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Entomophagy species as an emerging source of nutraceutical proteins

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Abstract
Edible insects have attracted significant global interest as they provide a sustainable or nutrient-dense alternative instead of using traditional protein sources.
They contain bioactive compounds with promising nutraceutical potential and are abundant in essential minerals, vitamins, amino acids, and high-quality proteins. Insects such as ants, termites, and grasshoppers exhibit antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory properties, making them valuable functional food ingredients for health enhancement and disease prevention.
Insect farming requires fewer resources, aligning with environmental sustainability goals. Furthermore, it results in lower greenhouse gas emissions. Despite its potential, consumer acceptance, standardization, and regulatory frameworks pose significant challenges to widespread adoption.
This review emphasizes the nutritional profile, health benefits, processing technologies, and safety considerations of insect-derived proteins. It underscores the crucial role these proteins play in the development of innovative nutraceuticals. The integration of entomophagy species into conventional food systems could significantly enhance global food security, improve human health, or promote sustainable development within the nutraceutical sector.

Keywords: Edible insects, nutraceutical proteins, insect-based nutrition, functional foods, sustainable protein sources

Introduction

Various predictions suggest that the worldwide population is anticipated to surpass 9 billion by the year 2050 [1]. Insects are characterized as the most diverse groups of multicellular organisms, representing over 70% of all living species on the planet. The estimated number of existing insect species ranges from 2.5 to 10 million, exhibiting lengths from less than 1 mm to 20 cm. Their diversity and ongoing survival can be attributed to several characteristics, including a brief life cycle and the capacity to inhabit new ecological environments [2]. Over 2300 species of edible insects are found globally, mainly in Africa, Asia, and the Americas, as per statistics [3]. Isoptera, Lepidoptera, Orthoptera, and Hymenoptera are mostly feeding insects through the world [4]. Many are available only during specific seasons, and the local community employs various methods to collect them. There is a necessity for alternative protein sources. Among these sources are algae, mycoproteins, cultured meat, plant-based proteins, and insects. Additionally, the environmental footprint associated with insect farming is significantly lower than that of traditional livestock production [5]. At every phase of development, edible insects serve as an exceptionally nutritious food source due to their rich nutrient profile. Their elevated levels of protein and fat make immature insects, such as larvae and pupae, especially appealing to consumers [6]. Edible insects have surfaced as a viable alternative source of protein owing to their significant nutritional benefits, minimal environmental impact, and effective resource use. The advantages encompass their elevated protein levels and quality, reduced greenhouse gas emissions, cost-effective production, and capacity to flourish on organic waste [7].

Examples of emergent and sustainable food sources encompass vegetables (such as wheat, beans), microorganisms (including fungi and microalgae), and insects (for instance, Hermetia illucens). From few years, significant increase in the popularity of plant-based products, primarily driven by dietary subjects increasing interest in adopting an eco-friendlier diet [8]. The (FAO) has carry out research on the benefits of insect consumption used as protein content, fat content, micronutrient in western world. entomophagy species frequently serve as an additional protein source when other options are scarce during specific times of the year. For instance, individuals in Madagascar enhance their protein consumption by incorporating various insect species during the lean season [9].

Insect proteins possess numerous advantageous characteristics, including significant nutritional benefits and high digestibility, alongside their environmentally sustainable nature. Nevertheless, to successfully integrate these proteins into various food products, it is essential to comprehensively evaluate their functional properties throughout each phase of the transformation process. Consequently, this article examines the potential of insect proteins as high value-added functional components in food formulation, in comparison to traditional proteins currently utilized in the industry. Additionally, it addresses the challenges, perspectives, and the scope of future research required to enhance understanding in the expanding field of edible insect proteins [10].

This review highlights the studies related to insects used as nutraceuticals aimed to highlight that the insects are used as most interesting and emerging protein enrich source with high technological attributes. However, the work describes about different methods used for extraction of proteins from insects and their use as nutraceuticals [11].

Current Patterns of Insect Consumption as Nutraceutical and Medicine Most consumed insects as food in (Asia)

In Korea canned canned silkworms and grasshoppers are mostly consumed by rural people [12]. In Japan bees, grasshoppers, wasp larvae are mostly eaten. In Japan, there exists a dish known as imago, which consists of fried grasshoppers that are flavoured with soy sauce. In India multiple uses of insects like silkworms for silk and food [13].

India is home to 59,353 insect species across 619 families. Consequently, it presents a promising opportunity for the utilization of insect bio-resources due to their extensive potential. Nevertheless, India is not unique in this regard, as it also exhibits positive aspects of human-insect interactions. Therefore, promoting the ongoing practice of entomophagy in the country, and potentially revitalizing certain entomophagic traditions, should be regarded as beneficial actions for the nation as a whole. Edible insects from south and central India includes chin kara and ants used as dietary in Madhya Pradesh; tribe is used as nutraceutical in Tamil Nadu. Edible insects from north east India montona are used as food [14].

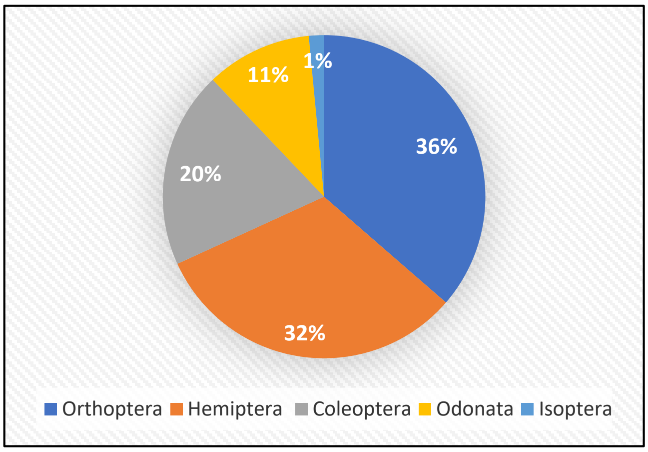

Fig:1 (Percentage contribution of Entomophagy Species in Nagaland) [58]

In Japan bees, grasshoppers, wasp larvae are mostly eaten. In Japan, there exists a dish known as inago, which consists of fried grasshoppers that are flavoured with soy sauce [15].

Food security represents a significant strategic concern for all nations, but it is particularly vital for China given its substantial population. As one of the most densely populated countries globally, China is projected to accommodate 1.4 billion individuals by 2050, accounting for roughly 14% of the global populace [16].

Table 1: Percentage of Insects used as nutraceuticals **[17]**.

Orders	Examples	Percentages
Coleoptera	Beetles	31%
Isoptera	Termites	3%
Hymenoptera	Bees	14%
Hemiptera	Leafhoppers	10%
Diptera	Flies	2%

Most Consumed Insects as Food In (Africa)

The practice of consuming insects, known as entomophagy, plays an important role in promoting food security, particularly in developing nations such as Nigeria [18]. The world population is increasing and is projected to reach approximately 9 billion by the midpoint of this century. In Africa, the population is anticipated to grow to around 2.53 billion individuals by the year 2050. For many years, edible insects have been incorporated into the human diet in Africa Fig: 3(c) [57]; indeed, insects constitute a complementary food source in 90% of diets across the continent [19].

The consumption of insects as a food source is predominantly a widespread practice among individuals residing in isolated areas of developing nations, particularly within the tropical and subtropical climatic zones of Africa and Asia [20]. Throughout Africa, the commerce and street sales of edible insects are predominantly carried out by women Fig: 2(b) [57], thereby directly enhancing the economic welfare at the household level. Additionally, insects are perceived as advantageous to numerous communities as they can yield silk, honey, and wax, serve as dyes and manna, are consumable, can be utilized as medicinal resources, and can be crafted into exquisite ornaments [21].

Throughout Africa, the number of newly registered private companies is increasing daily, driven by the substantial base of insect farmers and the availability of local experts who provide training and starter kits (such as eggs or 5-day-old larvae) to assist new market entrants as the market expands rapidly and demand rises. [22].

Table 2: Insects and Their Purpose / Uses in Africa **[18]**.

Insects	Purpose and uses
Black ant Smith (*Carebara vidua*)	Medicinal and nutritional purpose
Termites	Consume as relish
Winged termites	Medicinal purpose
Edible grasshopper	Consume as relish
Cricket	Taken as food

Nutritional Composition

The practice of consuming edible insect's dates back almost 7000 years. Over 2300 species from 18 different orders have been documented as edible, with 5 of these orders containing at least 100 recorded species [23]. Insects offer clear benefits in terms of nutritional value. Their nutritional profiles are, in fact, quite comparable to those of conventional animal-based foods [24].

At all the life stages insects are enriched with animal proteins. The crude protein content typically ranges from 40 to 75 percent when calculated on a dry weight basis, with average values varying by order from 33 to 60 percent. insects generally have a higher crude protein content than traditional meat, although their amino acid profiles are often similar. As a food source, they offer essential amino acids at an optimal level, with digestibility rates generally between 76% and 96% [25, 29].

it is crucial to ensure that infants and children receive these essential nutrients adequately. Agricultural products such as vegetables and domesticated animals are often either illegal or too expensive for these populations. In contrast, insects are typically inexpensive and traditional diets. Additionally, certain insects are considered traditional food sources in specific regions. Consequently, various products have been developed, and promising outcomes are emerging. The SOR-Mite project, which focuses on protein-enriched sorghum porridge, offers further insights into enhancing dietary quality. In numerous African nations, the grains that local populations consume daily are deficient in proteins and fats. Nevertheless, these grains can be nutritionally complemented by flying termites, which are readily collected. The porridge created from this combination is both nutritious and cost-effective [30].

As per WHO balanced diet is essential when insects constitute the primary component of a meal. However, apart from these specific species, insects typically fulfil the WHO's guidelines for amino acid intake. By consuming a suitable mix of products, most insects can deliver adequate levels of essential amino acids [31].

Table 3: Total Protein Content **[23]**.

Insect Name	Part	Protein content
Periplaneta australasiae	Adult	66%
Callicoon barbatus	Larva	41%
Zophobas morio (superworm)	Larva	45%
Krizousacorixa azteca (waterboatman)	Eggs	64%

Insects are great resource of fats. Trace quantities of various fatty acids have been identified in certain insects, encompassing. These acids are regarded as insignificant. The fat content in immature insect ranges from 8 to 70 percent when measured by dry weight. The compositions of fatty acids are comparable across different meat sources, including all categories of insects [26]. The lipid content in Lepidopteran and Heteropteran larvae surpasses that found in other edible insect species. Among the various life stages of insects, larvae serve as the most significant source of fatty acids or oils. Adult insects mainly exhibit a leaner physique, with fat content falling below 20%. The predominant form of fat present in insects is triacylglycerol [32].

Process of Extraction of Proteins from Edible Insects

1. Insect Collection and Pre-treatment

Insects (such as crickets, mealworms, and locusts) are gathered, deprived of food for a period of 24 to 48 hours to clear their digestive systems, and subsequently cleaned meticulously [33].

2. Dehydration and Milling

Insects undergo a drying process through either oven-drying at temperatures ranging from 50 to 60 degrees Celsius or freeze-drying to inhibit the degradation of proteins. The dried insects are then processed into a fine powder utilizing a grinder or blender [34].

3. Defatting

The removal of fat is accomplished through the use of solvents like hexane or petroleum ether within a Soxhlet apparatus for a duration of 6 to 8 hours. This process enhances the efficiency of protein extraction [35].

4. Protein Extraction (Alkaline Solubilization Method)

Insect powder is combined with an alkaline solution (for instance, 0.1–0.5 M NaOH) at a solid-to-liquid ratio ranging from 1:10 to 1:20 (w/v). The mixture is agitated at room temperature or at 50°C for a duration of 1 to 2 hours [36].

5. Centrifugation

The mixture undergoes centrifugation at a speed of 8,000–10,000 rpm for a duration of 15–30 minutes to facilitate the separation of soluble proteins from chitin and other debris. The supernatant, which contains the protein-rich fraction, is then collected [37].

Protein Precipitation (Isoelectric Point Precipitation)

The supernatant is modified to reach the isoelectric point (approximately pH 4.5–5.0) by the addition of 1 M HCl, which facilitates the precipitation of proteins. Subsequently, the solution undergoes centrifugation to isolate the protein pellet [38].

6. Drying and Storage

The protein precipitate undergoes washing with distilled water and is subsequently subjected to freeze-drying or oven-drying. The final protein extract is preserved at a temperature of 4°C or −20°C for the purposes of analysis or food application [39].

Identifying Insects Used as Nutraceuticals

The nutritional worth of consumable insects is highly varied, primarily due to the extensive range and diversity of species Fig: 2(a) [58]. The nutritional content can differ significantly even among a single group of insects, influenced by factors such as the stage of metamorphosis, the insect's origin, and its dietary habits [40].

Honey Bee

The proximate nutrient profiles of dry larvae Fig:3(d) [56], pupae, and adult worker bees were assessed. Chemical analyses were performed on the samples, measuring the concentrations of 16 amino acids, 10 fatty acids, and 12 metals, which were then compared to their levels in conventional animal and plant-based foods. Our findings indicate that as larvae transition to the imago stage, the levels of carbohydrates and fats decline from 46.1percent to 6.9 percent respectively, while protein levels rise from 35 to 51 percent [41].

Honey has been regarded as one of the most esteemed and valued natural substances known to humanity since ancient times. It is not only the source of nutrition but also improve health, as outlined in traditional medicine, and is utilized as an alternative therapy for various medical conditions, including wound healing and cancer treatment [42].

Larvae: Contains high-quality proteins (up to 50%), essential amino acids, B-complex vitamins, minerals, and lipids. This composition contributes to antioxidant activity, enhances immune function, boosts energy levels, and supports growth in individuals suffering from malnutrition.

Pupae: Composed of proteins, fatty acids, vitamins, sterols, and bioactive peptides. These components exhibit antimicrobial and anti-inflammatory properties, aid in muscle recovery, promote brain health, and help maintain hormonal balance [43, 45].

Grasshopper

These insects have been identified as a valuable source of various nutrients, particularly protein. Nonetheless, the nutritional quality of these insects may be influenced by multiple factors that need to be addressed to optimize their use in food applications. This study evaluated the impact of two distinct diets, alfalfa and maize green fodder, on the chemical composition of the grasshopper consumed in Mexico. Significant differences were observed in the dry matter, crude protein content, amino acid profile, in, fat, and insoluble fiber content in between grasshoppers that were fed alfalfa and those that were fed maize (p-value less than 0.05) [46].

Maggot

it contains 55 percent (CP), 27.65 percent ether extract, 8.33 percent ash, 3.37 percent (CF), 2.14 percent nitrogen-free extract, the supplementation of maggot meal has an impact on various factors including, feed conversion ratio, dressing percentage, mortality rates, antibody titers against Newcastle disease, and organoleptic characteristics [47]. Maggot meal can serve as a substitute for fish meal in broiler chicks because of its high nutritional content. The biological value of maggot protein is comparable to that of fish meal, while it significantly surpasses that of groundnut cake and soybean meal, based on the amino acid profile of maggots [48].

Protein is present in maggots and termites. It is widely recognized that maggot protein is utilized in poultry feed. The nutritional analysis of maggots indicates that they contain 60% crude protein and 20% crude fat, suggesting their potential as a protein source in poultry feed. However, various researchers have documented differing nutritional values for maggot-based diets. These discrepancies are associated with variations in house fly species, the age of the pupae, and the processes involved in converting maggots into meal, such as rearing and drying methods [49].

Termites

Termites are primarily recognized for the damage they inflict on human structures in both urban and rural settings. This research aimed to compile a comprehensive list of termite species utilized worldwide through a literature review, categorizing them based on their applications by human populations. The findings indicated that at least 45 termite species, classified into four families, are utilized globally, with 43 species incorporated into the human diet and/or for livestock nourishment. In total, 45 species of termites from four families were documented as being utilized by human populations, with 43 species contributing to human dietary needs or livestock feed [50]. Termites have significantly contributed to the historical context of human nutrition across Africa, Asia, and Latin America [51].

Fig:2 (a) Fried silkworms (b) Fried locusts

Fig: 3 (c) Edible caterpillars in Africa (d) Edible honey bee larvae

Table 4: Edibility and medicinal uses of insects across different countries [30, 52, 53, 54, 55].

Insect	Edible in countries	Medicinal or nutraceutical uses
Honey bee (*Apis mellifera*)	China, Thailand, India, Korea.	Larvae/pupae rich in protein, vitamins, fatty acids Antioxidant, anti-inflammatory Used in traditional medicine for fatigue, wound healing
Grasshopper (*Locusta migratoria*)	Thailand, Mexico, India	Used in anemia treatment, Antioxidant, antimicrobial activity, Traditional remedy for asthma and respiratory
Maggot (Housefly larvae-*Musca domestica*)	China, South Africa	Used in maggot therapy to clean wounds. Rich in enzymes and antimicrobial peptides
Termite	Nigeria, India	Used to treat asthma, bronchitis

Conclusion

Edible insects, including grasshoppers, maggots, and termites, present considerable promise as sustainable sources of nutraceutical compounds, which encompass high-quality proteins, essential amino acids, beneficial lipids, and healthy fats.

Throughout their various developmental stages—larvae, pupae, and adults—these insects display a range of nutritional profiles that can contribute to addressing global issues related to food security and malnutrition. Their abundant composition not only fulfils dietary requirements but also offers bioactive compounds with medicinal properties, such as antimicrobial, antioxidant, effect. Maggots provide therapeutic enzymes and immune-enhancing properties, while termites play a role in traditional medicine practices and are abundant in essential micronutrients. Incorporating these insects into contemporary nutraceutical and functional food systems can enhance health and wellness while fostering ecological sustainability. Future research and regulatory backing are crucial to maximize their use and gain public acceptance in mainstream nutrition and healthcare.

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