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Future of Food Exploring Edible Insects- An Alternative Approach: A Review

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ABSTRACT

The burden of human population is influences availability and quality of food, therefore edible insect may be an alternative source for food. Almost all insects are rich in their nutritional content and have the potential to be served as food for animals and humans. It is provide important necessary nutrition required for the people, while its nutritional content may vary from species to species and genus to genus. Many numbers of insect are recognized as edible that belong to genus Ocalea, order Coleoptera. Apart from direct consumption, edible insects have a huge impact in the food processing industry. These insects are extremely rich in their nutritional value and can help to resolve the world's hunger crisis and other global deficits. At present day, most of the edible insects are collected from the wild area, even though in-house and these insects provide sustainable product. Till date, there is total of 1,900 edible insects are reported from worldwide. This review is summarizing on the different types of edible insects availability, nutritional composition and production strategies.

Key words: Edible insects, Insect protein content, Protein malnutrition, Protein source.

Climate change, global warming, environmental ruination, decreasing production area and it negatively influence the quality and quantity of food production. The world population may reach about nine billion after two-three decades, which increases demand of agriculture product and food sources (Kim *et al*., 2019). Negative impacts of population on food, force us to look the alternate sources like edible insect and animal source. The animal sources taking to much time and caring while edible insects have been received the maximum recognition because high nutritional content possesses (Dobermann *et al*., 2017) and produce in short time (Quah *et al*., 2023). The edible insects are alternate food sources can prevent shrubs trees and animal killing from being chopped.

The protein requirement is good for health can also be fulfilled through using edible insects (Poma *et al*., 2017). There are some insect groups like lepidopterans, orthopterans, isopterans and hymenopterans are well known to use in the form of food (Van Huis, 2013). Adult or larva stage of edible insects such as crickets and grasshoppers (orthopterans), mealworms (coleopteran larvae), caterpillars (lepidoptera larvae), some fly larvae (dipterans), could provide an alternative meat source and improve food security. The insects are used as common food sources in tropical and subtropical regions due to the warm and moist climate (Labu *et al*., 2022). Tropical insects are generally large and have more protein part due to a stable life cycle. Based on above qualities of insects make excellent food source from sustainability, health benefits, easy accessibility, and palatable nature (Berezina *et al*., 2018). Entomophagy is a better option for nutritional supplements in the diet. About two billion of the world's population consumes insects in the form of meals. Over two thousand species of insects have been categorized as edible insects (Tang *et al*., 2019; Jongema *et al*., 2017).

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The Food and Agriculture Organization (FAO) of the United Nations has requested research about insect in the form of food to improve personal life style intensify trade, escalate availability, and normalize insects (Sosa and Fogliano, 2017). Edible insects are source of lipid and contain some bioactive sources of antioxidant, antihypertensive, anti-inflammatory, antimicrobial and immune-modulator to help human health (Aguilar-Toalá *et al*., 2022). Insects are providing huge variety of ecological services, additionally authentic connection among human population which stretches rearwards to the relic. During the nineteenth century insect ability were divided into seven categories by Chung (2010): 1) Silk delivering insects; 2) Honey, wax producing insects; 3) Dyes from insects; 4)

Insects producing manna; 5) Edible insects; 6) Medicinal insects; 7) Insects as ornaments.

Few societies have made the inedible insect species to consume after processing or to attract otheredible insects species. The stink bug *Encosternum delegorguei* Spinola mainly found in Africa, are made edible by releasing their pheromones when washed with warm water or boiled in water and sun-dried (Dzerefos *et al*., 2013). The armoured ground cricket, *Acanthoplus spiseri* Brancsik is converted in edible insects by removing the head and gut and placing the insect in boiling hot water (Yen, 2009). The boiling water helps in the release of toxic matter from the insect which can lead to severe irritation (Rumpold and Schluter, 2013). Insects and their protein source have a great potential to compensate the food insecurity and it also used for treatment of human disease (Gupta *et al.,* 2017). It is essential to record and keep up conventional information about production of edible insects and further research for a better diet (Solon-Beit *et al*., 2020). The received information about edible insects is very less while there might be large amount of information recorded to many insects' population which support in growing meat consumption as well as promoting healthier diets.

Edible insect in India

Entomophagy is a culture of tribal people found in Phek, Dimapur and Kohima districts of Nagaland eat grasshoppers, cricket, red ant and larvae of mulberry silkworms. They eat green color larvae infested on golmohar tree in the month of March and April (Srivastava *et al*., 2009). Some tribal people in Midnapur district of West Bengal eats red ant eggs, larvae and also uses them as fish bait. Tribal people of Kandhamal, Koraput, Sundergarh, Keonjhar and Mayurbhanj districts of Odisha eat red ant and termite. Termites were collected at the time of swarming, while red ants were collected from the nest formed on the plant. The villagers of Pithra village of Simdega district of Jharkhand eat eggs of Demta, a red ant found on the trees (Srivastava *et al*., 2009). Tribes in Karnataka and Irumbars tribe in the North Arcot district of Tamilnadu consumed winged termites as food which is commonly called as Eesal. In Kerela at least five species of insects (bees, ant and termite) were consumed as food (Chakravorty, 2014). In Arunachal Pradesh, the Nyishi and Galo tribes consume at least 81 species of local insects, belonging to 26 families and 5 orders of insects (Chakravorty *et al*., 2011a). The most favorable insect life-stages are the caterpillars and pupae of the mulberry silkworm, Bombyx mori and non-mulberry silkworms (Lepidoptera: Saturniidae), *viz*. *Antheraea pernyi, Antheraea assamensis, Attacusricini* and *Samia ricini* (Gahukar, 2020). Some people uses termite insect as source of protein and carbohydrates in Meghalaya and also mineral content of termite used greater than conventional vegetarian food, salmon fish and broiler chicken in sexual forms (Paul and Dey, 2011). Most of the tribal people of are also habituated with the consumption of Giant water bug (Lethocercus indicus), cricket, locusts, honeybee brood, especially late instar larvae and pupae *etc*. (Doley and Kalita, 2012). The commonly consumed insects of Assam are *Dorylus orientalis, Gryllus sp., Lethocercus grandis, Odontotermes obesus, Apis indica, Vespa sp., Agabetes acuductus or Hydrochera rickseckeri, Heiroglyphus bannian, Neoconocephalus palustris, Philosomia ricini, Antheraea assama, Bombyx mori, Acheta domesticus* etc. (Doley and Kalita, 2012). The Ahom community of Assam uses red tree ants (*Oecophylla smargdina*) as one of the food items during an Assamese festival Bohag Bihu during April month (Doley and Kalita, 2012). It is believed that these insects keep free from infection of diseases. The formic acid of these insects is being used in connection with scabies, malaria, tooth aches, stomach disorders, blood pressure anomalies *etc*. (Chakravorty *et al*., 2011b).

Traditional history

The current food production record may not be satisfactory according to world population and meat products consumption patterns due to climate change in particular area (Henchion *et al*., 2021). Some insect species are used in Western countries like Africa, Asia and Latin Americain (Baiano, 2020). These edible insectsare an ancient nutritional source that is followed by many customs over the globe. The name of some important well-known edible insects are present worldwide are shown in Table 1. The aim of western country is ensuring security of the meat-protein supply (Gómez-Luciano *et al*., 2019).

Insects are a part of the traditional diet for millions of people around the globe. Few insects can also cater to certain animals as food. Individuals living in tropical regions consume more insect-based food than temperate regions, the reason being, the climatic conditions in tropical regions are more suitable for the growthof these insects than in other temperate regions (Johansson *et al*., 2020). There are following insect such as *Macrotermes subhyalinus, Acheta domesticus, Rhyncophorus phoenicis, Alphitobius diaperinus, Ruspolia diferens, Gryllotalpa africana, Apis mellifera larvae, Nomadacris septemfasciata*, *Locusta migratoria*, *Rhynchophorus ferrugineus, Imbrasia oyemensis, Imbrasia epimethea, Oryctes monoceros, Cirina forda*, Nsike, Kigelegele, Kansenda, Bangwangwa, Maguina, Mingungu, Ngohangoha, Bikolongo and Bachache are recognised as a source of food in Fizi, Kabare, Mwenga and Walungu Territories (Ishara *et al*., 2022). Since the availability of insects is in abundance, the locals prefer insects in their food when compared with chicken, fish, and meat (Tim *et al*., 2019). Harvesting of these insects in the tropical region is far easier than the temperate regions, because insects frequently remain in cluster and enormous quantity; so can be captured easily, whereas in temperate regions during winter season insects go into hibernation for protect themselves from unfriendly weather. This reason, there are not many insects are available in unfavourable environment as their growth is halted (Shen *et al*., 2006).

Table 1: List of some worldwide available edible insect.

Insect common name	Zoological name	Reference
Rhinoceros beetle	*Allomyrina dichotoma*	Fan *et al.,* 2021
Flower chafer	*Protaetia brevitarsis*	Lee *et al.,* 2022
Mealworm	*Tenebrio molitor*	Tan *et al.,* 2022
Silkworm pupa	*Bombyx mori*	Khammuang *et al.,* 2022
Cricket	*Gryllodes sigillatus*	Zielinska *et al.,* 2018
Locust	*Schistocerca gregaria*	Labu *et al.,* 2022
Asian weaver ant	*Oecophylla smaragdina*	Pattarayingsakul *et al.,* 2017
Cotton leafworm	*Spodoptera littoralis*	Vercruysse *et al.,* 2005
Yellow mealworms	*Tenebrio molitor*	Chen *et al.,* 2019
Mexican katydid	*Pterophylla beltrani*	Montiel-Aguilar *et al.,* 2020
Boopies	*Boopedon flaviventris*	Kulma *et al.,* 2016
Grasshopper	*Sphenarium histrio*	Mariod *et al.,* 2011
Cockroach	*Blatta lateralis*	Elmadfa and Kornsteiner 2009
Soldier fly	*Hermetia illucens*	Józefiak *et al.*, 2016
Melon bug	*Aspongubus viduatus*	Kulma *et al.,* 2016
Honeybee	*Apis mellifera*	Finke, 2005
Mopane caterpillar	*Imbrasia belina*	Van Huis *et al.,* 2013
Stink bug	*Euschistus egglestoni*	Mariod *et al.,* 2011
Termite	*Macrotermes nigeriensis*	Belluco *et al.,* 2013

Table 2: General composition of nutrients, vitamins and minerals of edible insects.

Nutrients (%)	
Proteins	10.3%-70.7%
Essential amino acids	46.0%-96.0%
Fatty acids	10.5%-69.8%
Fibers	2.0%-25.1%
Ashes	2.5%-8.6%
Minerals and Vitamins (mg/100 g)	
Folic acid	0.5-0.9
Niacin	0.9-12.6
Riboflavin	1.4-11.1
Thiamine	0.1-3.4
Vitamin C	0.1-36.1
Minerals	(mg/100 g)
Calcium	24.5-210.0
Iron	5.5-229.7
Magnesium	33.1-1094.4
Phosphor	352.0-957.8
Potassium	259.7-2206.0
Sodium	44.8-435.1

Insects play an important role in the sector of food security in countries that are economically unstable due to which there is food sacristy. Since insects are rich in protein content, easily available in nature and require very less maintenance, individuals can consume insect-based protein foods instead of chicken, pork, fish and meat in economically under-developed countries (Raheem *et al*., 2019). Ants are the most consumed insects in several regions around the globe. Ants help in recycling nutrients from the environment but also behave as predators of pests in orchards (Diamé *et al*., 2017). The pupa form or famously called as ant eggs are used as a delicacy in most of Asia (Zhao *et al*., 2016).

Nutritional Value of Insects

Edible insects are varying in nutrient content depending upon their species type, habitat, metamorphic stage and diet (Meyer-Rochow *et al*., 2021) (Table 2). An approximate of 1,900 species was discovered edible insect and classified according to their orders. The maximum number of edible insects belong to the order Coleoptera (beetles) 31%, Lepidoptera (butterflies) 18%, Hymenoptera (bees/wasps) 14%, Orthoptera (crickets/grasshoppers) 13%, and the rest of the orders make up to23% of the total edible insect population and the most consumed insects species belong to the order Coleoptera (Lange and Nakamura, 2021).

Insects contain high levels of protein along with fats, carbohydrates, vitamins, and minerals. Few insects have been identified slightly higher level of proteins, fats and minerals as comparison with meat and fish (Shah *et al*., 2022). According to the Cheng and his co-worker, average amount of protein ranges from 35.37% for termites (Isoptera) and 61.32% for crickets (Orthoptera) (Patel *et al*., 2019). It has been reported that several grasshopper species contain about 77% (dry weight) of protein (Rumpold and Schluter, 2015). In Mexico, 87 consumable edible insects were explored, where the examination indicated that 15-81% was protein content and 76-96% was the insect protein digestibility.

The protein content of these insects was extremely like egg protein (95%) or bee (98%) and was also found to be more than plant proteins (Kuntadi *et al*., 2018).

Worldwide issues of protein production will be solved by edible insects, and it is considered as one of the most encouraging options for protein. The insect protein sources have low environmental cost of production; hence it essentially satisfies the global protein demand (Costa-Neto, 2016). Tang *et al*. (2019) have recorded essential amino acid proportion in edible insects that was differs from one species to another species. However, Illgner and Nel (2000) had observed 100g dry weight of insect contains about 32.59-76.69% of protein, 6.9-29.47% of fat, 0.92-30.76% of carbohydrates, 2.08-5.79% of ash and a total of 407.34-517.5 k/Cal energy. Based on their fatty acid profile, they generally have more unsaturated fatty acids than saturated fatty acids (de Castro *et al*., 2018). Among the main minerals, iron (Fe), zinc (Zn), potassium (K), sodium (Na), calcium (Ca), phosphorus (P), magnesium (Mg), manganese (Mn) and copper (Cu) have been described (van Huis *et al*., 2013). Edible insects could also be considered a dietary source of nutritionally important vitamins (B1, B2, B6, C, D, E and K) and antioxidant provitamins with functional properties (*i.e*., carotenoids) (de Castro *et al*., 2018). For example, thiamine content in edible insects has been reported in a range between 0.1 and 4 mg/100 g of dry matter.

Protein malnutrition

Malnutrition overall is not solely due to the deficiency of protein intake; it is also due to a less caloric diet. Malnutrition can be controlled from plant and animal-based proteins from daily meals, especially in developing countries. Tolerant individuals can use lactose as a substitute instead of consuming dairy products (Hertzler *et al*., 2020). Animal based proteins are recommended as a major part of the diet since it is covering a wide range of health risks such as malnutrition and hence considered as a good substitute due to its economic stability, high efficiency, nutritional values, and health benefits (Elmadfa and Meyer, 2017). Protein malnutrition is a type of deficiency in body which occurs due to absence of protein in dietary supplements under the food sources (Tao and Li, 2018). The alternate food sources are always supplying nutrition demand in developing countries. The immature insects (pupae and larvae) are main sources of abundant amino acids and fatty acids. It not only ensures nutritional value but also provide a unique flavor after dry or product formation. The crude protein amount is enriched 40-75% based upon dry weight (Zhou *et al*., 2022). Beneficial insects usually contain more crude protein in comparison to meat though as containing amino acid. They can provide all essential amino acids which are present in digestible form to absorb from the body (Orkusz *et al*., 2021). They grow faster than poultry animals (beef, veal, sheep, pig). Developing countries are facing more challenges related to food security when compared to develop countries because lack of resources and low economical status (https://www.fao.org/publications/sofi/2022/en). As people living in developing countries have no other choice of insect but edible insects is part of their diet compensate as source of protein in place of chicken and beef; since these are not easily accessible all societies (Kim *et al*., 2019). Preparation and collection of edible insects requires very less technical skill since these insects are readily present in the whole environment and easily recognised by the local person (Gahukar, 2020).

Source of bioactive compounds from edible insects

Insects are attracting human population by bioactive compounds and potential health (Shah *et al*., 2022). Bioactive compound reported in edible insects is β-carotene, which has been detected in some caterpillars of the species *Imbrasia oyemensis, I. truncata* and *I. epimethea* in values between 6.8 and 8.2 μg of β-carotene per 100 g of dry matter (Kouøimská and Adámková, 2016). Interesting content of various groups of polyphenols and their metabolites, such as kaempferol-3-O-glucoside and kaempferol-3, 7-di-O-glucoside as the primary compound, which- are believed to be a biotransformation product of plant kaempferol. Other compounds which are reported like myricetin-3-O-rhamnoside, quercetin3-O-rhamnoside, and kaempferol-3-O-rhamnoside (Nino *et al*., 2021).

Market of edible insect in food and feed industry

Globally, the edible-insect market is developed about USD 522 million by 2023 (Han *et al*., 2017). Edible insects are developing insect-based ingredients in the form of food products showing their original appearance (Mishyna *et al*., 2019). Insect-based animal feeds are particularly attractive if considering the cost of standard feeds, currently accounting for 70% of livestock-production expenses (van Huis *et al*., 2013). The most promising, well-studied candidates for industrial feed production are black soldier flies, larvae, yellow mealworms, silkworms, grasshoppers, and termites (Dobermann *et al*., 2017). Insect meal can partially replace commercial meal in broiler feed, particularly protein sources. For example, housefly-larvae meal can replace 4% of the fish meal in broiler diets without negative effects on carcass weight and feed efficiency (Awoniyi *et al*., 2003).

Another report indicated that broiler diets containing 31%, 26%, and 20% soybean meal can be successfully modified to contain 0%, 5% and 10% dried yellow mealworm, respectively (Ramos-Elorduy *et al*., 2002). As compared with commercial corn/soy-based diets, a housefly-larvae-based diet significantly increased the carcass weight, total feed intake and average daily gain of broiler chickens (Pretorius, 2011). However, a more recent study found that replacing soybean oil with black-soldier-fly-larvae meal has no impacts on the growth performance of broilers (Schiavone *et al*., 2017).

Philippines is consuming pasture-grown chickens fed with grasshoppers, resulting in higher price compared with chickens on commercial feed. The replacing fish meal with dried mealworm increased egg production by 2.4%. Fully replacing the protein content with larvae meal in a laying-hen diet did not negative affect feed intake, feed conversion efficiency, egg production hen health and immune status (Marono *et al*., 2017).

Use of edible insect in laboratory diet

Laboratory diets have some advantage over natural plant material for rearing silkworms; such diets are semi-synthetic and can be used for several speciesdiet (Meyer-Rochow *et al*., 2019). Developed artificial diet contains rice seed head, finger millet seed head, wheat bran, chicken egg buster, sorghum seed head, germinated finger millet, sim-sim cake, crushed dog biscuit pellet and shea butter (Rutaro *et al*., 2018). This type of diets is rich with linoleic acid and fatty acid composition. The essential fatty acid increased by adding grasshoppers in diets. Ghaly (2009) was prepared a diet from dry ingredients (corn flour + whole wheat flour + wheat bran + dried yeast powder mixed in a ratio of 3:3:3:1, by weight) and liquid ingredient (glycerine + honey mixed in 1:1 ratio, by weight).These ingredients mixed in a 1:1 ratio in plant material (*Gonimbrasia belina* and *Anthoaeraz ambezina*) and used for diet in Zambia.

The *G. belina* larvae included on a semi-synthetic diet (corn starch + vegetable oil + glucose + cellulose + mineral mix + vitamin mix + protein) contained 7.1% carbohydrates, 35.2% protein, 15.2% fat and 7.4% ash In Nigeria. These contents were comparatively low in larvae fed only natural plant biomass (Ekpo, 2011). These diets are common with other lepidopteran larvae consumed in Africa. It is containing 40% stover (corn) by weight. After analyses it showed that the larvae contained all the essential amino acids in 32 days. The insects completed metamorphosis and all larvae survived on a 100% stover diet for multiple generations. Therefore, this diet can be recommended for the rearing of Tenebrio and possibly some other beetle species in the laboratory. Indoor rearing can be further improved by fortifying the laboratory diet. For example, Vitamin D-enriched diet by *B. mori* larvae prepared by De Wit (2017). There were significant changes in the content of the macro nutrients compared with diets that had not been fortified, *e.g*. increases in protein (61.2% versus 58.8%) and reduction in fat (37.3% versus 39.5%). The addition of the commercial protein supplements Nutrilite increases by, larval instars of *B. mori* and fibrous protein by 68% and 56%, respectively. This dietis prepared from edible insects to obtain a greater amount of nutrients from the insect biomass.

On average, the content of essential amino acids ranges between 46% and 96% of the total amount of amino acids (Xiaoming *et al*., 2010). Some species of insects contain significant amounts of lysine, tryptophan and threonine, which are deficient in certain cereals and tubers. Thus, the resulting nutritional deficiency could be compensated by the consumption of insect species with high amounts of the amino acids that are lacking in these traditional foods. Taken together, these data demonstrate and support the potential use of edible insects in the food and nutritional industry. Edible insects contain an average of 10%-70% fat in dry matter, which is higher in the larval and pupal stages than in adults (Kouøimská and Adámková, 2016). The distribution of fats in edible insects varies. Triacylglycerols make up approximately 80% of the total fats, while phospholipids represent the second most important group, with a content generally less than 20%, depending on the life stage and the insect species.

Edible insects are capable of providing economical benefits, since they seem environmental friendly than other animals (Halloran *et al*., 2018). According to growing population a substantial increase is required for food production. This development will decrease heavy burden on limited natural resources, such as energy, water, land and oceans. Environmental degradation and significantly elevated greenhouse gas emissions are decrease food production in present form. Raising livestock will contribute environmental problems, since approximately 70% global agricultural land use also will be free (FAO, 2021, https://www.fao.org/indigenous-peoples/our-work/monitoring-forests/en/). Huge environmental costs are incurred by the large-scale facilities producing livestock and fish. For example, manure contaminated both groundwater and surface water with pathogens, heavy metals and other toxins and spreading manure may create emission to large quantities of ammonia with acidifying effects on ecosystems (Rashmi *et al*., 2020).

CONCLUSION

This review has explained about the importance of consuming edible insects in the part of the diet and different types of health benefits possessed by eating these insects are an excellent source of lipids, proteins, amino acids, peptides micro and macro nutrient. Starvation and malnutrition can be solved by implementing entomophagy in the form of balanced diet and that rich to protein content and protein recovery. Using edible insects as part of the diet has many advantages for all the age groups. Hence, researchers must focus more on finding out new strategies and ways to incorporate edible insects as part of the daily diet during 2050, world meat consumption will be increase about 44% due to population is increasing. Alternate food sources must be made available before the world runs out of food. Insect based diet has proven to be healthier than the regular diet consumed by humans. Many countries in the tropical regions insects used as daily diet. These insects are easily available in her environment due to the favorable conditions; hence insects can help in covering the food shortage in tropical countries. Western peoples are used insects not only for nutrition and also consuming for fun. However it is still concerned that utilization of edible insects are more healthy and safe than beef. The market of edible insects is not synchronous benefits they are in initial stage.

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Conflict of interest

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