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Jessica Ayensu, Reginald Adjetey Annan, Anthony Edusei, Herman Lutterodt,

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Jessica Ayensu and Reginald Adjetey Annan
Department of Biochemistry and Biotechnology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Anthony Edusei
Department of Community Health, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, and
Herman Lutterodt
Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

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Abstract

Purpose – Edible insects have emerged as a promising inexpensive option to address malnutrition among vulnerable groups in the world. However, it is not clear whether including insects in diets can improve health outcomes. This paper aimed to investigate the impact of edible insect consumption on human health.

Design/methodology/approach – A search was conducted in PubMed Central, BioMed Central, Plosone, Cochrane, Google Scholar, Google Search and bibliographies for all human studies on the impact of edible insect consumption on human health published from January 1990 to April 2018.

Findings – Twelve studies met the inclusion criteria. Consumption of cereals fortified with edible insects improved iron status and growth in infants and led to the development of life threatening anaphylactic reactions in sensitive people.

Practical implications – Edible insects are nutritious. More rigorous studies are needed to confirm nutrient bioavailability, acceptability and nutritional benefits in humans.

Originality/value – This review shows that the utilization of edible insects as food promotes desirable health outcomes, but caution must be taken to prevent allergic reactions in some cases.

Keywords Nutrition, Human health, Edible insects, Allergies, Entomophagy

Paper type Literature Review

1. Introduction

Entomophagy, the consumption of insects as food by humans, has existed for thousands of years in many parts of the world. This is traditionally practiced by more than two billion people worldwide, mostly in Africa, South America and Asia (Rumpold and Schlüter, 2013). About 2000 species of insects are known to be consumed as food by humans (van Huis, 2013) and out of these 31 per cent are beetles, 18 per cent are caterpillars, 15 per cent are wasps, bees and ants, 13 per cent are crickets, grasshoppers and locusts, 11 per cent are true bugs and 12 per cent are termites, dragon flies, flies and others (Jongema, 2017). The

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preference for an insect species by humans for food depends on the palatability, availability and nutritional value of the insect as well as the customs and traditions of the local area.

The history of insect consumption dates as far back as the nineteenth century when British entomologist V.M. Holt through his small booklet published in 1885 titled "Why Not Eat Insects?" encouraged his fellow Englishmen to consider the idea of consuming insects. This was continued by other scientists like DeFoliart and others (DeFoliart, 1997; Ramos-Elorduy, 1997) who aimed their studies at popularizing the eating of insects and investigating the place of insects in human nutrition. In recent times, scientific studies have focused on documenting indigenous knowledge around the insects; identifying the species used and developing databases (FAO, 2012); developing insect products to enhance the palatability of insect protein to encourage consumption (Van Huis *et al.*, 2013). There is a lucrative trade in insects all over the world, insects that are preserved or incorporated into several foods or ingredients like baking flour, pasta, cornflakes, candies and chocolate bars are sold to the general public in supermarkets, open air markets and restaurants.

According to a report from the Food and Agriculture Organization (FAO), the growing global population will result in a 75 per cent growth in the demand for meat by 2050 (Van Huis *et al.*, 2013). Because of the rising cost of animal protein, food insecurity, environmental pressures and population growth, insects as food have gained a lot of attention. Insects are a highly nutritious and healthy food source with high fat, protein, vitamin, fibre and mineral content comparing well with other forms of protein such as beef, fish and poultry (Rumpold and Schlüter, 2015). For example, van Huis *et al.* (2013) found the composition of unsaturated Omega-3 and Omega-6 fatty acids in mealworms to be comparable with that in fish (and higher than in cattle and pigs), and the protein and micronutrients content of mealworms similar to that in fish and meat.

Several beneficial factors support an increased utilization of insects as a sustainable animal protein source. Compared with conventional livestock, insects have a high fecundity and low space requirements. They also emit less greenhouse gases and ammonia than pigs and cattle (Oonincx *et al.*, 2010) and have high feed conversion efficiency. For example, only 2 kg of feed is required by crickets to gain 1 kg body weight (van Huis et al., 2013). Most importantly, insects have the potential to contribute to protein, food and feed security. Despite all these beneficial factors supporting the consumption of insects, there is paucity of data on nutrient bioavailability, effects of different processing methods on the nutrients and hazards associated with this practice making it difficult for worldwide acceptance. This paper therefore aims to systematically summarize existing evidence on the impact of entomophagy on human health.

1.1 Nutritional composition of edible insects

Numerous scientists have reported on the nutritional component of different species of edible insects. Overall, the main constituents are protein and fat followed by fibre, nitrogen-free extract (carbohydrates) and ash (Rumpold and Schlüter (2013); FAO, 2012; Elemo *et al.*, 2011; Shantibala *et al.*, 2014; Ogbuagu *et al.*, 2014). A part from the fact that insects are a tasty food commodity, their nutritional composition has captured the attention of health stakeholders such as nutritionists and physicians (FAO, 2010). Rumpold and Schlüter (2013) compiled nutrient compositions for 236 edible insects, as published in the literature (based on dry matter).

1.2 Protein and amino acids of edible insects

Proteins represent the main components of the nutritional composition of edible insects. The protein content of edible insects on a dry basis ranges from 35.3 per cent for termites

(Isoptera) to 61.32 per cent for crickets, grasshoppers and locusts (Orthoptera) (Rumpold and Schlüter 2013). Generally, edible insect species from the order Orthoptera (grasshoppers, crickets and locusts) are very rich in proteins. Grasshoppers have been reported to have a protein content of about 77 per cent dry weight (Ramos-Elorduy, 1997, Ramos-Elorduy *et al.*, 2007). The protein content of edible insects depends on several factors such as the species, cooking method, feed and metamorphosis stage (FAO, 2013). For example, Ademolu *et al.* (2010) found that grasshoppers in Nigeria that are fed with bran, which contains high levels of essential fatty acids have double the protein content of those fed on maize.

Amino acid composition of edible insects differs largely among species and orders. According the World Health Organisation (WHO, 2007), the amino acid composition of most edible insects satisfactorily provides the essential amino acids required for human nutrition. High amino acid values have been found for phenylalanine, tyrosine, tryptophan, lysine and threonine (Rumpold and Schlüter, 2013). Ogbugu *et al.* (2014) found the level of essential amino acids such as leucine, isoleucine, phenylalanine and tyrosine in palm weevil larvae to be higher than FAO reference standard values. To make recommendations regarding the use of edible insects as food enrichments in diets, it is important to look at traditional diets in their entirety, in particular at staple foods and to compare their nutritional quality against that of edible insects locally available in the region.

1.3 Fats in edible insects

In addition to proteins, the other major nutrient component of edible insects is fat. Womeni *et al.* (2009) investigated the content and composition of oils extracted from several insects. He found the oils to be rich in polyunsaturated fatty acids. On a dry matter basis, the average fat content of edible insects ranges from 13.4 per cent for grasshoppers, crickets and locusts (Orthoptera) to 33.4 per cent for beetles and their larvae (Coleoptera). The fatty acid profile of edible insects mostly collected in the wild as reported by Rumpold *et al.* (2013) shows that, saturated fatty acids (SFA) range from 31.8 per cent for bees, wasps and ants (Hymenoptera) to 42.0 per cent for termites (Isoptera). Monounsaturated fatty acids (MUFA) range from 22.0 per cent for termites (Isoptera) to 48.6 per cent for bees, wasps and ants (Hymenoptera) whereas polyunsaturated fatty acids (PUFA) range from 16.0 per cent for flies (Diptera) to 39.8 per cent for caterpillars of butterflies and moths (Lepidoptera). Just like conventional livestock, St-Hilaire *et al.* (2007) reported that the fatty acid composition of edible insects depends on their feed composition.

1.4 Micronutrients in edible insects

Micronutrients play a significant role in the nutritional value of food and in human health. Micronutrient deficiencies can have major adverse health effects, leading to impairments in growth, immune function, mental and physical development and reproductive outcomes that cannot always be reversed by nutrition interventions (FAO, 2011c). Edible insects when consumed can provide significant amounts of minerals such as copper, iron, magnesium, manganese, phosphorous, selenium and zinc. Sirimungkararat *et al.* (2010) found that insects contain more iron and zinc than beef, pork and chicken. Similarly, Paoletti *et al.* (2003) found the level of calcium in earthworm to be comparable to the calcium content of fresh cheese and higher than the calcium content in conventional meat.

In addition to minerals, edible insects provide several vitamins. Regarding vitamin requirements for human adults recommended by the FAO (2004), edible insects are high in riboflavin, pantothenic acid and biotin. Edible insects of the Orthoptera order (Grasshoppers, crickets, locust) and the Coleoptera order (beetles and their larvae) are rich in folic acid (Rumpold and Schlüter, 2013). However, insects in general, are not reliable sources of vitamin A, vitamin C, niacin, vitamin E and thiamin.

2. Objective

The objective of this paper is to examine the impact of edible insect consumption on human health.

3. Methods

3.1 Inclusion criteria

All human studies including experimental (randomized controlled trials and quasi experimental studies), observational (cohort, case control and cross-sectional studies) and case reports examining the impact of entomophagy on human health published from January 1990 to April 2018 were included in this review. Only studies that met the outcomes and exposures of interest were included in the study.

3.1.1 Exposures

- The insects were consumed either raw, cooked or as an ingredient in a food product.

3.1.2 Outcomes

- allergies;
- food poisoning; and
- nutritional status (biochemical indicators, anthropometric indicators and haematologic indicators).

3.2 Exclusion criteria

Studies were excluded if they fell within any of the following categories:

- animal studies;
- *in vitro* studies; and
- literature reviews.

3.3 Sources of data

- Electronic databases had included PubMed Central, Cochrane, Plosone, Biomed Central, Google Scholar and Google Search.
- Bibliographies of selected papers were also scrutinized for additional studies.

3.4 Search strategy

All available evidence for the impact of entomophagy on human health published from January 1990 to April 2017 was systematically retrieved and analysed. A search was done in PubMed Central, Biomed Central, Plosone, Google Scholar and Google Search with key words including: "Entomophagy AND Human Health", "Entomophagy AND Human Nutrition", "Entomophagy AND Human Allergies", "Edible Insects AND Human Health", "Edible Insects AND Human Nutrition", "Edible Insects AND Human Allergies" "Anaphylaxis AND Edible Insects". Detailed manual searches including cross-references and bibliographies of available publications were undertaken.

3.5 Quality assessment
Quality assessment and risked of bias was assessed using a standardized form consisting of 22 criteria. Briefly, study population, setting and design, baseline characteristics, losses to follow-up, sample selection, exposure and outcome measurements, the appropriateness of data analyses and the study results. According to the score obtained (from 0 to 22), studies were classified as being of low (>16), medium (12-16) or high (<12) risk of bias.

4. Results

4.1 Search results
The initial search in the electronic data bases yielded 1,768 citations. Screening of titles and removal of duplicates led to the elimination of 1,650 and 79 papers, respectively. The bibliographies of the remaining 39 papers were screened for relevant articles, which yielded 13 papers. Twelve papers remained for thorough review after the abstracts of the remaining 47 papers were screened. Out of the twelve, seven were obtained from bibliographic search and five from the electronic search (two of these were published articles, and the remaining three were obtained from published PhD theses). A summary of the selection process is presented in Figure 1. Five out of the seven studies focused on entomophagy and nutritional status and the remaining two were acceptability studies.

4.2 Data extraction
Data extraction was conducted based on the following criteria:

- publication details (author, date of publication);
- study design;
- country;
- sample size;
- population;
- duration;
- results;
- quality assessment and risk of bias score; and
- insect studied.

4.3 Study characteristics
In all, 12 studies were used for this review. The studies were published from January 1990 to April 2017 and Seven of the studies included about 2,094 infants aged between six and 24 months and the remaining five were case reports and reviews involving about 150 people. All the studies were conducted in Africa and Asia. Seven the studies assessed the impact of edible insects as ingredients in food products and five were case reports on anaphylactic reactions resulting from edible insect consumption. A summary of the major findings and the characteristics of the studies included in this review can be found in Tables II and III.

4.4 Edible insect consumption and adverse health effects
Two studies were identified which assessed the acceptability of food products fortified with edible insects and five other studies reported the cases of adverse health outcomes, that is allergic reactions or food poisoning associated with edible insect consumption in different individuals of different origins. Konyole *et al.* (2012) assessed the acceptability of three

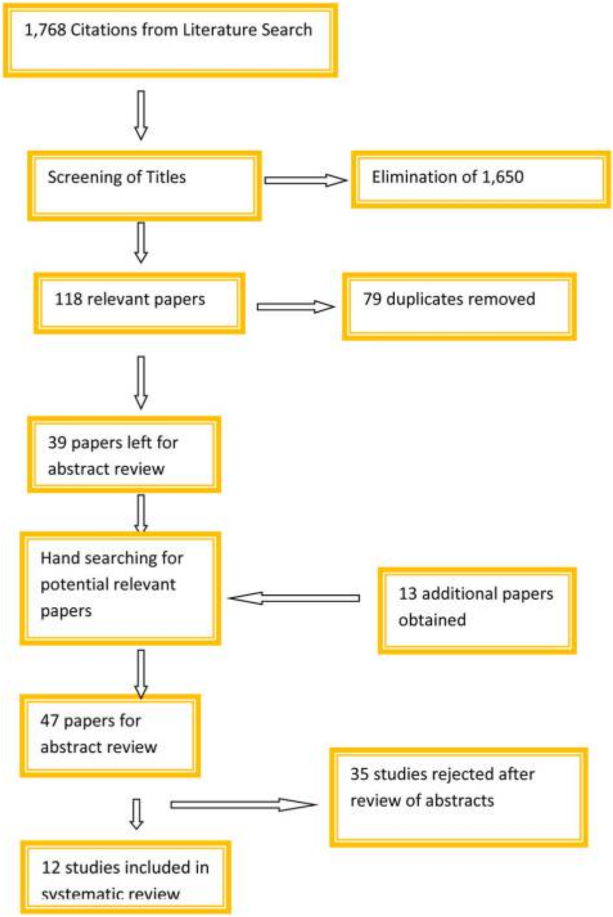

Figure 1.
Selection process

flours and porridges of complementary foods based on germinated amaranth and maize with or without edible termites and dagaa small fish named "Winfood Classic" and "Winfood Lite" compared to corn soy blend plus (CSB+) among 57 Kenyan infants aged six months to 24 months. They ascertained infant tolerance of foods by evaluating the incidence of adverse health outcomes such as diarrhoea, vomiting, stomach ache, skin rashes and difficult breathing before, during and after the acceptability study. Results of their study revealed no adverse health outcomes with any of the foods including the "Winfood Classic" which had the termites. The measured cases of adverse health outcomes (9.3 per cent), vomiting, which occurred in the group that received the corn soy blend plus, was below the 10 per cent threshold required to declare a product to have adverse effects. In the second acceptability study, Bauserman *et al.* (2015a, 2015b), recorded only one incidence of vomiting among 20 Congolese infants aged eight to 10 months who were made to consume a cereal made from dried caterpillars and other local ingredients (ground corn, palm oil, sugar and salt) for one week. According to their results, the infant experienced the vomiting only

Table I. Average nutrient composition of edible insect orders (on a dry matter basis)

Nutrients	Cockroaches (Blattodea)	Beetles (Coleoptera)	Flies (Diptera)	Beetles (Hemiptera)	Bees, wasps, ants (Hymenoptera)	Termites (Isoptera)	Caterpillars Lepidoptera)	Dragon flies (Odonata)	Grasshoppers, locusts Crickets (orthoptera)
Data amount (n)	3	45	6	27	45	7	50	2	51
Protein (%)	57.3	40.69	49.48	48.33	46.47	35.34	45.38	55.23	61.32
Min	43.9	8.85	35.87	27	4.09	20.4	13.17	54.24	6.25
Max	65.6	71.1	63.99	72	66	65.62	74.35	56.22	77.13
SD	11.74	15.61	13.12	15.09	15.19	15.19	15.56	1.4	14.65
Fat (%)	29.9	33.4	22.75	30.26	25.09	32.74	27.66	19.83	13.41
Min	27.3	0.66	11.89	4	5.8	21.35	5.25	16.72	2.49
Max	34.2	69.78	35.87	57.3	62	46.1	77.17	22.93	53.05
SD	3.75	18.91	9.35	18.74	11.96	9.05	17.89	4.39	10.9
Fibre (%)	5.31	10.74	13.56	12.4	5.71	5.06	6.6	11.79	9.55
Min	3	1.4	9.75	2	0.86	2.2	0.12	9.96	1.01
Max	8.44	25.14	16.2	23	29.13	7.85	29	13.62	22.08
SD	2.81	6.5	2.81	5.74	6.32	2.47	5.15	2.59	4.23
NFE (%)	4.53	13.2	6.01	6.08	20.25	22.84	18.76	4.63	12.98
Min	0.73	0.01	1.25	0.01	0	1.13	1	3.02	0
Max	10.09	48.6	8.21	18.07	77.73	43.3	66.6	6.23	85.3
SD	4.91	12.33	3.25	5.93	20.56	17.16	19.81	2.27	17.22
Ash (%)	2.94	5.07	10.31	5.03	3.51	5.88	4.51	8.53	3.85
Min	2.48	0.62	5.16	1	0.71	1.9	0.63	4.21	0.34
Max	3.33	24.1	25.95	21	9.31	11.26	11.51	12.85	9.36
SD	0.43	4.83	8.4	5.44	1.56	3.98	2.65	6.11	1.65

Source: Adapted from Rumpold and Schlüter (2015)

Table II.
Summary of studies included in study

Publication details	Country	Population	Sample size	Study design	Duration of study	Quality assessment and risk of bias score	Insect used	Results
Bauserman *et al.* (2015a, 2015b)	Democratic Republic of Congo	Healthy infants aged six months	175	Cluster randomized	12 months	18 (Low)	Caterpillar (Cereal)	High haemoglobin levels in intervention than control group 10.7g/dl verse 10.1g/dl (p = 0.03); fewer anaemia cases in intervention than in controls, 26 and 50% respectively, (p = 0.006); no effects on stunting detected
Konyole *et al.* (2012)	Kenya	Healthy infants aged six to 24 months	57	Acceptability trial	Four weeks	13 (Medium)	Termites	No adverse effects found
Konyole *et al.* (2012) (PhD thesis)	Kenya	Healthy infants aged 6 months	428	Randomized community-based trial	Nine months	18 (Low)	Termites	All three foods improved growth (length and weight with no significant difference
Omolo (2014) (PhD thesis)	Kenya	Healthy infants aged six months	499	Randomized double blind trial	Nine Months	18 (Low)	Termites	No significant differences in impact on lean mass accrual, essential fatty acids profile and gross motor milestone attainment were observed from feeding locally produced complementary foods with or without animal source foods (termites and small fish) compared to a standard plant-based product
Skau *et al.* (2015)	Cambodia	Healthy infants aged six months	419		Nine Months	18 (Low)	Edible spiders	There was no difference in fat-free mass increment in WF or WF-L compared with CSB+ [WF: +0.04 kg (95% CI: 20.20, 0.28 kg); WF-L: +0.14 kg (95% CI: 20.10, 0.38 kg)] or CSB++ [WF: 20.03 kg (95% CI: 20.27, 0.21 kg); WF-L: +0.07 kg (95% CI: 20.18, 0.31 kg)] and no effect on iron status

(*continued*)

Publication details	Country	Population	Sample size	Study design	Duration of study	Quality assessment and risk of bias score	Insect used	Results
Bauserman *et al.* (2015a, 2015b)	Democratic Republic of Congo	Healthy infants aged eight to 10 months	20	Acceptability	One week	14 (Medium)	Caterpillars	No serious adverse effects identified
Konyole (2014a, 2014b)	Kenya	Healthy infants aged six months	428	Randomized community-based trial	Nine months	18 (Low)	Termites	Significant effect of all products on iron status of infants ($p < 0.001$)

Table II.

Publication details	Country	No. of cases	Insect specie	Clinical signs after consumption of insect
Ji *et al.* (2008)	French (visiting China)	14	Silkworm (*Bombyx mori)* pupa	Angioedema, abdominal pain, dyspnoea; fainting, flushed appearance, hypotension, headache, nausea, pruritus; urticaria, unconsciousness,
Choi *et al.* (2010)	Korea	5	Vegetable worm (*Cordycepssinensis*)	Conjunctivitis, rhinorrhea, nasal obstruction, cough and dyspnoea
Okezie *et al.* (2010)	Botswana	1	Mopane worm (Imbrasiabelina)	Itchy skin rash, facial swelling and mild hypotension
Yew *et al.* (2012)	China	1	Sago worms (*Rhynchophorusferrugineus)*	Difficulty in breathing, itchiness (face, arms and body) Takotsubo Cardiomyopathy
Chomchai *et al.* (2018)	Thailand	28	Silkworm (*Bombyx mori)* pupa, grasshoppers bamboo borers, crickets	Flushing, pruritus, urticarial rashes, headache, nausea, vomiting, diarrhoea, dyspnea and bronchospasm

Table III.
List of case reports and case series of food allergy to insects

on the first day of the acceptability test and continued the study with no other adverse outcomes.

Ji *et al.* (2008) reported 14 different cases of anaphylactic shock manifesting in different individuals after they consumed silkworm pupae for the first time. In one of the cases, a 37-year-old French man with a known history of allergic rhinitis, experienced breathing difficulty, mild nausea, flushing and swelling of his face, itching in his mouth and face, hypotension (70/40 mmHg) and elevated pulse (105/min) after ingesting oil-fried silkworm pupae during his visit to China. In another article, Choi *et al.* (2010) reported five cases involving Koreans (3 females and 2 males) who developed allergic symptoms 30 to 120 min after drinking tea containing vegetable worm. It was also reported that the patients developed symptoms like those elicited by vegetable worm after consuming silk worm pupae. Further investigations by use of ELISA inhibition tests revealed cross-reactivity between silkworm pupae and vegetable worm. There was another case of a 36-year-old woman who experienced body swelling, itchy rashes, nausea and malaise about 2 h after eating 20 gm of mopane worms. This woman had lived in Botswana and eaten mopane worms all her life with no episodes of food allergy (Okezie *et al.*, 2010). Yew *et al.* (2012) also presented the case of a 46-year-old Chinese man who developed Takotusbo cardiomyopathy resulting from anaphylactic reactions after consuming about 20 sago worms. In a more recent retrospective cohort study, 28 Thai students were reported to have experienced several allergic reactions after consuming snacks containing insects (Chmochai *et al.*, 2010). The insects in context were bamboo borers, grasshoppers, crickets and silkworm pupae and the symptoms of the reaction included flushing, pruritis, urticarial rashes, headache, nausea, vomiting, diarrhoea, dyspnoea and bronchospasm. According to the authors, attack rates were highest among those who consumed the grasshoppers and the silkworm pupae than those who did not. Based on epidemiological analysis and laboratory evidence, the authors attributed the clinical manifestations to histamine poisoning from the fried insects.

4.5 Edible insect consumption and nutritional status

Five papers were identified for this category (all randomized trials). All the studies examined the impact of complementary foods fortified with dried insects and other ingredients on the nutritional status of infants (four looked at growth and three out of the five looked at iron status as well). The edible insects used in the studies were spiders, caterpillars and termites. In a cluster-randomized trial, Bauserman *et al.* (2015a, 2015b) examined the efficacy of a complementary cereal made from dried caterpillars and other local ingredients on reducing stunting and anaemia in 175 Congolese infants. When compared to the control group, infants who received the caterpillar cereal had significantly higher haemoglobin levels (10.7g/dl) than those who received no intervention (10.1g/dl), $p = 0.03$.

Fewer cases of anaemia were recorded in the intervention group (26 per cent) than in the control group (50 per cent), p-value of 0.006. Although Konyole (2014a, 2014b) observed improved iron and anaemia status in Kenyan infants who were treated to a cereal containing termites (Winfood Classic – cereal-based complementary food fortified with termites and dagaa small fish), the observed improvement was not significantly different from the groups that received Winfood Lite (cereals with only dagaa small fish) and CSB+ (corn soy blend plus). On the contrary, Skau *et al.* (2015), found a higher prevalence of anaemia among Cambodian infants who received rice-based cereals fortified with small fish and edible spiders named "Winfood" (53.7 per cent) than those assigned to "Winfood light" (rice-based cereal with small fish), CSB+ (fortified corn soy-based cereal and CSB++ (corn soy-based cereal fortified with dried skimmed milk), 39.8, 35.2 and 35.2 per cent, respectively. The also recorded a general increase in anaemia in all their intervention groups and attributed this to inadequate supply of iron in their treatment foods.

Four of the studies included in this review assessed the impact of entomophagy on growth in infants. Two studies (Konyole *et al.,* 2012 and Skau *et al.,* 2015) recorded increased weight gains in infants who received complementary cereals fortified with termites and spiders respectively. In addition, Konyole *et al.* (2012) recorded increased length among infants who were treated to cereals fortified with termites. Results of a randomized double-blind trial by Omolo (2014), revealed improved lean body mass and gross motor skills in Kenyan infants who were given complementary cereals fortified with termites for nine months although the improvement was not significantly different from other treatments. The study also assessed the effects of different treatments "WinFood Classic" (maize and amaranth fortified with termites and small fish), "WinFood Lite" (multi-micronutrient fortified maize and amaranth complementary food) and CSB+ (multi-micronutrient fortified corn soy blend plus) on whole blood fatty acid profile. Infants who received the Winfood Classic treatment had significantly high blood levels of arachidonic acid than the other groups, $p = 0.02$.

5. Discussion

Humans have consumed insects and insect products like honey for thousands of years in some cases as emergency food, in other circumstances as a staple and in still other instances as delicacies, snacks and ingredients. Edible insects have received much recognition from regional and sub-regional organisations for their rich source of protein, essential fatty acids, fibre, minerals and vitamins. At the same time, several concerns regarding safety, effects of processing and nutrient bioavailability have been raised. This systematic review was aimed at summarizing existing evidence on the impact of entomophagy on human health. Findings from this review indicate that consumption of insects can result in adverse health outcomes or related allergic reactions; that insect consumption can lead to weight and length gain in infants; cereals fortified with termites and caterpillars but not spiders can improve iron status of children.

Food allergy is defined as an adverse health effect arising from a specific immune response that occurs reproducibly after exposure to a given food (NIAID-Sponsored Expert Panel and others 2010). Food allergies can range from mild symptoms, such as coughing, vomiting, stomach cramps, hives, wheezing, shortness of breath, trouble swallowing and dizziness to severe reactions, such as (Sampson *et al.,* 2006). Although any food can cause an adverse reaction, eggs, milk, shellfish, nuts, wheat, fish and soy are widely known to be able to induce allergic reactions in susceptible individuals (Ayuso, 2011). Insects, like other common foods, may cause allergic symptoms, even after the first exposure. For instance, the silkworm pupae, a rich source of protein and amino acids for humans is well known for its allergenicity as its ingestion results in anaphylactic reactions in over 1,000 patients in China every year. It has been suggested that individuals allergic to shrimp may also be allergic to other shellfish and arthropods such as cockroaches, grasshoppers, fruit flies and other edible insects (Leung *et al.,* 1996; Reese *et al.,* 1999). Ribeiro *et al.* (2018), in a systematic review which summarized results of studies that assessed cross-reactivity/co-sensitization between crustaceans and edible insects, identified tropomyosin and Arginine kinase, known arthropod pan-allergens, to be cross reacting allergens. Their results conscientizes individuals allergic to crustaceans and arthropods to be cautious with regards to edible insect consumption.

Reports of cases included in this review indicate that consumption of edible insects such as crickets, grasshoppers, bamboo borers, silkworm pupae, vegetable worm, mopane worm and sago worms can induce life threatening allergic reactions. The development of the anaphylactic reactions could have resulted from allergens in the individual insects consumed or because of cross-reactivity. In one of the studies, Choi *et al.* (2010) reported cross-reactivity between silkworm pupae and vegetable worm, such that, patients developed similar anaphylactic reactions after eating both insects at separate times. In another case, the development of anaphylactic reactions after sago worm ingestion resulted in Takotsubo cardiomyopathy which was characterized by chest pain and congestive heart failure of New York Heart Association (NYHA) class IV (Yew *et al.,* 2012). Apart from allergy hazards, other potential hazards that have raise a lot of concerns when it comes to edible insect consumption are of microbial, chemical and parasitical. It has been reported that insects in general can harbour *Salmonella Spp., Campylobacter* and *Staphylococcus Spp.*, flukes foodborne and water borne pathogens and chemical hazards (Belluco *et al.,* 2013). As these hazards can also be present in edible insects, hygienic handling and storage of edible insects must be of prime concern to avoid potential risks associated with their consumption. Again, it is only wise and safe for individuals who are sensitive to shellfish and other allergens to exercise caution regarding insect consumption. Appropriate labelling by producers will also help to prevent potential adverse health outcomes.

The nutrient compositions of varied species of edible insects have been reported (Rumpold and Schlüter, 2013). Although significant variations exist in results of nutrient composition studies, results of such studies indicate that many edible insects can provide adequate amounts of energy and protein, meet amino acid requirements for humans, are high in monounsaturated and polyunsaturated fatty acids, and they are rich in micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium and zinc. The World Health Organisation (WHO) has considered insects as a suitable food to meet the protein needs of starving individuals, including HIV-positive subjects who require higher quality nutrition to counteract immunological impairment (World Health Organization and Food and Agriculture Organization of the United Nations, 2002). The improved nutritional status (weight, length and iron status) of infants in the studies included in this review can be attributed to the nutritive value of insects (Bauserman *et al.,* 2015a, 2015b, Omolo, 2014, Konyole *et al.,* 2012).

Edible insects such as caterpillar and termites which were studied in this review are rich sources of proteins, iron, zinc and essential fatty acids which are necessary for optimum growth and developments in children. The average protein content of caterpillars and termites on dry matter basis as documented by Rumpold *et al.* (2013) is 45.38 and 35.34 per cent, respectively. Christensen *et al.* (2006) also recorded high levels of iron in termites consumed in Kenya. Adequate protein intake is essential to meet the growth needs of infants and the results of this study suggests that consumption of insects such as termites and caterpillars in resource poor countries can help reduce the incidence of stunting and protein energy malnutrition which are pertinent issues of concern among health professionals worldwide.

Iron deficiency anaemia is a preventable deficiency, which has been flagged by the WHO as the world's most common and widespread nutritional disorder (WHO, 2011). Health consequences of iron deficiency in infants include impaired physical and cognitive development and increased risk of morbidity. The improved iron levels reported in the studies reviewed indicates the potential for edibles insects to reduce the incidence of iron deficiency anaemia not only among infants but especially pregnant women in iron deficiency endemic areas in the world. Anaemia is a preventable deficiency but contributes to 20 per cent of all maternal deaths.

Omolo (2014) recorded elevated levels of arachidonic acid in infants who were treated to complementary food containing termites and small fish than the other treatment foods. Arachidonic acid, a polyunsaturated Omega-6 fatty acid, is one of the most abundant fatty acids in the brain and is present in similar quantities to docosahexaenoic acid. These two are important for neurological health and early neurological development. Results of a randomized controlled trial by Birch *et al.* (2007) showed that, infants (aged 18 months) given supplemental arachidonic acid for 17 weeks demonstrated significant improvement in intelligence. Paoletti *et al.* (2003), recorded high proportions of polyunsaturated fatty acid (46.7 to 54.2 per cent) in earthworm with arachidonic acid being the highest constituent (33 to 45 per cent). This also suggests that consumption of edible insects could improve and maintain cognitive development and function in children especially in cases where there is a deficiency in linoleic acid or if there is an inability to convert linoleic acid to arachidonic acid.

6. Conclusions

The majority of the studies included in this review suggest that the utilization of edible insects as food promotes desirable health outcomes, but caution must be taken to prevent allergic reactions in sensitive people. Given the limited number of papers retrieved, more research is necessary to determine if comparable results will be obtained for other insects and confirm that consumption of insects improves health status.

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Corresponding author

Jessica Ayensu can be contacted at: jessicaayensu@yahoo.com