** mealworm larvae flour.[57]

Zoonotic diseases: Large-scale breeding of livestock can elevate the likelihood of pathogens affecting humans and other related animals, and in some instances, contribute to antibiotic resistance.[59] Diseases like Bovine Spongiform Encephalopathy, foot and mouth disease, H5N1 avian influenza, and swine fever are cited in this context. These

Figure 8: Processing of insects to food component.[58]

pathogens pose a significant risk to human health.[60,61] By contrast, insects are less likely to transmit zoonotic diseases to humans, likely because of the limited contact between them.[62,63]

Toxicity and Allergy: In various regions worldwide, local populations have a history of consuming insects, but instances of poisoning and allergic reactions have been documented. In south-west Nigeria, cases of seasonal ataxic syndrome following the consumption of silkworms have been reported. Ataxia, characterized by a loss of full control over bodily movements, can be caused by thiamine deficiency. The larvae of Anaphevenata contain thiaminase, an enzyme resistant to heat, which, when consumed in silkworms, can break down thiamine in the human body, leading to acute ataxia.[64] The growth of microbes in insects can result in the transmission of toxins through insect-derived foods. Initially, freshly reared mealworms tend to have a total viable microorganism count of 7–8 log cfu/g. It is essential to reduce this elevated microbial level in mealworms initially and then prevent any subsequent microbial growth to minimize the risk of foodborne illnesses.

Acceptance of Edible Insects across The Globe: Consuming insects as both food and feed is a common practice among numerous ethnic communities in Africa, Asia, South America, and Mexico, with varying levels of acceptance across different biogeographical areas.[65] Based on available literature, around 250 types of edible insects have been documented in Africa.[10], In Thailand, there are 50 palatable species from the Meimuna, Allonemobius, and Cotinis genera, as documented in reference.[66] Additionally, Mexico has recorded 348 appetizing species.[67] China has identified 187 species, including Bombyx mori, Antheraea pernyi, Tenebrio molitor, Apis cerana, Locusta migratoria, Odontotermes formosanus, and Anax parthenope, as stated in reference.[68] Japan has 55 tempting species like Oxya yezoensis, Oxya japonica, Vespula lewisii, and Bombyx, which are consumed.[69], Meanwhile, India has documented 60 species of edible insects.[70] Recent research indicates an increased willingness, particularly among populations not traditionally accustomed to eating insects, to consume products that incorporate ground insects rather than whole ones.

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4. Conclusion

Entomophagy offers a sustainable solution to consumption by lessening the environmental burden of food production and supplying nutritious food worldwide. Insects boast significant nutritional value, emit fewer greenhouse gases, use minimal land and water, and efficiently convert feed into edible mass, tackling protein shortages. To make this a reality, advancements in farming technology, changes in consumer habits, revised food and feed regulations, and inventive insect utilization are necessary.

5. Source of Funding

None.

6. Conflict of Interest

None.

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