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Review Article

INSECTS: A NEW FOOD SOURCE

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Abstract: The world population approaching 9 billion by 5050 and the changing climate along with conflict ridden countries, the future of food supply isn't favourable. There is a need to explore unconventional sources of food. Insects are a sustainable option to this challenge as they have good nutritional content and can convert food side-streams into edible food. They can be potential solution to current world hunger and malnutrition issue and address the problem of organic waste. More than 3500 species of insects are known to be consumed by more than 2 billion people in the world today, but they are still considered non-traditional due to low acceptability. Insects are rich in protein, energy, essential fatty acids and amino acids in comparable quantities to traditional meat and plant based foods. They can grow in almost every climate and their nutrient composition depends on their diet, climate and stage of metamorphic. They are eaten as whole, can be dried and stored or processed into foods or used as ingredients in traditional foods.

Keywords: *Food Source, Plant based foods*

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Introduction

FAO estimated that more than 820 million people in the world face hunger every day, with the number likely to rise in future years. 811 million people are undernourished which accounts for roughly 10% of world's population [1]. The situation of malnourished is especially alarming for children and women of reproductive age. 21.9% children around the world are stunted, 8.5% are wasted. 32.8% women of reproductive age in the world face anaemia, which puts them and future children they might have at risk. Africa and Asia about 90% of world's undernourished. Situation in Africa is especially dire with 52.4% of population facing moderate and severe food shortage and 21.5% people facing food insecurity. Drought and conflict are the main causes of hunger around globe. Changing climate and increasing world population will only worsen the production of food and food availability and this calls for new food sources to be explored. Insects provide a sustainable solution to this issue as novel source of food. The practice of eating insects is called as entomophagy or human entomophagy (when humans consume insects). Historic evidence suggests that early consumes insects for nutrition [2]. Although it might seem uncommon, insects are consumed by general populace in Africa, Thailand, China, Australia, etc. Insects that are consumes in these places are grasshoppers, locusts and crickets (Orthoptera) (13%), cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) (10%), termites (Isoptera) (3%), dragonflies (Odonata) (3%), flies (Diptera) (2%) and other orders (5%) are the most commonly consumed insects [3]. More than two billion in 113 countries around the world already practice human entomophagy. Insects as are used as direct source of food or as a food ingredient [3, 4]. Although, it is said that insects are a non-traditional source of food, the fact that half the countries and more than one fourth of world's population already consumes them states otherwise. [5] reported production of insects as food source is 2-5 times more environmentally friendly and sustainable than traditional food production systems. Insects can also utilize waste products/side streams of current food production and processing industry and turn it into valuable source of food. Thus, insects can both be a solution of food insecurity and unsustainable food production. More than 3500 species of insects have been recorded to be consumed [6]. They are rich in energy, carbohydrates, proteins, have a superior amino acid profile, contain essential fatty acids and are rich in vitamins and minerals [7-9]. Additionally, insects can be source of livelihood development in the regions where they can be reared and grown and bring about economic development especially in developing and under-developed countries. The aim of this this review is to shed some light on nutritional profile of insects all around the world with hope to alleviate their use.

Nutritional Composition of edible insects

Edible insects are rich in protein and energy and contain essential amino acids and fatty acids. Their nutritional composition is influenced by factors such as diet, climate and stage of metamorphic. Insect of the same species and variety may have considerable difference in nutrient composition owing to their diet [10]. Decrease in protein content and increase in fat content (633 vs. 583 and 182 vs. 231 g/kg dry mass, respectively) of locust due to variation in diet (addition of wheat bran) was reported by [11]. Addition of carrots in locust in the same study further increased the fat content (231 to 271g/kg dry mass). Addition of wheat bran in locust diet decreased the β-carotene concentration whereas addition of carrots in the diet increased the β-carotene concentration. This offers us a chance to change the diets of insects in accordance with the nutritional need of the consumers.

Energy and fibre content

The energy content of insects depends on their composition, especially the fatty acid profile and protein content. Fats contribute greatly to the energy present in the food. The energy content relates inversely to the protein content and directly proportional to fat content in an insect. Also, adult insects generally have less energy than larvae or pupae.

Table-1 *Energy, protein and fibre content of edible insects*

Common name	Species	Consumption stage	Energy (kcal/100g)	Protein (%)	Fibre (%)	Reference
Termites	*Syntermes* soldiers	Adult	502.86	64.72	23.03	[20]
	Macrotermes bellicosus	Adult	696.10	40.72	5.27	
Crickets	*Brachytrupes spp*	Adult	536.42	65.35	13.29	
Short-horned grasshopper	*Chondacris rosea*	Adult	373	68.89	12.38	[7]
Mole cricket	*Brachytrupes orientalis*	Adult	381	65.74	8.75	
Beetles	*Allomyrina dichotoma*	Larvae	-	54.18	4.03	[8]
	Protaetia brevitarsis	Larvae	-	44.23	11.06	
	Tenebrio molitor	Larvae	-	53.22	6.26	
Cricket	*Teleogryllus emma*	Adult	-	55.65	10.37	
	Gryllus bimaculatus	Adult	-	58.32	9.53	
Scarab beetles	*Lepidiota mansueta*	Adult	379.29	76.42	5.16	[21]
	Lepidiota albistigma	Adult	371.04	68.54	6.73	
Mealworm	*Gryllodes sigillatus*	Adult	452	70.00	3.65	[14]
Locust	*Tenebrio molitor*	Adult	444	52.35	1.97	
Cricket	*Schistocerca gregaria*	Adult	432	76.00	2.53	
Javanese grasshopper	*Valanga nigricornis* Burm.	Imago	407.34	76.69	3.99	[10]
Paddy locust	*Nomadacris succincta* L.	Imago	421.79	65.42	4.93	
Cricket	*Gryllus* sp.	Imago/nymph	515.84	32.59	3.24	
Silkworm	*Bombyx mori* L.	Pupae	509.03	60.03	3.79	
Giant mealworm	*Zophobas morio* F.	Larvae	517.50	49.96	6.53	
Yellow mealworm	*Tenebrio molitor* L.	Larvae	498.68	38.30	4.63	

The energy content of insects ranged from 293 kcal to 762kcal/100g fresh weight in a study conducted in Mexico [12]. An increase in protein content of locusts was proportional to decrease in fat content and hence decrease in energy content which was in turn influenced by the diet of locust [11]. A study conducted by [13] demonstrated that 100g of fresh insects had comparable calories to common meat products, excluding pork.

Protein content

Insect proteins have favourable protein profiles and can replace/complement the traditional sources of food [14]. Ramos-Elorduy *et al.* [12] examined protein content of 87 species of insects across 10 order and found protein ranging from 15-81%. The digestibility of these proteins was comparable to those of egg, beef and even higher than some plant proteins. The concentration of proteins in an insect also depend on stage of metamorphic. Adult wasps have been reported to have more protein than pupa and larva stage Yin *et al.* [15]. Variegated grasshopper, *Zonocerus variegatus* (raw), also had higher protein in its adult stage (21.4%) than instars [16]. The protein content may also be affected by the processing method or its lack thereof. Bukkens, [17] reported higher protein in dried (57%) mopane caterpillar than in dry-roasted (48%). The diet of insects has also been reported to affect the protein concentration of insects [16]. Bran fed grasshoppers in Nigeria had higher protein content than the ones fed on maize. The difference in protein content of *Eulepida mashona* and *Henicus whellani* samples collected from different location in Zimbabwe had varying protein content and amino acid profile [18]. Xiaoming *et al.* [19] reported that essential amino acids made up 46-96% of proteins in more than 100 edible insects. Insects have been reported to be rich in essential amino acids like phenylalanine, tyrosine, lysine, tryptophan, and threonine [4]. Studies conducted by Chakravorty *et al.* [7] on 2 edible species of insects in Arunachal Pradesh (India) concluded that more than half the dry weight of insects consisted of protein. As for protein quality, insects had more concentration of essential amino acids than recommended by FAO/WHO/UNO. Similar results regarding the quality of insect protein quality were reported by [8]. House crickets contain the required amount of cysteine and methionine as recommended by WHO [14].

Fat content

Insects have been reported to be a good source of lipids and fats. Triglycerides form 80% of insect fat, followed by phospholipids [22]. The exact composition of fat however depends on metamorphic stage of the insect. There was a great variation in fat content of species of the same insects. *Homorocoryphus nitidulus*, a species of cricket in Cameroon had more than 50% fat on dry weight basis [9]. Whereas *Brachytrupes* spp, another cricket species from northern Uganda had contained only 11.76% fat on dry weight basis [20]. Thus, diet and climate can have tremendous effect on fat content on insects. Womeni *et al.* [9] investigated fat content and composition of several insect species and reported fat content ranging from 6-67%. The fat was rich in poly-unsaturated fatty acids and contained essential fatty acids linoleic acid and α-linoleic acids. The ratio of PUFA/SFA was higher than 8.0, which is associated with good cholesterol. Similar trends in insect fatty acids composition was reported by [7, 8, 14, 20]. All these studies also reported a higher concentration poly-unsaturated fatty acids and mono-unsaturated fatty acids than saturated fatty acids, which are good for health. The concentration of PUFA and MUFA was more than 50% of total fat in *Rhynchophorus phoenicis* (Raphia weevil), *Zonocerus variegates* (grasshopper), *Homorocoryphus nitidulus* (cricket), *Protaetia brevitarsis* (beetle), and *Teleogryllus emma* (cricket) species [8, 9, 20]. Every edible insect assessed for fat content exhibited the presence of essential fatty acid, linoleic acid or α-linolenic acid or both ranging from 20-60% of total fat content. Cholesterol, campesterol, stigmasterol, β-sitosterol and other sterols constitute minor lipophilic content of insect fat [23]. The fatty acids composition of insects has been reported to depend on their feed [24]. Insects with high fat content are also a high source of energy. For example, mealworms contain 25% fat and are thus have high energy content [25].

Vitamins and minerals

Micronutrients like vitamins and minerals are as important as macronutrients in diet and play an important role in biological processes. Edible insects are rich in mineral and certain vitamins or their precursors. Micronutrient content of insects vary across species, orders and is also influenced by diet, climate and growth stage. Consuming the whole insects generally increases the nutritional content. [17] reported the presence of Vitamin A, thiamine, riboflavin, niacin, pyridoxine, folic acid, pantothenic acid, biotin and cyanocobalamin in several caterpillar species. Similar trends for presence of vitamins were reported by [26, 27]. Several species of termite, rhinoceros beetle, snout beetle, honey and caterpillar contained more riboflavin (vitamin B2) than the RDA suggested by FAO. They also contained appreciable amounts of ascorbic acid and retinol. Insects are also rich in minerals, ergo, sodium, potassium, calcium, phosphorus, iron, manganese, magnesium, zinc and copper [11, 17, 26, 27]. Most edible insects have higher content of iron than beef [24]. Mopane caterpillar (31-77mg/100g) has 6-12 times the iron content of beef (6mg/100 DW). The iron content in locust ranges from 8-20 mg/100g DW and it depends on their diet. Ground and freezer dried silkworm powder were rich in Vitamin E (9.65 mg/100g) [28].

Table-2 *Fat content and its composition in edible insects*

Common name	Species	Fat content (% DW)	Major fatty acids	% of oil content	SFA %	PUFA %	MUFA %	PUFA/SFA	Ref
Raphia weevil	*Rhynchophorus phoenicis*	54	Palmitoleic acid	37.60	3.94	50.86	43.63	*16.70*	[9]
			Linoleic acid	45.46					
Edible grasshopper	*Zonocerus variegates*	67	Palmitoleic acid	23.83	2.34	58.36	34.96	*24.84*	
			oleic acid	10.71					
			Linoleic acid	21.07					
			α-Linolenic acid	14.76					
			γ-Linolenic acid	22.54					
Termites	*Macrotermes* sp.	49	Palmitic acid	30.47	40.31	9.41	49.73	0.23	
			Oleic acid	47.52					
			Oleic acid	9.06					
			α-Linoleic acid	38.01					
Cricket	*Homorocoryphus nitidulus*	~50	Palmitoleic acid	27.59	0.59	62.39	34.75	105.75	
			Linoleic acid	45.63					
			α-Linolenic acid	16.19					
Termite	*Syntermes* soldiers	30.5	Stearic acid	9.18	14.83	19.62	37.64	1.32	[20]
			Oleic acid	37.64					
			Linoleic acid	16.74					
Termite	*Macrotermes bellicosus*	44.84	Palmitic acid	27.71	40.06	9.55	49.93	0.24	
			Stearic acid	11.59					
			Oleic acid	47.73					
Cricket	*Brachytrupes* spp	11.76	Palmitic acid	21.31	39.44	24.68	39.23	0.71	
			Stearic acid	12.24					
			Oleic acid	38.27					
			Linoleic acid	22.14					
Beetle	*Allomyrina dichotoma*	20.24	Palmitic acid	31.72	34.24	4.00	45.95	NG	[8]
			Oleic acid	39.23					
	Protaetia brevitarsis	15.36	Plamitic acid	11.78	15.36	6.77	61.98	NG	
			Palmitoleic acid	10.48					
			Oleic acid	51.11					
	Tenebrio molitor	34.54	Plamitic acid	13.64	20.09	22.52	48.00	NG	
			Oleic acid	45.05					
			Linoleic acid	21.92					
Cricket	*Teleogryllus emma*	25.14	Palmitic acid	12.17	14.36	40.37	31.90	NG	
			Oleic acid	27.76					
			Linoleic acid	38.23					
	Gryllus bimaculatus	11.88	Palmitic acid	18.18	27.36	36.45	26.35	NG	
			Oleic acid	24.50					
			Linoleic acid	34.93					
Short-horned grasshopper	Chondacris rosea	7.88	Palmitic acid	17.24	35.25	41.61	23.14	NG	[7]
			Stearic acid	12.42					
			Oleic acid	21.12					
Mole cricket	*Brachytrupes orientalis*	6.32	Palmitic acid	50.32	85.57	2.98	11.47	NG	
			Stearic acid	32.06					
Mealworm	*Gryllodes sigillatus*	18.23	Palmitic acid	23.5	33.74	31.93	34.33	NG	[14]
			Oleic acid	29.14					
			Linoleic acid	29.78					
Locust	*Tenebrio molitor*	24.7	Palmitic acid	18.00	25.32	31.37	23.27	NG	
			Oleic acid	40.86					
			Linoleic acid	29.68					
Cricket	*Schistocerca gregaria*	12.97	Palmitic acid	23.26	35.30	26.28	38.35	NG	
			Oleic acid	36.22					
			Linoleic acid	14.04					

SFA: Saturated fatty acids, PUFA: Poly-unsaturated fatty acids, MUFA: Mono-unsaturated fatty acids, NG: not given

Bukkens *et al.* [24] reported high concentration of α-tochopherol (35mg/100g) and γ+β-tochopherols (9mg/100g) in palm weevil larvae. The RDA of Vitamin E is 15mg/day.

Sensory aspects of insects as food

Acceptance of a new food depends equally on its nutritional and sensory aspects. Insects, as general rule, are associated with pests, germs and thus are already biased against [30]. People who haven't eaten insects before evaluating insects based on their visual features and prior experiences, which generally associate insects with inedibility [31]. The method of preparation, and curiosity may influence willingness to try new food in consumers. In a study conducted by [32] showed that people preferred to eat invisible insects (insect flour or as a food ingredient) to visible ones or whole insects.

Studies have been conducted on using insects as food ingredient to increase their nutritional potential and measure the acceptability of insects as food ingredient. Choi *et al.* [33] added yellow mealworm in fruankfurters (type of snack) instead of pork. Frankfurters with 5% and 10% yellow mealworms had comparable sensory acceptability and keeping quality to control samples. A study conducted in Belgium evaluated the acceptability of beef burgers, beef/insect burger, beef/lentil burger and lentil/insect burger. The acceptability of beef/insect burger was comparable to that of beef burger with respect to texture, taste and flavour [34]. Adding flavours like chocolate, have been shown to improve the acceptability and appeal of mealworm-based products [35].

Conclusion

Insects hold tremendous potential as nutritious food and their importance increases with increasing population and climate change. They are an important future food which hold the potential to provide sustainable livelihoods to people in developing countries. Studies on nutrient composition are less as they aren't accepted in many parts of the world as traditional food. Also, there are variations in quality of insects and their nutrients and hence their sensory properties owing to feed. Stage of metamorphic and processing also affect the nutrient composition. Wild varieties of edible insects need to be sought out to choose and selectively breed the one with superior nutrient composition. Some insects are rich in protein and fats and yet there are no storage studies to determine the effect of storage with respect to oxidation on the protein and fatty acids in edible insects. The way forward is to study processing and preservation of individual insect variety and develop methodologies to preserve them. The major reason of unacceptability of insects as food source is their appearance. Turning them into eye-catching snacks to increase their visual acceptability can be on possible approach to increase their acceptability. Work can also be done with respect to improving their flavours using processing techniques or using them as ingredients in traditional foods.

Table-3 *Vitamin and mineral content of edible insects*

RDA of following vitamins and minerals (mg/day) unless specified			375-600 µg/day	03-1.3	25-45	1000-1300	3-14	7.5-58.8	220-260	0.9-1.3	[29]
Common name	Consumption stage	Scientific name	Vit A (µg)	Vit B_2 (mg)	Vit C (mg)	Ca (mg)	Zn (mg)	Fe (mg)	Mg (mg)	Cu (mg)	Ref
Termite	Wing adults, queen	*Macrotermes bellicosus*	2.89	1.98	3.41	21	NA	27	0.15	NA	[27]
		Macrotermes notalensis	2.56	1.54	3.01	18	NA	29	0.26	NA	
Cricket	Adult	*Brachytrypes spp*	0.00	0.03	0.00	9.21	NA	0.68	0.13	NA	
Grasshopper	Adult	*Cytacanthacris aeruginosus unicolor*	1.00	0.08	1.00	4.40	NA	0.35	0.09	NA	
Short-horned grasshopper	Adult	*Zonocerus variegatus*	6.82	0.07	8.64	42.16	NA	1.96	8.21	NA	
Rhinoceros beetle	Larvae	*Analeptes trifasciata*	12.54	2.62	5.41	61.28	NA	18.2	6.14	NA	
Scarab beetle	Larvae	*Anaphe spp*	2.78	0.09	3.20	7.58	NA	1.56	0.96	NA	
Snout beetle	Larvae	*Anaphe infracta*	2.95	2.00	4.52	8.56	NA	1.78	1.01	NA	
Honeybee	Egg, larvae, puape	*Anaphe reticulate*	3.40	1.95	2.24	10.52	NA	2.24	2.56	NA	
Caterpillar	Larvae	*Anaphe venata*	3.12	1.25	2.22	8.57	NA	2.01	1.56	NA	
		Cirina forda	2.99	2.21	1.95	8.24	NA	1.79	1.87	NA	
		Apis mellifera	12.44	3.24	10.25	15.4	NA	25.2	5.23	NA	
		Rhynchophorus phoenicis	11.25	2.21	4.25	39.58	NA	12.24	7.54	NA	
		Oryctes boas	8.58	0.08	7.59	45.68	NA	2.31	6.62	NA	
Caterpillar	Adult	*Nudaurelia oyemensis*	32.0	3.4	ND	149	10.2	9.7	266	1.2	[17]
		Imbrasia truncate	33.0	5.5	ND	132	11.1	8.7	192	1.4	
		Imbrasia epimethea	47.3	4.3	ND	225	11.1	13.0	402	1.2	
Superworm	Larvae	*Zophobas morio*	<30	0.75	1.20	17.7	3.07	1.65	49.8	0.36	[26]
Giant mealworm	Larvae	*Tenebrio moliter*	<30	0.161	2.40	18.4	4.45	2.15	86.4	0.64	
Mealworm	Larvae	*Tenebrio moliter*	<30	0.81	5.40	16.9	5.20	2.06	80.1	0.61	
Mealworm	Adult	*Tenebrio moliter*	<30	0.85	2.40	23.1	4.62	2.18	60.6	0.75	
Waxworm	Larvae	*Galleria mellonella*	<30	0.73	<1.0	24.3	2.54	2.09	31.6	0.38	
Silkworm	Larvae	*Bombyx mori*	47.0	0.94	<1.0	17.7	3.07	1.65	49.8	0.36	
Cricket	Adult	*Acheta domesticus*	<30	0.341	3.00	40.7	6.71	1.93	33.7	0.62	
Cricket	Nymph	*Acheta domesticus*	<30	0.95	1.80	27.5	6.80	2.12	22.6	0.51	

NA: Not analysed; ND: Not detected

Insect can also serve as source for extraction of bioactive compounds which can be added in traditional food products for biofortification and enrichment. Studies on potential of edible insects as a possible solution of food production and processing waste can be streamlined to create an insect based biorefinery which can turn waste into edible food in a sustainable manner.

Application of research: With growing world population the pressure on the current food supply increases every passing. There is urgent need to explore unconventional sources of nutritional food which are safe. Insects are a possible solution to this conundrum since they are nutritious and are safe to consume. This review article hopes to shed light on the advances made in the field of utilisation of insects as food or food ingredients.

Research Category: Entomology

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Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Jharkhand Rai University, Ranchi, 835222, Jharkhand, India

Insect name: *Rhynchophorus phoenicis, Zonocerus variegates, Homorocoryphus nitidulus, Protaetia brevitarsis and Teleogryllus emma*

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