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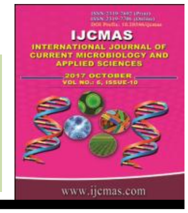

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Entomophagy: A Viable Opportunity for Food Security

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A B S T R A C T

For rapid growing population, production of animal protein source in a sustainable manner is very difficult from conventional protein source under climate change scenario. Insects are the best alternative food source for conventional livestock. Entomophagy is one of the viable option to meet the global animal protein demand. Eating of insects has several advantages over consumption of conventional animals includes nutritional, environmental, social and economical opportunities. Several insect species are reared as feed for poultry and aquaculture. Insects are also used in world food programmes to alleviate malnutrition in children by improved use of traditional food. Insect harvesting or rearing is low tech and low investment option that gives the opportunities for both urban and rural people. Though edible insects are promising alternative for the conventional production of meat, either for direct human consumption or for indirect use as feedstock, nevertheless, a tremendous amount of work still needs to be done to fully realize the potential that insects offer for food security.

Introduction

In the world about 795 million people of the 7.3 billion people, which accounts one in nine, were suffering from chronic undernourishment by 2016, mostly belongs to developing countries (FAO, 2015). The world population reaches above 9 billion by the 2050, feeding this growing world population with decreasing arable land for cultivation under the pressure of climate change scenario predictably increases the pressure on already inadequate resources such as land, water energy and fertilizers, which leads to deforestation and environmental degradation and increases in greenhouse gases (GHG) emissions. Hence, we need to think the alternate food sources and pattern of food consumption, which can combat with problems such world hunger and global climate change (Sachs, 2010). FAO emphasizing the entomophagy *i.e.*, insects as food to overcome the above said problems because eating insects offers several opportunities over the others such as nutritional, environmental, social and economic benefits.

History of entomophagy

Entomophagy is a not newly evolved concept, people are practicing from ancient times. Aristotle (384-322 BCE) mentioned about entomophagy, where he described taste of adult female cicada in his *Historia Animalium* (Bodenheimer, 1951). Li Shizhen included many of edible insect species, which mainly used for medicinal purpose from ancient China in his famous book, Compendium of Materia Medica, which is one of comprehensive books on Chinese medicine. An eminent American entomologist C. V. Riley appointed as first State Entomologist for the state of Missouri and studied the outbreak of the Rocky Mountain locusts, which covers over large area in most of western part of the country during nineteenth century. He suggested that eating of the locust is the only viable option for control (Lockwood, 2004).

Status of entomophagy in the world

The most common insects species used in worldwide for food purpose belongs to the order Coleoptera, which estimates around 31 percent, followed by Lepidoptera, estimated at 18 percent, which are mostly used by sub Sahara African people. Hymenopteran insects such as bees, wasp and ants widely used by in Latin American people, accounts 14 percent in total entomophagy. Followed by Orthoptera (grasshoppers, locusts and crickets) estimated around 13 percent, Hemiptera (planthoppers, scale insects, cicadas, leafhoppers,) 10 percent; Isoptera (termites) 3 percent; Odonata (dragonflies) 3 percent, Diptera (flies) 2 percent and remaining orders occupied 6 percent (Van Huis *et al.,* 2013). The feeding stages of insects vary from order to order for example both adults and larvae of the beetles (Coleoptera) are eaten, Lepidopterans mostly consumed as caterpillars and rarely pupae also consumed and Hymenopterans are consumed mostly in their larval or pupal stages. While mature stages of Orthoptera, Homoptera, Isoptera orders are mostly eaten (Cerritos, 2009).

The estimation of actual number of edible insects' species is very difficult because mostly entomophagy observed in tribal people, who use different vernacular names for describing a species in different regions. However some attempts were made to estimate number of edible insect species all over the world. From Africa around 250 (Van Huis, 2005), Mexico 549 (Elorduy *et al.,* 2008), China 170 (Chen *et al.,* 2009) edible insect species were reported. Paoletti and Dufour (2005) were reported 428 edible insect species from Amazon.

Nutritional values of edible insects

The nutritional values of edible insects are highly variable because of its richness in species diversity. Even within same insect species also differences exist in nutritional values depending on the stage of the insects (egg, larvae, pupa and adult in case of holometabolous insects and egg, nymph and adults of hemimetabolous insects) and their food sources, habitat, preparation and processing methods (Oonincx and Dierenfeld, 2011). Even though existence of difference in of nutritional composition most of the edible insects offers reasonable amount of dietary energy, essential amino acids, fatty acids, macro and micro vitamins and minerals.

Dietary energy

Elorduy *et al.,* (1997) estimated energy content in 78 insect species obtained from Mexico, which ranges from 293–762 kilocalories per 100 g of dry matter. Oonincx and Poel, (2011) estimated total energy of *Locusta migratoria* (migratory locust) which ranges between range 598–816 kJ per 100 g fresh weight. *Oecophylla smaragdina* (weaver ant) and *Chortoicetes terminifera* (Australian plague locust) from Australia have 1272 and 499 Kcal/ 100 gm fresh weight respectively. *Gryllus bimaculatus* (Field cricket), *Lethocerus indicus* (Giant water bug), *Oxya japonica* (Rice grasshopper) and pupa of

Bombyx mori (Domesticated silkworm) from Thailand having energy content of 120, 165, 149 and 94 Kcal/ 100 gm fresh weight respectively (FAO, 2012f).

Proteins and amino acids

The protein and amino acid content varies from species to species and largely depends on the feed and preparation. For example mopane caterpillar has protein content 48 percent when dry roasted, 57 percent when simply dried. In case of termites protein content 20 and 32 percent, in raw form and fried fresh weight respectively (Bukkens, 1997). The protein content of different species from a number of insect orders ranges from 13 to 77 percent of dry matter. Protein content in larvae and adults of Coleoptera, larvae and pupae of Lepidoptera and nymph and adults of Orthoptera ranges from 23 to 66, 14 to 68 and 23 to 65 percent respectively (Xiaoming *et al.,* 2010). This high quality and quantity protein present in insects can help increase dietary quality.

Insects enriched with almost all essential aminoacids. Many of the Saturniidae family caterpillers, larvae of palm weevil and aquatic insects have lysine 100 mg per 100 g crudeprotein (Bukkens, 2005). Traditional entomophagy in several developing and underdeveloped countries helps in supplementing the amino acids by providing missing amino acids in staple food. For example the staple food of the Democratic Republic of the Congo cereals, which is deficient of lysine content this nutritional gap fulfilled by consuming of lysine-rich caterpillars. Same way tubers are staple food of Papua New Guinea people, which are deprived of lysine and leucine, so these peoples compensate this nutritional gap by intake of palm weevil larvae (Bukkens, 2005). Maize eating African countries such as Kenya, Nigeria, Zimbabwe and Angola suffering from tryptophan deficiencies this problem overcome by consuming temite species like *Macrotermes bellicosus*, which widely followed by Angola people (Sogbesan and Ugwumba, 2008).

Fat content

Edible insects consist of substantial amount of polyunsaturated fatty acids and essential amino acids such as linoleic and α-linolenic acids which play important role in growth and development of children (Michaelsen *et al.*, 2009). Edible grasshopper (*Ruspolia differens*), African palm weevil (*Rhynchophorus phoenicis*) having fat content from 67 and 54 percent respectively with palmitoleic acid and linoleic acid as major fatty acids. Termites (*Macrotermes* sp.) and Saturniid caterpillar (*Imbrasia* sp.) having fat content 49 and 24 percent respectively with Palmitic acid and Oleic acid as main fatty acids composition (Womeni *et al.,* 2009).

Micronutrients and minerals

Micronutrients including vitamins and minerals are most important for growth, development and health. The micronutrient deficiencies prevalent in developing and underdeveloped countries due to inaccessibility of quality food sources. In developing countries specially pregnant women and about 40 percent of preschool children suffering from anemia. About 250 million preschool children are vitamin-A deficient (WHO, 2016). Iron contents in most of the edible insects having equal or higher than beef (Bukkens, 2005). Where, beef has an iron content of 6 mg, while the iron content of the mopane caterpillar is 31 to 77 mg per 100 g of dry weight. Zinc deficiency is another major problem in children, which leads to suppression of growth, skin problems, delayed bone and sexual maturity and failure of immune system leads to more infections (WHO, 2016). Most insects are rich source of zinc. Example larvae of *Rhynchophorus phoenicis* (Palm weevil) contain 26.5 mg zinc per 100g, whereas beef contains only 12.5 mg per 100 g (Bukkens, 2005).

Many of insects contain thiamine (vitamin B1) between range of 0.1-4 mg and Riboflavin (vitamin B2) ranges between 0.11 and 8.9 mg per 100 g of drymatter (Bukkens, 2005).

Vitamin B12 present in several species of insects such as yellow mealworm larvae (*Tenebrio molitor*), adult of house cricket (*Acheta domesticus*), which estimated about 0.47 µg and 5.4 µg per 100 g, respectively (Bukkens, 2005). Freeze dried and powdered silkworm (*Bombyx mori*) is rich source of Vitamin E, which contains 9.65 mg per 100 g (Tong *et al.*, 2011).

Insects considered as source for fibre, which is in the form of chitin, which is a polymer of N-acetyl glucosamine. Chitin is similar to the polysaccharide cellulose found in plants, which is largely believed to be indigestible by humans, even though chitinase has been found in human gastric juices (Paoletti *et al.*, 2007). This chitin can play role as dietetic fibre (Muzzarelli *et al.*, 2001)

Role of entomophagy to battle with malnutrition

Many countries focusing on use of edible insects to alleviate the malnutrition which is very prevalent in developed and under developed countries, among that Denmark came up with Win Food project which is supported by the Consultative Research Committee for Development Research and Danida. The main aim of this project to develop nutritionally improved foods for newborns and children, by concentrating on traditional food systems based on wild native plant or animal food sources such as fruits, roots, fish, snails, frogs and insects. At the same time Cambodia and Kenya also developed Winfood projects based on locally available food sources, where Cambodia uses rice, fish and spiders (*Haplopelma albostriatum*) and Kenya uses amaranth grain, maize, fish and termites (*Macrotermes subhyalinus*) in its Win Food composition (FAO, 2013; Van Huis *et al.*, 2013).

Fortified blended food products (FBFs), which are the blends of partly precooked and milled cereals, and pulses, fortified with micronutrients, aims to offer protein and micronutrient supplements in food assistance programmes during emergency periods. Chance of using edible insects in FBFs products should be considered because of their protein, micronutrient availability and their cultural suitability in a majority of developing countries (FAO, 2013; van Huis *et al.*, 2013).

Environmental benefits

Livestock, poultry, beef and fish are the major animal protein source for human consumption. Production of these animal protein viable for short term only because these production of animal protein cause vast environmental costs. During production of beef, manure is the subsidiary product, which contaminates surface and ground water (Thorne, 2007). On the other hand if any increase in livestock production needs to be accommodating additional arable land to growing feed, which leads to deforestation (Steinfeld *et al.,* 2006). Hence, other alternate protein source cultured meat, seaweed, beans, fungi and insects (Sachs, 2010). Among these insects as protein source offers great environmental benefits like they have high feed conversion efficiency, can be grown on waste products such as manure and biowaste, produce relatively less greenhouses gases, require less amount of water *etc*.

Feed conversion efficiency (FCE)

It is defined as the capacity of an animal to convert feed into body mass, expressed as kg of feed per kg of weight gain. FCE is more for insects since they are poikilothermic, which doesn't waste much energy to maintain body temperature. For example, the production of 1 kg weight of crickets requires 1.7 kg of feed (Collavo *et al.,* 2005), where as in the case of chicken requires 2.5 kg, pork requires 5 kg and beef requires 10 kg of feed (Smil, 2002). If we compare edible portion of insects and other livestocks, insects have high percentage of edible and digestible portion. For example crickets having 80 percent of edible and digestible portion, where as 55 percent in chicken and pigs, 40 percent in cattle (Nakagaki and DeFoliart, 1991).

Production of greenhouse gases

Greenhouse gases are major reason for global warming. GHGs are produced in several ways such as fossil fuel consumption, industrialization and agriculture and allied activities such as fertilizer production for crops, on-farm energy expenses, fodder transport, animal waste processing (manure), enteric fermentation in ruminants and from farm animal manure. GHGs production per kg of mass gain from three insect species such as mealworm larvae, crickets and locusts studied by Oonincx *et al.,* (2010), revealed that all three insect species produce less GHGs as well as ammonia compared to per kg of mass gain from pigs and beef cattle. Insect species such as termites, cockroaches and scarab beetles produce methane due to the bacterial fermentation (Hackstein and Stumm, 1994; Egert *et al.,* 2003). However insect species such as mealworms, crickets and grasshoppers which are economically suitable for mass production has less GHGs production characters remains the viable options for producing alternate food source.

Water use efficiency

Water availability plays a major role in determine the productivity crops. Water scarcity already hits the many parts of the world and it was estimated that by the 2025 about 1.8 billion people will going to face absolute water scarcity and two third of total population under water stress (FAO, 2012b). About 70 percent of fresh water used for Agriculture (Pimentel *et al.,* 2004).

The virtual water (water required for production of commodity including all stages) requirement for production of 1 kg of chicken, pork and beef estimated around 2300 litres, 3500 litres and 22000 litres respectively. In case of cattle it may reach up to as high as 43000 litres (Pimentel *et al.,* 2004). Since many of insects such as mealworms, crickets more drought tolerant and having higher feed conversion ratio than other live stocks, emphasizing the possibility of production of insects with less virtual water requirement.

Biowaste: from burden to resource

Edible insects can be grown even biowaste and other organic side streams such as manure, compost. Several insects species such as *Hermetica illucens* (black soldier fly), *Musca domestica* (house fly) and *Tenebrio molitor* (yellow mealworm) can bioconvert organic waste in an efficient manner (Veldkamp *et al.,* 2012). Indirect use of insects reared on organic side streams is that, the developed insects either in filly grown larvae or pupal stage can be used as feed for animals, which are reared for meat purpose (Veldkamp *et al.,* 2012). Other benefits of growing insects have several advantages over conventional livestock farming like less land area and energy requirement for production of insect protein compared to production of other protein sources. For example production of milk protein, chicken protein and beef protein requires 2.5, 2-3.5 and 10 times more land area for production of similar quantity of mealworm protein, respectively. Energy required for the production of 1 kg of mealworm protein was lower than for beef and pork but slightly higher than for chicken and milk. However production GHGs and global warming potential of mealworms is less compare to production of common animal proteins such as milk, pork, chicken and beef (Oonincx and Boer, 2012).

Insect farming

Rearing of silkworms for production of silk started in 5000 years ago (Yi *et al.*, 2010). Many people, who practicing entomophagy across the world, gather edible insects such as termites, bugs and grasshoppers from field or forest areas. Around 94 percent of edible insects harvested from wild, 6 percent sem-domesticated and 2 percent farming (Jongema, 2014). Insect farming for human consumption has been practicing some parts of the world. Semi-cultivation practiced in some parts of the world, where the habitat of edible insect modified to ensure year round availability (Itterbeeck and van Huis, 2012). Typical example for semi-cultivation is deliberate cutting of palm trees in a selected place and time to ensure harvesting of large number of grubs of *Rhynchophorus palmarum*, *R. phoenicis* (Africa), *R. ferrugineus* after one to three months (Choo *et al.*, 2009). Insect farming can be carried out in urban and rural areas (Oonincx and de Boer, 2012) and having many advantages such as require less space, high reproductive rate, income generation within a short period, easy to manage, easy to transport (FAO, 2011b). In Thailand cricket species such as *Gryllus bimaculatus* and *Acheta domesticus* are commercially being reared (Hanboonsong, 2012). Other insects such as mealworms and grasshoppers are also mass reared for human consumption. The Expert Consultation Meeting on Assessing the Potential of Insects as Food and Feed in Assuring Food Security, held at FAO, Rome in 2012, made recommendations for improving the mass production technologies by adapting mechanization, automation to reduce production costs; Food and feed safety issues such as extensive study to identify potential insect allergies and chitin digestibility in humans; Supporting of entomophagy in areas where it is already present; educate the people about benefits entomophagy; develop the methods to integrate edible insects into regular diets; efficient use of organic waste; and developing marketing strategy to reach the consumers.

Insects were used as a source of food from ancient times and will be continue for future generations too. Insects, because of their high reproduction rate, high energy conversion rate, short life period and short space requirements will provide one of the viable alternative opportunities for food security. International, national and public private institutions have to be work together and develop new technologies related to entomophagy. Lack of awareness among the consumers is one of the major drawbacks by this way entomophagy industry is still in infancy stage. Considering nutritional qualities and environmental benefits of edible insects over conventional meat producing animals, entomophagous industry can play important role in achieving global food security. Edible insects may not necessarily main source of food to the humans but it supplements the existing food sources. The insects can also mass reared as a feed for livestock, poultry and fish, by which we can reduce the competition between animals and humans for food grains. However still there is a great research is need to explore edible insects nutritional status like carbohydrate, protein, fat content and their biosafety then only we can drag the attention of consumers towards the entomophagy. The further exploration should carried out for identifying edible insect species and assessing their nutritional, environmental factors and their viability to mass produce. The strategies for sustainable harvest of edible insects from forest should be developed. Since, current production systems are expensive, research is needed to develop low cost methods to reduce the production cost.

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