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MINI-REVIEW

Insects in food and feed systems in sub-Saharan Africa: the untapped potentials

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Abstract

Insects as food and feed have the potential to alleviate food, feed and nutrition insecurity in sub-Saharan Africa (SSA) against a backdrop of climate change. Such use has gained unprecedented attention in the past decade and the trend will probably continue due to the species diversity, new discoveries in the nutritional, neutraceutical and medicinal potentials of edible insect species. In order to meet the increasing demand for insects as food and feed, insect farming should complement sustainable wild insect harvesting. The ecological impact of insect farming, economics, species biological and processing aspects deserve empirical investigation. This is crucial in order to effectively guide potential insect producers and processors. Besides the use of insects in folk medicine, several industrial products including polyunsaturated and monosaturated fatty acids, peptides, enzymes, and antimicrobial compounds can be obtained from edible insects. With the teaming world population, value addition via product fortification is a practical strategy to enhance the acceptance of edible insects for human food and nutrition security. The future of insects as food and feed will witness the development of international trade and SSA governments should be ready to comply with product standardization and legislation requirements to penetrate external markets. Despite the diversity of edible insects in SSA and some commonalities there-in, not all consumers are well-informed on the inherent risks of allergens, toxicants and antinutritional compounds occurring in some edible species. Further research needs and future strategies to exploit the untapped potential of insects as food and feed in SSA are mapped out.

Keywords Entomophagy · Insects as medicine · Edible insects · Insect food and feed safety · Insect farming · Nutritional and anti-nutritional composition

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Introduction

Africa' population is projected to double from 1.1 billion to 2.2 billion people by 2050 (UNDESA 2017). In 2050, 50% of these 2.2 billion people will be urban-based. To meet food demand then, a 60% increase in the amount of food currently produced and accessible will be required (Alexandratos and Bruinsma 2012). In the long-term (2100), sub-Saharan Africa (SSA) is predicted to be one of the world's most vulnerable regions to climate change, with consequent rising temperatures and increasing rainfall variability temparorally and spatially (Niang et al. 2014) which have severe impacts on conventional agriculture largely rain-fed. In addition SSA is home to some of the most nutritionally insecure people in the world where 22.8% of the overall population are undernourished (FAO 2019). FAO (2015) estimated that commercial feed production will need to increase by 70% by 2050 to meet

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the growing demand for protein. It is against this background that insect farming for food and feed are envisaged to contriute critically towards the alleviation of some of the aforementioned challenges experienced today and persisteing into the long-term furture.

Insects have been utilized as food and feed from the prehistoric time. About 2000 species are consumed all over the world, with a little less than 500 consumed in Africa alone (Kelemu et al. 2015; Jongema 2017). In most African countries, insects are mainly consumed as complementary food (Paiko et al. 2012; van Huis et al. 2013; Niassy et al. 2016). The factors that influence the use of insects as food and feed include culture, knowledge of its usefulness, availability, taste and affordability, among others. It is assumed that some insects that are safe as human food can be safe as animal feed, with little or no concerns for toxicity against the animals. That view has given birth to an increased number of experimental trials on the use of insects as animal feeds (Amao et al. 2010; Sanusi et al. 2013; Oyegoke et al. 2014; Maurer et al. 2015; Al-Qazzaz and Ismail 2016; Cullere et al. 2018; Van der Fels-Klerx et al. 2018; Biasato et al. 2019). Apart from the nutritional values of insects (Ramos-Elorduy 2009; Kinyuru et al. 2010; van Huis 2015; Niassy and Ekesi 2016; Oibiokpa et al. 2017, Manditsera et al. 2018; Haber et al. 2019; Kunatsa et al. 2020), some species are believed to be useful in folk medicine all over the world (Fasoranti 1997; Lawal and Banjo 2007; Ayieko and Oriaro 2008; Dzerefos et al. 2013; Musundire et al. 2014; Tamesse et al. 2016; Loko et al. 2019). This reveals the neutraceutical potentials of the edible insects. Although some earlier reports on the use of edible insects in folk medicine lack the scientific basis for the reported efficacies, recent and current studies are designed to elucidate the basis for such acclaimed efficacies, especially when the paramedical are involved in the collaborative studies.

Today, edible insects have received more attention from entomologists, and non-entomologists than other groups of insects (pollinators, biological control agents, medical/veterinary pests, agricultural pests etc.) because of the multiple functionalities (DeFoliart 1991; van Huis et al. 2013; Sogari et al. 2019). In recent reviews of the subject matter, multidisciplinary approach has been the guide in the team selection (Micek et al. 2014; Kinyuru et al. 2018; Raheem et al. 2019). This implies that edible insects have become case studies for interdisciplinary collaboration. Hence, future research is likely to witness more of collaborations of entomologists and non-entomologists such as food scientists/nutritionists, biochemists, animal nutritionists, and pharmacologists in different combinations. Despite all the earlier works done on edible insects, new reviews of the literature are necessary in order to elucidate the recent research trends that have not been clearly articulated. The fact that insects have been used in entomophagy and as animal feeds does not imply that all edible species are safe for the acclaimed purposes (Musundire et al. 2016a; Fraqueza and Patarata 2017; Kachapulula et al. 2018). For instance, *Anaphe venata* has been associated with ataxic syndrome in Nigeria (Nishimule et al. 2000). When insects are harvested from the wild, they also stand the risk of being contaminated with pesticide residues, especially when they are harvested in a pesticide prone ecology (Rumpold and Schlüter 2013).

The SSA consists of four regions (Western Africa, Eastern Africa, Southern Africa and Central Africa) that lie south of the Sahara desert. According to the United Nations, 46 out of 54 African countries are included in the sub-Saharan African continent, excluding Egypt, Algeria, Djibouti, Libya, Morroco, Somalia, Sudan and Tunisia. The excluded countries are often regarded as Northern Africa (Fig. 1). The four regions are all tropical, with each country having her peculiar climate with few commonalities. The region is endowed with high diversity of edible species partly due to the favourable climatic conditions. With the influence of climate change, there is on one hand, the likelihood of edible insects occurring in newer areas while on the other hand, there is also the possibility of decline or even disappearance of some edible species in areas they used to be abundant. Similarly, different cultures may adopt the edible species eaten by their neighbours. Although there is comparatively low edible insect diversity in the western world (Jongema 2017), the concept of entomophagy is beginning to gain acceptance in the region. Today, with the on-going global empirical studies that elucidate the potentials of the insects as food and feed, the western world may overtake the tropical continents which provide the natural habitats for the edible species, on the acceptance of the edible insects.

Recent reviews and surveys on insects for food and feed in Africa have focussed on: inventory, diversity and contribution to food security (Kelemu et al. 2015); gender, culture, local knowledge and beliefs (Niassy et al. 2016; Mmari et al. 2017; Okia et al. 2017); diets and nutrition (Kinyuru et al. 2018); different safety aspects of wild and reared edible insects (Mujuru et al. 2014); and processing methods (Mutungi et al. 2019). The current review is a synthesis of most of the work done so far in SSA to provide one resource material for researchers, scholars, practitioners, entrepreneurs and policy-makers interested in edible and feed insects. The review was carefully designed to collate, analyse and synthesise information on: (a) History and perspectives of the usage of insects as food and feed in SSA (b) Diversity of insect species used as food and feed (c) Proximate and mineral composition of the species consumed in SSA (d) Medicinal values of African insects used as food (d) Cautionary matters on insects as food and feed, and (e) Viability of the edible insects as food and feed enterprise. The analysis and synthesis were then used to discern trends in research and development and distil key issues on insects for food and feed. Additionally, the

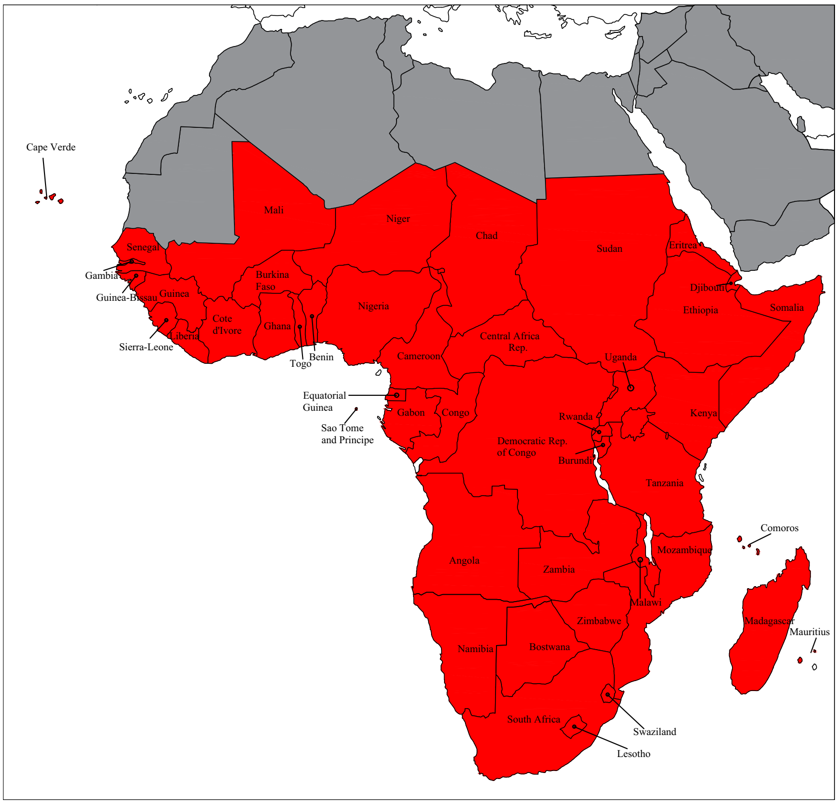

Fig. 1 Map of Africa showing sub-Saharan Africa in red. (Source: Pinterest.com: https://i.pinimg.com/originals/25/59/30/2559302604b1a6b334ad302dec1864ce.gif)

untapped potentials of insects as food and feed are identified, while further research and development needs and strategies to develop and optimise the untapped potentials are discussed.

History and perspective of the usage of insects as food and feed in Africa

Before the early humans were able to invent tools to hunt animals, insects were probably part of their diet. The entomophagous animals had their natural instincts to identify the tasty species and the early humans took the cues from the wild animals to select the species they consumed (Bryant 2008). Those who ate insects were believed to be motivated by primates and other animals that were observed eating different species of insects (Weiss and Mann 1985; Jones et al. 1994). Subsequently, during the time of Biblical Moses (around 1444 BC), some insects in the Order Orthoptera were mentioned as those that the Israelites were permitted by God to eat (Leviticus 11: 20–23). The practice was retained for about 1500 years when John the Baptist was born and his foods were locust and honey (Matthew 3:4).

Early hominids in South Africa were termite eaters who forced termites out of their termataria with bones, then collected them. According to Ledger (1971), termites and bees were possible diet of man in Melville koppies, South Africa for about a million years (Blackwell and d Errico 2001). The earliest Ethiopian community of insect eaters to be described was probably locust eaters (Brothwell and Brothwell 1998). Consumption of insects was learnt from grandparents (Dzerefo et al. 2013), and was passed down to grandchildren over the centuries in West Africa (Rasmous-Elorduy 2009). Subsequently, over the times, insects became an indispensible traditional food in African diet (DeFoliart 1992; Nonaka 2009; Mlcek et al. 2014). To a very large extent, insects are not used as emergency food in the times of starvation, but are used as normal part of the diet when they are available (Adepoju and Daboh 2013). At present, among the four regions of SSA (Western Africa, Eastern Africa, Southern Africa and Central Africa), the West Africa and Southern Africa regions seem to be leading in the diversity of edible insects (Illgner and Nel 2000; Jongema 2017; Raheem et al. 2019).

There are different perspectives among the different African ethnic groups on the usage of insects as food and feed. Such perspectives are influenced by the historical backgrounds, literacy level, culture and religious affiliation. In some parts of south-western Nigeria, West Africa, certain wasp species (Hymenoptera: Vespidae) is allowed to build its nests around residential places and are regarded as guards, since they do not attack humans as long as they are not disturbed. Therefore, their immatures are believed to have protective magical values and are used by the traditionalists. In the same part of Nigeria, *Macrotermes* species queen is also believed to increase intelligent quotient when a whole queen is consumed either raw or roasted. According to Fasoranti and Ajiboye (1993), members of the Nigerian Ire clan, do not eat field crickets because Ogun, the iron deity does not accept animals without blood.

Among the Ijebus -a Yoruba ethnic group in Ogun State, Nigeria- some edible insects are used for rituals (Banjo et al. 2006). In Kenya, East Africa, the Legion Maria religious sect claims that insects should not be eaten because they lack blood. It is believed by the sect that consumption of flies can induce an invitation of evil spirits unto family (Ayieko and Oriaro 2008). Among the Bisa people in the Kopa area of the Zambian Mombo Woodlands, it is believed that consumption of young caterpillars is associated with misfortunes such as insanity on the consumers, or the consumer being bitten by snakes or being struck by lightning (Holden 1991). However, with the advent of westernization, the traditional rules are disappearing (Kenis et al. 2006). The African pygmies do not eat *Goliathus* spp. because it is used in fetish preparations (Bergier 1941). In some parts of Cameroon, insects are eaten for several cultural rites (Tamesse et al. 2016); for instance, the lion ant is believed to be effective to solidify marital bonds when admixed with specific herbs and offered new couples to drink (Seignobos et al. 1996).

Many edible insects harvested from the wild feed on economic trees and are therefore regarded as pests. A good example of such edible insects is the larva of *Cirina forda* which infests *Vitellaria paradoxa* (=Butyrospermum parkii)*,* a tree which fruit is used for the production of shea butter. In addition, the larva of *Bunaea alcinoe* infests many economic tree species like *Prosopis africana*, *Parkia biglobosa* and *Khaya senegalensis* (Akanbi and Ashiru 2002). *Gmelina arborea, Terminalia catappa, Spondias mombim, Harungana madagascariensis, Cananga odorata* and *Anthocleista* species are also fed upon by the insect (Braide et al. 2010). Since the edible insects are perceived as enemies of the trees, application of chemical insecticides is regarded as a prompt strategy to protect the forest.

A major bottleneck to the adoption of the edible insects as a replacement for protein in human food in some parts of Africa is the habitat of the edible species. Among the literates in some parts of Nigeria, the habitat of many species that have been reported to be edible in other parts of the globe attracts strong criticism. Their perspective is that the habitats of such insects are not hygienic and their consumption can pose a serious health risk to humans, if they are eaten. The American cockroach, *Periplaneta americana,* which is regarded as a delicacy in some parts of Asia and Africa (van Huis 2003), is a taboo in those parts of Nigeria because the species is usually found at refuse dump sites and latrines; and is greatly detested because of the perception that it can serve as a vector of many human or zoonotic diseases.

Common species consumed in sub-Saharan Africa and their harvesting and processing methods

The insects' fauna in Africa is factually rich, with approximately 100,000 species of insects that have been described from SSA (Miller and Rogo 2001). The available data on insect species consumed in Africa show some degrees of variations. For instance, while Ramos-Elorduy et al. (1997) reported 524 edible insects in Africa, a later study by van Huis (2003) reported about 250 edible insect species in the same continent, while Cerritos (2009) reviewed different registers of edible insects and reported 320 species. According to the updated world list of edible insects by Jongema (2017), an estimated total of 475 insect species are consumed in Africa, five edible species more than what Kelemu et al. (2015) reported after carrying out an inventory of edible insects in Africa. Such variations could be attributed to the spread of study, method of study, time of study and the targeted respondents (in the case of surveys). Across the globe, however, the leading Orders that have been reported to be consumed by humans are Coleoptera, Lepidoptera, Orthoptera, Hemiptera and Blattodea. The specific genus and species eaten, and their harvesting and processing methods, however, vary from one country/region to the other. Plate 1 shows some common edible species in SSA.

Animal flesh and products are rich sources of proteins, minerals and vitamins but are not affordable by low income earners and rural poor individuals. Consequently, many dwellers of sub-Saharan African countries have been consuming edible insects which are cheap source of protein (van Huis et al. 2013) in order to reduce problems of protein and micronutrients deficiencies. Tao and Li (2018) reported that about two-thirds of Africa's population are suffering from hunger and could not afford other forms of livestock because they are expensive. This has, however, led to consumption of insects for sustenance among the teeming African population. Moreover, van Huis (2013) recommended the use of insect as food due to their significant contents of protein, vitamins and minerals.

Due to their nutritional compositions, insects have attracted the attention of other researchers who are not entomologists (Chen et al. 2009). The number of edible insects increases with new studies, with the figure that has been identified as edible around the world being about 2000 (Niassy and Ekesi 2016; Bernard and Womeni 2017), while Africa alone consumes about 500 (Niassy and Ekesi 2016). From the various literatures that document the checklist of the insects used for

Plate 1 Some edible insect species **a** *Henicus whellani*; **b** *Eulepida mashona*; **c** *Brachytrupes membranaceus;* **d** *Encosternum delegorguei;* **e** *Cirina forda* (Photo Credit- Faith A. Manditsera & Samuel A. Babarinde)

food and feed in SSA, the lists of the species were given with some taxonomic descriptions and common names that made the identification of the species comparatively easy. However, in some literature, the details on the postharvest processing were sparse with the exception of Ebenebe et al. (2017) and Dzerefo et al. (2013), who did their studies in West and Southern Africa, respectively. Alamu et al. (2013) documented the postharvest processing of few insect species in the presented list, while others were not presented. The reason for this could either be an oversight on the part of the researcher during the conceptualization and design of the research or the attitude of the respondents involved in the survey, who failed to supply the required information on the postharvest processing methods.

Several authors (Christensen et al. 2006; Kinyuru et al. 2010; Oibiokpa et al. 2017; Haber et al. 2019; Kunatsa et al. 2020) have documented the nutritional and health importance of edible insects and their potentials in alleviating food and nutrition insecurity. The increasing awareness of nutritional importance of insect has increased its potential as food and food ingredients among local food processors and majority of African rural households. The types of edible insects consumed in SSA vary from location to location. In Nigeria, the most commonly consumed ones are from the Order of Lepidoptera, Coleoptera, Hymenoptera, Isoptera with the prominent insects being palm weevil, termites, variegated grasshopper, rhinocerous beetle, cricket, emperor moth larva and moth caterpillar (Idowu et al. 2014; Idowu et al. 2019; Oibiokpa et al. 2018). Termites and lake flies are consumed in Lake Victoria region in Kenya and Uganda (Ayieko 2010), edible winged termite, grasshopper (*Ruspolia differens*), edible stinkbugs, emperor moth larva in Kenya and Zimbabwe (Kinyuru et al. 2013; Kunatsa et al. 2020) and palm weevil in Ghana (Parker et al. 2020).

Apart from its availability, the insect consumption diversity is a function of the knowledge and culture of the people in any case study. An edible species may be abundant in a region and may not be consumed by the inhabitants of the region, if its nutritional values are unknown. For instance, while *Zonocerus variegatus* was consumed in some parts of north western Nigeria, it is not accepted as a delicacy in the south western part of the country, despite the fact that it is common in both regions of the country. Table 1 gives a summary description of major species consumed in SSA.

Nutritional composition of edible insect species found in Africa

The real and potential contribution of edible insects to nutrition of people who consume them have been well-documented by many researches (van Huis et al. 2013; Kinyuru et al. 2015; Manditsera et al. 2018). Edible insects are consumed because of their nutritional value amongst other motives that include taste and medicinal properties. Edible insects are consumed for their valuable contents, which include both macro- and micronutrients. Incidentally, the contents vary depending on the species, metamorphic stage, habitat, diet and season. Considerable research has been done on the nutritional analysis of the insect species consumed in SSA. Whilst nutritional analysis of edible insects for both food (See Siulapwa et al. 2014; Manditsera et al. 2019) and feed (Madibela et al. 2007; Alegbeleye et al. 2012; Shumo et al. 2019) has been carried out, most of the studies were focussed on evaluating the nutrient content for food purposes. More so, the data of insects collected from the wild are enormous, though more studies on reared insects are recently coming up due to the increase in the captive rearing of insects.

Table 2 shows the proximate composition of some of the edible species consumed in Africa. As previously reported (Mutungi et al. 2019), African edible insects are a valuable source of proteins as indicated by values as high as 70% (Table 2) despite the wide range of the protein values. The large variation in the proximate composition of the reported

Table 1 Common insect species consumed in sub-Saharan Africa

Region	Scientific name	Order	Family	Life stage consumed	References
West Africa	*Alphodius rufipes* Linnaeus	Coleoptera	Scarabaeidae	Larva	Paiko et al. (2012)
	Macrotermes bellicosus (Smeatham)	Blattodea (= Isoptera)	Termitidae	Winged adults & queen	Banjo et al. (2006); Fombong and Kinyuru (2018)
	Brachytrypes membranaceus Drury	Orthoptera	Gryllidae	Adult	Agbidye et al. (2009)
	Zonocerus variegatus Linnaeus	Orthoptera	Pyrgomorphidae	Adult	Banjo et al. (2006)
	Cirina forda (Westwood)	Lepidoptera	Saturnidae	Carterpillar (Larva)	Agbidye and Nongo (2012); Adepoju and Daboh (2013); Badanaro et al. (2014); Oyegoke et al. (2014)
	Acoeypha picta	Orthoptera	Acrididae	Adult	Raheem et al. (2019)
	Acorypha glaucopsis(Walker)	Orthoptera	Acrididae	Adult	Raheem et al. (2019)
	Acrida bicolor (Thungerg)	Orthoptera	Acrididae	Adult	Raheem et al. (2019)
	Scapteriscus vicinus Scudder	Orthoptera	Gryllotalpidae	Adult	Anankware et al. (2016),
	Rhynchophorus phoenicis (Fabricius)	Coleoptera	Cuculionidae	Larva	Banjo et al. (2006); Anankware et al. (2016),
	Oryctes boas (Fabricius)	Coleoptera	Scarabaeidae	Larva	Fasoranti and Ajiboye (1993)
	Oryctes boas (Fabricius)	Coleoptera			
	Apis mellifera mellifera Linnaeus	Hymenoptera	Apidae	Larvae & pupa	
	Cytacanthacris naeruginosus (Stoll)*unicolor*	Orthoptera	Acrididae	adult	Banjo et al. (2006)
	Analeptes trifasciata (Fabricius)	Coleoptera	Scarabaeidae	Adult	
	Lampetis sp. (spinthoptera) Casey	Coleoptera	Buprestidae	Adult	Tchibozo (2015)
	*Sternocera interrupta (*Olivier)	Coleoptera	Buprestidae		Riggi et al. (2013); Seignobos et al. (1996)
	Tarachodes saussurei Giglio-Tos	Blattodea	Tarachodidae		Barreteau (1999)
	Leuconodes laisalis (Walker)	Lepidoptera	Crambidae	Larva	Okore et al., 2014
	Aiolopus thalassinus thalassinus (Fabricius)	Orthoptera	Acrididae	Nymph/Adult	Tchibozo (2015)
	Rhynchophorus palmarum Linnaeus	Coleoptera	Curculionodae	Larva	Dué et al. (2009)
Southern Africa	*Eulepida mashona* Arrow	Coleoptera	Scarabaeidae		Musundire et al. (2016b);
	Henicus whellani Chopard	Orthoptera	Stenopelmatidae		Manditsera et al. (2019)
	Encosternum delegorguei (Spinola)	Hemiptera	Tessaratomidae	adult	Manditsera et al. (2019)
	Apis mellifera mellifera Linnaeus	Hymenoptera	Apidae		
	Carebara vidua (Smith)				
	Steraspis amplipennis (Fahr.)	Coleoptera	Buprestidae	Adult	DeFoliart (2002)
	Sternocera funebris Boheman	Coleoptera	Buprestidae	Adult	Chavanduka (1976)
	Sternocera orissa Buquet	Coleoptera	Buprestidae	Adult	Nonaka (1996)
	Tithoes maculatus (Fabricius) (=*Acanthophorus maculatus* Fabricius)	Coleoptera	Cerambycidae	Larva	Mbata (1995)
	Petascelis wahlbergi (Stål)	Hemiptera	Coreidae		Chavanduka (1976)
	Ioba leopardina Distant	Hemiptera	Cicadidae	Adult	Mbata (1995)
	Orapa sp. Distant	Hemiptera	Cicadidae	Adult	Roodt (1993)
	Ioba leopardina Distant	Hemiptera	Cicadidae	Adult	Mbata (1995), Malaisse (1997)
	Busseola fusca (Fuller)	Lepidoptera	Noctuidae	Larva	DeFoliart (2002)
	Imbrasia butyrospermi Vuillot	Lepidoptera	Saturniidae	Larva	Kelemu et al. (2015)
	Cardeniopsis nigropunctatus (Bolivar)	Orthoptera	Acrididae	Adult	DeFoliart (2002)
	Locusta migratoria migratorioides (Reiche & Fairmaire)	Orthoptera	Acrididae	Adult	DeFoliart (2002),
East Africa	*Carebara vidua* (Smith)	Hymenoptera	Formicidae		Ayieko et al. (2012)
	Chaoborus edulis Edwards	Diptera	Chaoboridae	Adult	Owen (1973)
	Chaoborus sp. Lichtenstein	Diptera	Chaoboridae	Adult	Ayieko and Nyambuga (2009)
	Coptotermes sp. Wasmann	Blattodea (= Isoptera)	Rhinotermitidae	Winged adult	Ayieko and Nyambuga, 2009
	Acanthotermes sp	Blattodea (= Isoptera)	Termitidae	Adult	Bodenheimer (1951)
	Anaphe panda Boisduval	Lepidoptera	Notodontidae	Larva	DeFoliart (2002)
	Pseudacanthotermes militaris (Hagen)	Blattodea (= Isoptera)	Termitidae	Adult	Kinyuru et al. (2013)
	Macrotermes bellicosus (Smeatham)	Blattodea (= Isoptera)	Termitidae	Adult	Kinyuru et al. (2013)
	Brachytrupes spp. Chopardi (Uvarov)	Orthoptera	Gryllidae	Adults	Akullo et al. (2018)
	Ruspolia differens Serville	Orthoptera	Conocephalidae	Nymph & Adult	van Huis (2003); Mmari et al. (2017)
	Chaoborus edulis Edwards	Diptera	Chaoboridae	Adult	Solomon and Prisca (2012)

Table 1 (continued)

Region	Scientific name	Order	Family	Life stage consumed	References
	Bunaea alcinoë (Stoll)	Lepidoptera	Saturniidae	larva	DeFoliart (2002)
	Macrotermes spp. Holmgren	Blattodea(-Isoptera)	Termitidae	adult	Okia et al. (2017)
Central Africa	*Rhypopteryx poecilanthes* Collenette	Lepidoptera	Lymantriidae		Latham (2005)
	Mallodon downesi Hope	Coleoptera	Cerambycidae	Larva	Bergier (1941)
	Zographus aulicus Bertolini	Coleoptera	Cerambycidae		Malaisse (1997)
	Golibathus sp. Lamarck	Coleoptera	Scarabaeidae	Larva	DeFoliart (2002) Hoare (2007)
	Mecynorhina sp. Hope	Coleoptera	Scarabaeidae	Larva	Hoare (2007)
	Oryctes boas (Fabricius)	Coleoptera	Scarabaeidae	Larva	DeFoliart (2002)
	Belostoma sp. Latreille	Hemiptera	Belostomatidae		Hoare (2007)
	Afzeliada afzelii Stål	Hemiptera	Cicadidae	Adult	Malaisse (1997)
	Ioba leopardina Distant	Hemiptera	Cicadidae	Adult	Malaisse (1997)
	Munza furva Distant	Hemiptera	Cicadidae	Adult	Malaisse, 1997
	Platypleura adouma Distant	Hemiptera	Cicadidae	Adult	Hoare (2007)
	Synagris sp. Latreille	Hymenoptera	Vespidae	Larva and pupa	DeFoliart (2002)
	Bellicositermes natalensis (Haviland)	Blattodea (+Isoptera)	Termitidae	Adult	Hoare (2007)
	Prodenia sp. Guenée	Lepidoptera	Noctuidae	Larva	Malaisse (2005)
	Elaphrodes lactea (Gaede)	Lepidoptera	Notodontidae	Larva	Malaisse (1997); Bomolo et al. (2017)
	Antheua sp. Walker	Lepidoptera	Notodontidae	Larva	Tchibozo (2015)
	Imbrasia alopia (Westwood)	Lepidoptera	Saturniidae	Larva	Tchibozo (2015)
	Heteracris guineensis (Krauss)	Orthoptera	Acrididae	Adult	Hoare (2007)
	Locusta migratoria migratorioides (Reiche & Fairmaire)	Orthoptera	Acrididae	Adult	Hoare (2007)
	Pyrgomorpha vignaudi (Guérin-M.)	Orthoptera	Pyrgomorphidae	Adult	Hoare (2007)

insects in Table 2 makes it difficult to make a conclusion on the relationship between different nutrients. For example, some species having high protein content are low in fat content, while some edible species have high fat and protein profiles. Ordinarily, insects with higher fat content are expected to have a correspondingly higher energy value. In addition, in nutrient content determination, researchers use different methods for analysis, sample preparation and this have influenced the nutrient values obtained. For example, in Manditsera et al. (2019), a protein conversion factor of 4.76 was used for protein determination of *Eulepida mashona* and *Henicus whellani*, whilst Musundire et al. (2016a, b, c) used a factor of 6.25. With regard to reared edible species, the substrate used for rearing the insects can have an influence on their nutritional values. The nutritive composition of edible insects can be manipulated by the choice of substrate fed to the insects (Shumo et al. 2019; Chia 2019). Shumo et al. (2019) reported significant difference in the nutritional value of black soldier fly (BSF) fed on different substrates (Table 2).

Most of the studies of edible insects in SSA focused more on existence, availability and consumption of insects in many regions of Africa and lack information on the nutritional analysis (for example Mbata et al. 2012; Okore et al. 2014; Latham 1999; Anankware et al. 2016; Stull et al. 2018). Moreover, most of the studies on nutritional composition focus more on the most commonly consumed insects in SSA such as caterpillars (Egan et al. 2014; Latham 1999) and termites (Stull et al. 2018). Table 2 shows such nutritional analysis of insect species done by more than one study even from the same country. Considering the estimated number of species consumed in Africa and the reported nutritional analysis of the insects, the nutritional data for the majority of the edible insects are still missing. As such, there is a need for more research on nutritional analysis. The knowledge gap is too wide and this can hinder the promotion of edible insects for food and nutrition security. The availability of nutritional data is fundamental in the recommendation of edible insects for consumption, considering the variations in the nutritional compositions of different insects. The presentation of nutritional data is of importance to nutritionists, food technologists, and edible insect farmers, as it will guide them on which species to select.

Not only should nutritional research be invested in proximate analysis, but for the micronutrients too. Table 3 shows the mineral composition of some of the edible species reported in Table 2. Whilst ash contents of edible insects give an estimate of the mineral composition, it is never indicative of mineral profile. High content of certain minerals can result in toxicity and one such mineral is manganese. Verspoor et al. (2020) observed a high concentration of manganese in termites and indicated that this could challenge future development of termite

Table 2 Proximate composition (based on dry matter) of some of edible insect's species consumed in sub-Saharan Africa

Insect species	Origin	Wild/ reared	Protein (g/100 g)	Fat (g/100 g)	Ash (g/100 g)	Fibre (g/100 g)	Energy kcal	Carbohydrate	References
Gonimbrasia belina	Zambia	wild	56.95	10	7	NR	385	7.8	Siulapwa et al. (2014)
Gynanisa maja	Zambia	wild	55.92	12.1	7.4	NR	394	10.7	Siulapwa et al. (2014)
Ruspolia differens	Zambia	wild	44.49	49	2.2	NR	618.2	8.4	Siulapwa et al. (2014)
Macrotermes falciger	Zambia	wild	43.26	43	7.3	NR	810.2	32.8	Siulapwa et al. (2014)
Cirina forda	Nigeria	wild	73.35	14.3	3.1	6.01	NR	NR	Agbidye et al. (2009)
Macrotermes natalensis	Nigeria	wild	66.62	21.35	4.05	7.85	NR	NR	Agbidye et al. (2009)
Brachytrupes membranaceus	Nigeria	wild	35.06	53.05	3.25	6.3	NR	NR	Agbidye et al. (2009)
Brachytrupes alcioes	Nigeria	wild	74.34	14.1	2.85	5.55	NR	NR	Agbidye et al. (2009)
Macrotermis nigernsis	Nigeria	wild	43.75	40.83	8	6.76	554	2.94	Oibiokpa et al. (2017)
Cirina forda	Nigeria	wild	64.05	12.5	7	9.3.	421.7	13.25	Oibiokpa et al. (2017)
Gryllus assimilis	Nigeria	Wild	71.04	7	6	8.28	397	12.46	Oibiokpa et al. (2017)
Melanoplus foedus	Nigeria	Wild	75.08	6.5	6.17	5.96	391	8.26	Oibiokpa et al. (2017)
Macrotermes subylanus	Kenya	Wild	39.34	44.82	7.58	6.37	NR	1.89	Kinyuru et al. (2013)
Pseudacanthomes militaris	Kenya	Wild	33.51	46.59	4.58	6.59	NR	8.73	Kinyuru et al. (2013)
Macrotermes bellicocus	Kenya	Wild	39.74	47.03	4.65	6.21	NR	2.37	Kinyuru et al. (2013)
Pseudacanthomes spiniger	Kenya	Wild	37.54	47.31	7.22	7.21	NR	0.72	Kinyuru et al. (2013)
Hermetia illucens fed on CM	Kenya	Reared	41.1	30.1	9.3	21.9	NR	NR	Shumo et al. (2019)
Hermetia illucens fed on KW	Kenya	Reared	33	34.3	9.6	20.4	NR	NR	Shumo et al. (2019)
Hermetia illucens fed on SG	Kenya	Reared	41.3	31	11.6	28.6	NR	NR	Shumo et al. (2019)
Eulepida mashona	Zimbabwe	Wild	55.1	9.06	4.56	NR	NR	NR	Manditsera et al. (2018)
Henicus whellani	Zimbabwe	Wild	66.7	7.58	4.99	NR	NR	NR	Manditsera et al. (2019)
Hermetia illucens	Kenya	Reared	36.3	29.6	3.9	8.6	NR	21.6	Nyangena et al. (2020)
Acheta domesticus	Kenya	Reared	52.3	18.3	3.6	8.1	NR	17.7	Nyangena et al. (2020)
Ruspolia differens	Uganda	Wild	43.8	28.4	3.1	4.2	NR	20.4	Nyangena et al. (2020)
Spodoptera littoralis	Kenya	Reared	38.5	17.4	7.6	6.4	NR	30.1	Nyangena et al. (2020)
Ruspolia differens	Kenya/Uganda	wild	47.7	35.53	4.66		524	NR	Fombong et al. (2017)
Zonocerus variegatus	Nigera	wild	61.5	6.87	14.8	0	NR	NR	Alegbeleye et al. (2012)
Bunaea alcinoe	DRCongo	wild	65.7	10		NR	NR	NR	Latham, 1999
Cirina forda	DRCongo	wild	51.9	13		NR	NR	NR	Latham, 1999
Imbrasis petiveri	DRCongo	Wild	57.9	9.1		NR	NR	NR	Latham, 1999
Anaphe panda	DRCongo	wild	45.6	35		NR	NR	NR	Latham, 1999
Hemijana variegeta	South Africa	wild	44.48	19.75	10.47	NR	306	15.1	Egan et al. (2014)
Brachytrupes membranaceus	Zimbabwe	wild	53.4	15.8	6	5	454.7	0.5	Musundire et al. (2016a)
Carebara vidua	Zimbabwe	wild	43.6	38.2	8.6	9.1	519.8	5	Musundire et al. (2016a)
Encosternum delegorguei	Zimbabwe	Wild	43.3	45	1.3	5.3	597.4	3.7	Musundire et al. (2016a)
Encosternum delegorguei	Zimbabwe	Wild	31.6	38.9	3.8	22	490.4	16.2	Musundire et al. (2016a)
Eulepida mashona	Zimbabwe	Wild	46.3	11.8	10.9	14.8	352.2	8.2	Musundire et al. (2016a)
Gonimbrasia belina	Zimbabwe	Wild	55.4	16.4	8.3	16	329.1	14.1	Musundire et al. (2016a)
Gonanisa maia	Zimbabwe	wild	51.4	10.9	7.7	16.2	355.3	47.2	Musundire et al. (2016a)
Gryllotalpa Africana	Zimbabwe	Wild	22	10.8	12.6	7.4	362.3	40.2	Musundire et al. (2016a)
Loba leopardina	Zimbabwe	Wild	25.8	12.6	6.6	14.7	542.5	0.4	Musundire et al. (2016a)
Macrotermes natalensis	Zimbabwe	Wild	37.1	41.6	3.5	4.9	503.9	18.2	Musundire et al. (2016a)
Ornithacris turbida	Zimbabwe	wild	42.7	29.4	4.5	2			Musundire et al. (2016a)

NR = no values were reported for the species by the author

alates. The possibilities of too high concentration of mineral elements and heavy metals in edible insects necessitates the treatment of insect species on an individual basis when considering using or marketing them as human food. Micronutrient deficiencies are a public health issue in SSA thus, micronutrient nutritional data of edible species can be of importance to screen species with high potential for helping alleviating the malnutrition problem or selection for rearing.

Not only is the nutritional content of edible insects important but also bioavailability/ bioaccessibility studies and influence of processing and storage on nutritional composition. A number of studies have reported on nutrient bioaccessibility and effects of processing methods (Madibela et al. 2007; Kinyuru et al. 2010; Fombong et al. 2017; Manditsera et al. 2019; Nyangena et al. 2020). However, there is need for more studies as results from published literature show wide variations between species, processing methods etc.

Nutritional diversity of edible insects used as animal feed

Some of the limitations in the nutritional profile of insect meal include high fat, amino acid imbalance, presence of mycotoxins, antinutritional factors such as chitin (Sánchez-Muros et al. 2016), and the endogenous production of 1,4-benzoquinone toxin (El-Kashlan et al. 1996). These isolated or combined factors may compromise the animal's immune system (Sánchez-Muros et al. 2016) and survival rates (Barker et al. 1998) or predispose man that consume such animal products to mycotoxicosis.

The chitin content in insects is high, for example about 8.7% in field crickets (Wang et al. 2004), but in larvae of *Cirina forda,* it is 9.4% (Akinnawo and Ketiku 2000). Chitin can change the percentage of protein in the insects. For example, the removal of chitin in adult honeybees led to an increase in protein from 42 to 62% (Ozimek et al. 1985). Chitin is also known to induce asthma and allergies depending on the particle size of the chitin substance (Brinchmann et al. 2011). Other authors related high chitin levels with the reduction of feed consumption, availability of nutrients, and negative effects on performance (Kroeckel et al. 2012; Sánchez-Muros et al. 2016). The presence of large spines on the tibia of grasshoppers and locusts may cause intestinal constipation, which has been shown to be fatal in monkeys after locust outbreaks and has occasionally required surgery in humans. Grinding or removing the legs and wings is therefore recommended prior to consumption (van Huis et al. 2013).

Pesticides

Pesticides are commonly used to control pests on farmlands and settlement areas. Traditional harvesting of insect from the wild poses a major risk to consumers where the control of chemical applications is difficult (van Huis et al. 2013) because of bioaccumulation of the chemical in the insects. Historically, high concentrations of residues of organophosphorus pesticides were detected in locusts collected for food in Kuwait after the outbreak of 1988/1989 (Saeed et al. 1993). In Korea, the mandatory use of pesticides in rice fields led to a decline in traditional grasshopper consumption in the 1970s (Makkar et al. 2014). In Mali, the increasing use of pesticides in cotton farming has led to a decline in grasshopper consumption by children in rural areas, with negative consequences on the protein intake of the children (van Huis et al. 2013).

Hygienic issues in insect processing for food

Traditionally, some communities in SSA consume insects with little or no processing to achieve desired sensory satisfaction. In some places where processing is done, traditional methods are employed. For instance, in Zambia as in many parts of Southern Africa, insects are processed by rural dwellers and sold in the cities. The traditional method of processing has increased concerns over their safety for wider

Table 3 Mineral composition (mg/100 g dry matter) of some of the edible species in sub Saharan Africa

Insect species	Origin	Fe	Zn	Ca	Mg	Na	K	Mn	Cu	References
Gonimbrasia belina	Zambia	26.7	NR	127.8	69.7	42.1	10.2	1.5	0.3	Siulapwa et al. (2014)
Gynanisa maja	Zambia	13.6		166.4	100	32.4	65.5	1.4	0.3	Siulapwa et al. (2014)
Ruspolia differens	Zambia	2	NR	9	5.2	14.6	9.1	0	0.1	Siulapwa et al. (2014)
Macrotermes falciger	Zambia	24.8		78	49	12.7	12.7	1.5	1.5	Siulapwa et al. (2014)
Macrotermis nigernsis	Nigeria	0.14	0.21	0.21	10.66	2.36	416.65	0.13	0.03	Oibiokpa et al. (2017)
Cirina forda	Nigeria	0.01	0.11	0.21	12.8	0.23	381.21	0	0.01	Oibiokpa et al. (2017)
Gryllus assimilis	Nigeria	0.15	0.24	0.09	8.92	0.42	367.13	0	0.02	Oibiokpa et al. (2017)
Melanoplus foedus	Nigeria	0.17	0.24	0.22	10.77	0.2	367.02	0.01	0	Oibiokpa et al. (2017)
Macrotermes subylanus	Kenya	53.33	8.1	58.72	NR	NR	NR	NR	NR	Kinyuru et al. (2013)
Pseudacanthomes militaris	Kenya	60.29	12.86	48.31	NR	NR	NR	NR	NR	Kinyuru et al. (2013)
Macrotermes bellicocus	Kenya	115.97	10.76	63.6	NR	NR	NR	NR	NR	Kinyuru et al. (2013)
Pseudacanthomes spiniger	Kenya	64.17	7.1	42.89	NR	NR	NR	NR	NR	Kinyuru et al. (2013)
Black soldier fly fed on CM	Kenya	0.6	0.3	3.2	4	2.4	4.9	1.4	0.4	Shumo et al. (2019)
Black soldier fly fed on KW	Kenya	2.2	0.3	2	3.3	2	5.7	0.9	0.2	Shumo et al. (2019)
Black soldier fly fed on SG	Kenya	0.3	0.3	2.6	3.5	2.6	4.4	1.1	0.5	Shumo et al. (2019)
Eulepida mashona	Zimbabwe	37.3	18.6	59.5	234	95.9	1507	1.75	2.73	Manditsera et al. (2018)
Henicus whellani	Zimbabwe	31.6	18.2	107	93.9	182	1378	2.01	3.48	Manditsera et al. (2019)
Ruspolia differens	Kenya/Uganda	216.56	14.63	895.67	145.75	54.01	779.19	7.4	1.66	Fombong et al. (2017)

population consumption (Kachapulula et al. 2018; Murefu et al. 2019). Nutrient-dense foods such as insects are easily attacked by chemical and microbial agents (Oibiokpa et al. 2018). Good hygienic practices and implementation of Hazard Analysis Critical Control Point (HACCP) plan are essential for processing of insects at industrial level. Insect can be contaminated with *Escherichia coli* through poor hygienic practices (Mujuru et al. (2014). Mouldy insects can be contaminated with aflatoxin and should be removed before processing.

The raw materials, to start with, must be in good and safe conditions; therefore collection of dead edible insects should be avoided. In a situation where the edible stage is the adult, processing of the immature as food or feed can increase toxicity risk in both human and animal. Consequently, appropriate harvesting of mature insects irrespective of the stages should be ensured. Considering the potential accumulation of toxic constituents in the gut and inability of some individual people to digest chitin, appropriate processing procedures such as thorough washing with portable water, removal of appendages and insect heads, de-winging, degutting, beheading (Kinyuru et al. 2018) should be adopted. This will reduce the risk of allergens in some individuals that lack chitinase (chitin digestive enzyme) (Kouřimská and Adámková 2016). Chitin and cellulose are similar in structure and are digested by chitinase found in gastric juices of human (Paoletti et al. 2007). Appropriate unit operations and processing are major determinants in achieving a healthy and good quality end product.

Good processing procedure begins with sorting the infected insects from the good ones. During sorting, any insect that does not meet the selection criteria should be removed. Conventionally, sundried and freshly degutted insects should be thoroughly washed to remove adhering dusts and dirt. Insects that are not meant for immediate consumption should be hygienically processed and stored under optimum storage condition to prevent re-contamination. For dried samples, safe moisture content for storage of insects should be maintained. Since insects contain appreciable amount of fat, the water activity for minimal enzymatic reaction must be maintained to prevent hydrolytic rancidity.

Different household methods of cooking (boiling, pan-frying, oven-cooking and vacuum cooking) influence the nutritive value and microbial load of mealworms. Boiling and vacuum cooking reduced the microbial load the most and maintained polyunsaturated fatty acids and high levels of protein of mealworms (Caparros et al. 2018). Since insects contain intrinsic microbiota (Fraqueza and Patarata 2017), heat treatment of insect during processing is a good approach for the reduction of the microbiota. Therefore, consumption of raw insects should be discouraged.

Appropriate food safety regulations are also required to ensure insect cocnsumers' safety. This regulation should provide appropriate guidelines for all insects' handlers and processors. Any suspected hazardous materials should be removed prior to processing. There could be recontamination of processed insects before it gets to consumers; therefore, adequate packaging and storage facilities are required to extend the shelf-life of insects. Strict compliance to food safety regulations must be ensured (Fraqueza and Patarata 2017). Training of local processors of insects for food and feed to minimize contamination during processing should be given utmost priority. Mujuru et al. (2014) reported that a combination of boiling and open-pan roasting with hygienic handling (through the use of gloves) during degutting can lower *the level of S. aureus and E. coli* in mopane worm.

The primary purpose of processing is to increase the palatability of foods. In addition, the nutritive composition of foods is also enhanced when their bioavailability increases. Different processing methods have varying impacts on nutrient quality (Severi et al. 1997; Manditsera et al. 2019). Therefore, using cooking as a stategy to ensure food safety should be done with proper knowledge. For instance, cooking can cause loss of minerals via leaching into cooking water (Kimura and Itokawa 1990). In an attempt to prevent these losses, eating boiled insects with boiling sauce can be adopted. This nutrient loss prevention method, however, might not be too adequate as some of the anti-nutrients can also leach into the cooking water and if used in food preparation can hinder the bioavailability of minerals.

Prospects of insects for food and feed

Sustainable non-conventional animal protein in animal feed

World food consumption patterns and preferences are expected to change due to population growth and urbanization by 2050 and this will credibly cause an increase in animal protein demands (van Huis 2013). About three-quarters of the predicted increase in meat demand will come from poultry and pigs (Vantomme 2015) that depend heavily on compounded ration. This will place a huge pressure on livestock feed which currently claim about 60–70% of production costs. This scenario becomes complicated with increasing shortage of conventional protein feed streams, particularly of animal origin such as fish meal which fluctuates in both price and supply. The search for suitable alternatives for this predominant animal protein in feed (fish meal) has caused untold pains to both farmers and the feed industry in Africa.

The nutritional analyses of various insect have revealed a profile that is similar to fish meal in terms of protein. A high crude protein (as high as 70%) and lipid contents (up to 36%) were found in insects. The latter could probably be extracted and used for other applications like biodiesel production

(Makkar et al. 2014). High protein digestibility between 76% and 98% with essential amino acid scores ranged between 46% and 96% has also been reported for several species of insects (Ramos-Elorduy et al. 1997). This is higher than the 40% of total amino acid content specified by the Food and Agriculture Organization (FAO) for a food to be considered of high nutritional quality. Optimum level of chitin, a polysaccharide found in the exoskeleton of insects, have been suggested to have a positive effect on the immune system (FAO 2015) and by implication may reduce the use of antibiotics in the poultry industry due to drug-resistant bacterial strains associated with meat from antibiotic-treated animals.

Insect meal can replace scarce fishmeal in feed ingredient, particularly in the fast growing aquaculture industry. The demand for edible insects is growing in Africa, mainly because animal protein is becoming more expensive and scarcer. The demand for healthier alternatives and insects has grown and has a huge potential in animal feed production (Raheem et al. 2019). Mutungi et al. (2019) and Tae-Kyung et al. (2019) reported that edible insects are commonly sold in open markets and school cafeterias and in Nigeria, Zambia and Zimbabwe as this forms a profitable business for the collectors. According to Dobermann et al. (2017) about 50% of dietary protein is derived from insects, which have higher market value than other protein sources. In addition, attention given to edible insects has increased rapidly since the FAO began promoting insects as feasible dietary options for humans (van Huis et al. 2013).

Increase in food and feed prices in the future will bring about the search for alternative protein sources. In manySSA countries, the main protein sources used in poultry feed include soya bean meal, sunflower seed meal, cotton seed meal and fish meal. However, market demand for fish and soya bean are high with little supply; hence, the need for importation and consequently increase in feed cost (Vernooij and Veldkamp 2018). There is therefore, much interest in possible replacements for these expensive ingredients.

The recent soaring demand and consequent high prices for fishmeal/soya bean with increasing aquaculture production is advancing new research into the development of insect protein for aquaculture and poultry. The insect-based feed products can have a comparable market to fishmeal and soya bean, which are presently the prime ingridients used in feed composition. Insect production for animal feed has a brilliant future; it can therefore be used as a replacement for fishmeal and soya bean in animal diets. The global industrial feed production in 2011 was estimated at 870 million tons, worth approximately US$350 billion (http://www.ifif.org). Smallholder farms in Asia and Africa commonly use insects as fish feed. Edible insects are potential protein source for animal feeds and have the prospect to meet increasing global demand. Insects are relatively high in nutrients, have low environmental impact, require less space for cultivation and are previously part of the natural diets of livestock which makes them an ultimate feed alternative (Dobermann et al. 2017).

Considering edible insect viability, Rumpold and Schlüter (2013) reported that a 100% protein substitution can be made with Black Soldier Fly (BSF) in layers and broilers feed production with no reduction in growth rates and in some cases, increased chick growth rates. Replacement of soya bean oil with BSF larvae, have no influence on growth or performance of broiler chickens; suggesting that edible insect is a viable alternative (Schiavone et al. 2017). Fiaboe and Nakimbugwe (2017) testified that the demand for insects to substitute conventional protein source in feed in Kenya is estimated at 115,000 t of dried insect annually for poultry feed alone. The replacement of fish meal with BSF meal in diets does not alter the odour, texture, or flavour of Atlantic salmon (*Salmo salar*) (Lock et al. 2016). Likewise, mealworms successfully replaced 40–80% of the standard catfish (*Ameiurus melas*) diet without harmful effects on growth performance (Roncarati et al. 2015). The silkworm pupa was also discovered to be another viable alternative to fish meal and this was tested successfully for African catfish (*Clarias gariepinus*) fingerling (Kurbanov et al. 2015).

Aquaculture is known to be one of the fastest growing industries. However, a major barrier to a sustainable growth of the industry is hinged on feed cost, particularly fishmeal and fish oil. Substantial proportions of fish used for the production of fishmeal are food-grade fish (Cashion et al. 2017), and ocean fish reserves are being drained by overfishing to provide the feed. The increasing limitations on unbridled fishing and catch allowance have enforced the aquaculture industry to search for alternative high-value protein resources for feed, which is where edible insects can play a significant role (Dobermann et al. 2017). In the short term, use of insect as protein source is estimated to decrease protein cost in feed production by 25 to 37.5% and in addition, it will carry higher potential in the medium and long term where over 50% cost reduction is being envisaged (Vernooij and Veldkamp 2018).

Insect farming

The commercial farming of insects could secure a consistent production in quantity and quality with moderate price, factors that guarantee feed protein sustainability on the African continent. Insects are known to efficiently upgrade low-value biomass into high-quality protein (van Huis et al. 2013) because they are cold-blooded animals. Larvae can feed on different waste streams such as raw food waste, organic, slaughter waste, and manure. This implies that insect transform organic remains into high-quality fertilizers in addition to forming "protein biomass" with excellent value (Henry et al. 2015).

About 30 metric tonnes of food waste was reportedly reduced to 10 metric tons while producing about one ton of dry biomass of insect (Salomone et al. 2017). This may offer practical solutions to agricultural waste production, as fly larvae can reduce organic waste by around 60% in 10 days as recently indicated by Shaphan et al. (2019). Field trials showed that insects have better conversion efficiency than pigs and cattle (Dobermann et al. 2017; Bosch et al. 2019). It takes much less feed and also land to produce a kilogram of insect protein than a kilogram of meat protein. The mass farming of insects requires between 50 and 90% less land than conventional agriculture per kilogram of protein and could reduce greenhouse gas emissions from the livestock industry by 50% (Bosch et al. 2019).

Several authors reported that insect meal could be an excellent replacement of fishmeal or soya bean meal in animal feed (Ogunji et al. 2008; Maurer et al. 2015; Cullere et al. 2018; Van der Fels-Klerx et al. 2018; Biasato et al. 2019). Table 4 presents a summary of the results of selected trials on the potentials of incorporating insects into animal feed. Low production cost was also associated with insect meal. Insects' breeding can be controlled in a comparatively simple manner void of complicated infrastructure and expensive labour costs which make them an excellent choice for poultry feed (van Huis 2013). Reliability of commercial scale production is one serious factor that must be critically looked into. Until now, there is no report on constant and large scale farming of insects in Africa; and with the natural endowments of a vast biodiversity of species, favourable atmospheric conditions and abundance of potential insects feed, large scale insect farming should indeed be a new industry with great prospects in the continent.

Perceived risks associated with the use of insect as feed

It is important to note very strongly that insects have been part of over 2 billion people's diets for many centuries and substantial percentage of these people are in Africa who had successfully subsisted on it. Similarly, free range animals particularly poultry consume insect as natural feed and hunted meal. These facts are quick indicators that may suggest safe use of insect meal in animal feed. Although, progress is relatively rapid in insect farming industry globally, the concept is still at infancy in Africa. There will be need for more empirical studies to provide strong scientific evidence to support the development of this industry.

The regulatory blockage from European Union pose the main barrier for the world-wide acceptability of insect meal in animal feed (Dobermann et al. 2017). There are two issues that need to be addressed in the current regulation: the use of insect meal and the substrate to grow the insects. For instance, purified fat obtained from insect larvae is allowed to be used in animal diets while the use of the insect protein (fat extracted meal) is still prohibited due to perceived safety and quality concerns. Similarly, the safe use of substrates on which insects can be economically reared need clear debate and verification. A recent study showed that insects raised on pure vegetable substrates for feed do not pose any risk to consumers (EFSA 2015). The use of organic waste and manure which have been severally considered cheap and innovative for insect culturing need further studies on health-related matters of the livestock and the human final consumer. Nonetheless, considering available facts from different reviews on use of insect as animal feed, it could be suggested that the current European regulation and legislation should be reviewed to permit insect meal as protein feed in livestock diets so as to ease, among other benefits- intercontinental trade of livestock products.

Insect-based product development

Potential of edible insect in food product development

Food product development has been employed as a measure in reducing food and nutritional insecurity and curtailing protein and micro micro-nutrient deficiencies in most developing countries. Most low-income-earners and the vulnerable groups cannot afford animal protein which is expensive and have sought plant and vegetable protein alternativesin. However, some of these plants are deficient in some essential amino acids and vital minerals. The advent of insects in food product development is a better alternative in achieving a cheap, health-friendly balanced diet. The use of edible insects as ingredients has a lot of prospect in food product development. It can also improve livelihood and income generation among major stakeholders along the food value chain (Kelemu et al. 2015). Edible insects can thus be fractionated into different components and used as ingredients in new foof products. However, this is still a virgin industry in SSA.

Roles of edible insects in food fortification

The potentials of insects as food are enormous. Several studies have been conducted on pilot/laboratory scale to evaluate authenticity of insects as food in food fortification. The viability of insect in production of honey spread in Lango sub region of northern Uganda was studied by Akullo et al. (2017). Incorporation of 8% flour from soldier termites into honey gave an acceptable spread that can be used in sandwiches, pastries etc. Production of a complementary food from blend of peanut and the palm weevil larva (*Rhynchophorus*

Table 4 Nutritional characteristics of feeding insect meal to selected animal species

Trial	Results	Animal used	Country	Authors
Substitution 0–100% of fishmeal with silkworm pupae	Fermented silkworm pupae or fresh silkworm pupae could replace fishmeal, resulting in a better feed conversion rate and an absence of fishy taint in the meat	Broiler	India	Rao et al. (2011)
Maggot meal replacing 0–50% fishmeal	Could replace 50% fishmeal (2% diet as fed) with higher performance and economic returns	Broiler	Nigeria	Okah and Onwujiariri (2012)
Cricket meal protein compared to soyabean and fish meal	The Protein Efficiency Ratio, and Net Protein Ratio values of cricket meal were comparable to that of FM and better than that soya bean meal	Broiler	Pakistan	Abdul Razak et al. (2012)
Replacing fish meal (by 25, 50, 75, 100%) of grasshopper meal	Grasshopper meal can completely replace Fish Meal in broiler diets without adverse effect on the performance characteristics.	broiler	Nigeria	Sanusi et al. (2013)
Effect of replacing dietary fish meal with silkworm	Compare favourably over fish meal up to 100% replacement	Broiler	Nigeria	Ijaiya and Eko, 2009
Fed 0%, 50% and 100% grasshopper meal to replace fish meal in broiler diet.	Found that grasshopper meal can replace significant quantity of fish meal	pigs	Nigeria	Hassan et al. (2009)
0%, 1.5%, 3.0%, 4.5% and 6.0% replacement of soyabean meal	Linear increase in Body Weight, Average Daily Gain, Average Daily Feed Intake, Dry Matter and Crude Protein digestibility	pigs	South Korea	Jin et al. (2016)
0%, 30% and 60% replacement of soyabean meal with defatted black soldier fly larva meal	Linear increase in Average Daily Feed Intake	pigs	Italy	Biasato et al. (2019)
Replacing fish meal with Defatted Insect Meal (Yellow Mealworm up to 100%	Improves the Growth and Immunity	Pacific White Shrimp	France	Motte et al. (2019)
Replacing fish meal with insect meal	It does not impact the amount of contaminants in the feed and it lowers accumulation of arsenic in the fillet	Atlantic salmon	Norway	Biancarosa et al. (2019)

phoenicis) is a good approach in reducing protein energy malnutrition prevalent in SSA. A traditionally consumed edible insect, *Rhynchophorus ferrugineus,* called *akokono* in Ghana was added to groundnut to produce a protein rich complementary food (Parker et al. 2020). The product meets the recommended dietary intake for essential amino acid but lacks lysine. When developing a complementary food using this insect, it is important to consider cereals that are rich in lysine to give a complete essential amino acid profile. An affordable nutritious food developed from soya bean, sweet potatoes and longhorn grasshoppers-senene (*Ruspolia baileyi*) in Kagera and Morogoro regions of Tanzania gave a protein rich product useful for rural poor individuals. Products with 25% level of the insect gave the best protein and energy values with good sensory properties (Mmari et al. 2016).

Insects can be made into flour and used in enriching foods such as custards, breakfast pastries and convalescent foods. The use of insect as composite flour will increase its incorporation into different types of flour products, thereby increasing its utilization. Omotoso (2006) suggested that *Cirina forda* larvae powder can be used in baked and fried foods due to the powder's high oil and water absorption capacities. The high fat absorption capacity of the powder will help in retaining flavour and improving the mouth feel of the final products. Duda et al. (2019) evaluated the effect of addition of cricket powder on the nutritional value, sensory and physical characteristics of pasta where inclusion of 5% cricket powder increased protein and ash contents, and improved culinary properties.

Edible insect can be used in production of snack foods. A protein enriched snack with good quality can be obtained with insects (Adeboye et al. 2016). Edible palm weevil (*Rhynchophorus phoenicis*) paste improved the protein content of snack product (chin-chin) when blended with composite maize-wheat flour. This is a great approach in improving the nutritional quality snack eaten by school children (Ojinnaka et al. 2016). Cookies can also be produced from blends of wheat and varying proportions of palm weevil larvae flour. Cookies containing 10% palm weevil larvae flour produced the highest energy. Protein content increased by 86.7% when compared with cookies produced from 100% wheat flour. Ayieko (2010) showed the potential of termites and mayfly obtained in Lake Victoria region of East Africa in processing of crackers/biscuits. It can be worked into production of extruded snacks, bread and pasta. Insect flours can also be used in preparation of ready to eat foods. The prospect of edible insect in extruded insect rice product from cricket and locust flour has been investigated by Tao et al. (2017). This novel product can naturally offer a supplement to the plain rice staple with about 150–200% protein increase than plain rice.

Insects protein isolate

Edible insects are rich in protein. Protein content of insects of different species ranged from 13 to 77% by dry matter (Kouřimská and Adámková 2016) where large amounts of lysine, tryptophan and threonine, deficient in major cereal proteins, are present. In some parts of Africa, the intake of these nutrients is supplemented by consumption of termite, *Macrotermes subhyalinus* (Sogbesan and Ugwumba 2008). Introduction of the protein isolates or concentrates in foods can help in addressing chronic protein deficiencies in Africa. Development of protein isolate or concentrate as food ingredient for product development can help in reducing allergy associated with insects. Extracted protein isolate and protein meal can be used in human food and animal feed (van Huis et al. 2013).

Fat and oil production

It has been reported that insect oil is rich in mono and polyunsaturated acids regarded as healthy oil (Rumpold and Schlüter 2013; Otero et al. 2020). Oil can be extracted from different insect's species for pharmaceutical and industrial purposes. Impact of different solvent extraction methods on quality and stability of oils can be studied. There is need for more research work to be carried out on functional and health properties of insects for inclusion in functional foods and nutraceuticals due to their potential antioxidants reported by researchers. This could help in developing novel insect-based food products. Igwe et al. (2011) reported that termites do not require oil for frying since they are naturally rich in oil. The delicious taste of fried termite makes them a good meal for all groups.

Preservation of insect-based products

Packaging is an important aspect in extending shelf-life of food (Verghese et al. 2013). Insects are highly perishable due to the high moisture and fat contents. To extend the shelf-life of the products, there is a need for drying of the products under a controlled atmospheric condition for better preservation of nutrients. In that case, appropriate packaging of insects and insect products is pertinent. The stored samples can be used as meat substitute or as ingredients in food product development when the insects are not available during their off-season. In moving insects as food and feed along the supply chain to end users, appropriate convenient and durable packaging materials are required. The design consideration should be in such a way that volatile compounds such as flavour are well-protected from escaping while protecting other essential nutrients of the processed insects.

The medicinal potentials of African insects used as food

Insects, apart from their nutritional values, also possess some medicinal properties. Incidentally, studies on the medicinal insects in Africa are scarce (Dzerefo et al. 2013). From available literature, many ethnic groups have the knowledge or perception of these medicinal potentials of the Class Insecta. For instance, termite's consumption is believed to improve fertility (Kelemu et al. 2015), in some parts of East Africa. The edible *Encosternum* (=*Haplosterna*) *delegorguei* Spinola has been widely studied for its medicinal value in the southern African region and is believed to cure many diseases like asthma, heart disease, sore throat, diabetes, arthritis and skin cancer; with the potentials to serve as appetizer, aid digestion, enhance libido and cure hangovers (Gardiner and Gardiner 2003: Dzerefo et al. 2013; Musundire et al. 2014). In East Africa, the lake fly (*Chironomus* species) is used by traditional healers to promote good luck in businesses, make men and women seeking marital partners to attract potential suitor, to strengthen ailing children and for curing certain ailments (Ayieko and Oriaro 2008). Recently, Loko et al. (2019) reported 28 insects that are used for medicinal purposes in the Plateau Department, Republic of Benin, West Africa and some of the species have been reported to be edible. A list of some edible insects used for medicinal purposes in SSA is presented in Table 5.

Apart from the fact that some insect species have medicinal values when consumed, certain bioactive compounds produced by the edible insects' self-defence have been investigated for their medicinal potentials to treat some common diseases (Bernard and Womeni 2017; Seabrooks and Lu 2017). For instance, Cecropins isolated from insects are highly potent against both Gram positive and Gram negative bacteria (Fitriyarti and Narsimhan 2018). Zielińska et al. (2017) showed antioxidant activities of the hydrolysates obtained from some insects including cockroach, locust, and cricket. The extracts obtained from *Tenebrio molitor* and *Acheta domesticus,* by ultrasound-assisted extraction and pressurized liquid extraction using ethanol or aqueous ethanol as solvents showed antioxidant activity and inhibitory capacity against pancreatic lipase (Navarro del Hierro et al. 2020). Similarly, Jantzen da Silva et al. (2020) reviewed the functional and bioactive compounds in edible insects and their review included some edible sub-Saharan African species.

According to Dossey (2010), insects' chemical biodiversity has a vast potential in drug discovery and other fields of biochemical sciences. For instance, Cantharidin (I) obtained from blister beetle (Coleoptera: Meloidae) has cytotoxic potentials, which suggest potential efficiency against cancer (Moed et al. 2001). The venom of several edible members of Hymenoptera also contains neurotoxins (Dossey 2010). The antibacterial and antiviral compounds isolated from edible insects, that are available in SSA have been reviewed (Dossey 2010). Seabrooks and Hu (2017) recently reviewed the biologically active natural products from Hymenoptera (Formicidae, Vespidae, Apidae, Halictidae, and Symphata), Coleoptera (Chrysomelidae, Curculionidae, Scarabeidae, and Meloidae), Blattodae (Blattidae, Rhinotermitidae, and Termitidae), Hemiptera (Tessaratomidae, Pentatomidae) Orthoptera (Romaleidae, Acrididae, Gryllotalpidae, and Gryullidae) and Lepidoptera (Bombycidae, Papillonidae). Although, an array of bioactivities linked to certain biologically active compounds obtained from edible insects has been identified, the compounds responsible for the bioactivity and the specific mechanism were often not vividly elucidated (Seabrooks and Hu 2017). Incidentally, Asia and South America seem to dominate the documented evidences of the medicinal potentials of insects' bioactive compounds. This is a research gap that needs to be closed for insects found in SSA.

Viability of insects as food and feed enterprise: prospects, commercialization and challenges

Economic importance of edible insect collection

Insects can be harvested from nature or farmed with little technical or capital expenditure. The practice of gathering insects from the wild, a time-consuming task, is commonly practiced by women and children especially under a rural setting. It is likely that the low entry requirements to engage in insect collection, processing and trade have stimulated the active roles played by women and children in the edible insect sector in developing countries. While the women are the main sellers of insects on a smaller scale, the more profitable large-scale trade is often dominated by men (Schuurmans 2014). The economic worth of edible insects cannot be over-emphasized because:

1 It is noteworthy that cultivation of these edible insects can be obtained in comparatively short periods of time due to their short life-cycles relative to the conventional livestock-based sources (Imathiu 2020) and could be produced throughout the year.

2 Kohler et al. (2019) opined that edible insects exist to guarantee three things which are (i) avoidance of starvation and malnutrition, a short-term alleviation strategy, (ii) food fortification which can serve as a medium-term alleviation strategy, and (iii) dietary diversification, a long-term mitigation approach to human dietary pattern. Out of these three, dietary diversification is the most economically feasible, environmentally-friendly and most sustainable option which can take various approaches including different food types. Some of these are under-utilized or under-exploited in the diet.

3 Rearing and gathering of insects as mini-livestock at the industrial scale or household level can present significant livelihood opportunities for people both in developing and developed countries. In many countries, the agricultural sector still accounts for the livelihoods of many households; hence, the gathering, preparation or processing and sale of edible insects can serve as a source of livelihood for some communities in different parts of the world (Schuurmans 2014). According to Imathiu (2020), the use and trading in edible insects has remained a principal form of livelihood diversification means among many rural communities. It also acts as a means by which the collectors earn a living in the form of cash income to meet other basic households needs such as purchase of other types of food and non-food items and farm inputs, among others. This will help to improve the living standards of the collectors and consequently improve the rural communities. In addition, some edible insect species are harvested early in the morning or at a later time in the day which makes collection well-synchronised with other livelihood activities hence, increasing the efficiency of income generation.

4 Insect cultivation also requires minimal land and market establishment efforts. This is because insects already form part of some local food cultures. Culturing insects can offer an inexpensive and viable opportunity to prevent nutritional insecurity through the nutritional structure, accessibility, simple rearing procedures and quick development rates. Hence, the recent increase in demand for insects as food has shifted its gathering from wild-harvesting to mass domestication. With the supports from some experts at the International Centre of Insect Physiology and Ecology (ICIPE), Kenya has also recorded the coming together of a group of farmers who are involved in rearing of crickets (World Economic Forum 2018).

The driving forces for increase in demand for edible insects are based on environmental concerns for conventional meat and the increasing food and feed prices. Table 6 shows the growing need for animal feed in Africa over the years. The number of the feed mills has approximately doubled over the past five years considered while the total production has increased by about 30%. This makes Africa the fastest growing continent for feed production in the world (Vernooij and Veldkamp 2018). This consequently will increase the demand

Table 5 List of edible insects used for multiple medicinal purposes in sub-Saharan Africa

Species	Ailments	Developmental stage used	Country/Regiom	References
Apis mellifera	Asthma, doziness, tiredness, myopia, madness, propolis, spleen inflammation, gastric burns, rheumatism and honey used for diverse diseases	Adult	Benin, Nigeira, Cameroon	Lawal and Banjo (2007), Tamesse et al. (2016), Loko et al. (2019)
Encosternum delegorguei	Hangover, skin cancer, sore throat, arthritis, asthma, heart diseases	Adult	South Africa, Zimbabwe	Gardiner and Gardiner (2003); Dzerefo et al. (2013), Musundire et al., 2014
Formica spp	Ulcer, malaria, jaundice, enuresis, memory loss	Adult	Benin	Loko et al. (2019)
Periplaneta Americana	Alcoholism, fever, external haemorrhoid, arthritis, epilepsy	Adult	Benin	Loko et al. (2019)
Chironomus species	To strengthen ailing children and for curing certain ailments, to attract potential marital suitor	Adult	East Africa	Ayieko and Oriaro (2008)
Gryllotalpa Africana	Microbial foot infections	Adult	Nigeria	Fasoranti (1997)
Synagris spp	Clay nests made by the wasp is ground and eaten by pregnant women to provide lime to the feotus		Congo	Adriaeus (1951)
Lamarckiana spp	Bedwetting in young children, nightmares	\	South Africa	van der Waal (1999)
Belonogaste Juncea	Body aches, Burn, Tiredness, Arthritis		Benin	Loko et al. (2019)
Rhynchophorus spp	To treat rejection of breast milk in babies, spleen inlamation, chicken pox, big navel, bone solidification		Cameroon	Tamesse et al. (2016)

for protein-based ingredients which create a large prospect for the use of edible insect for feed production.

Commercialization of edible insect in Africa

The consumption of insects is no longer perceived as a practice just for the under-privileged or rural populace as urban community and high income earners are becoming important consumers too. People consume insects not only because of their nutritional content, but also for their palatability (Hanboonsong et al. 2013). The marketing of insects presents another source of livelihood for the collectors, sellers and households in rural, urban, and peri-urban areas within the location where they are collected (Odongo et al. 2018*)*. Market outlets and commercial practices for edible insects are diverse and are in high demand domestically. With few exceptions, international trade in insects for food is inconsequential. Insect trade as food to the Western countries is largely determined by demand from migrated communities from Africa and Asia, or by the growth of niche markets for foreign foods. However, border trade in edible insects is significant, especially in Southeast Asia, Central Africa and Southern Africa. For instance, in Central African Republic, the principal importers of caterpillars were Chad, Nigeria and Sudan; they in return export caterpillars to African communities in Belgium and France. Simiarly, Zimbabwe exports caterpillars to Botswana, the Democratic Republic of the Congo, South Africa and Zambia (van Huis et al. 2013).

The market localities where edible insects are sold also reflect the extent of their commercialization. For example, in Burundi, edible insects were traded in weekly markets, which were located in districts and villages (Odongo et al. 2018). Table 7 presents the comparative prices of edible insects with animal products in few SSA countries. The listed cases indicate that trading in some edible insects have the potentials to generate good income. For the purpose of the usage of insects as animal feed, it is imperative that their prices should not be exorbitantly higher than the prices of conventional ingredients like fish meal, which the edible insects tend to replace in feed formulation. Otherwise, it becomes an uphill task to convince some livestock farmers to adopt edible insects as feed ingredients.

In some parts of Thailand, edible insect products are not only sold pre-cooked by sellers but they can be obtained uncooked, in frozen packages from supermarkets. A case point is cricket from which three kinds of products can be sold including: mature cricket which is the main product, cricket eggs and fertilizer from the waste produced from cricket farms (Hanboonsong et al. 2013). Sub-Saharan African countries can explore this economic slide to boost her local and international trade options. Although, in tropical countries the retail price of insects is frequently higher than that of regular meat, edible insects are often preferred, demonstrating how much they are valued as a delicacy. Different development levels of cultured or harvested insects can serve different nutritive purpose for the consumer and earn income for the collector.

Commercialization of edible insect creates a good opportunity for the farmers and the collectors in terms of livelihood activities and generation of income which consequently enhance the local economy where the insects are produced. According to van Huis (2013), the availability of the mopane caterpillar on the market usually affects the demand and sale of beef among the Pedi in South Africa. In Laos, income generation from collection of crickets can be greater than those from raising cattle or growing rice (Weigel 2016). Raheem et al. (2019) reported that Southern Africa harvested about 9.5 billion mopane caterpillars annually and the annual trade value from this harvest is worth over $85 million while in Malawi beekeeping is reported to be more than three times as profitable as growing maize, a staple crop. The acceptability of edible insect as a source of food and feed is gradually improving its marketing potential and it is a matter of time, its consumption will not be restricted to Asia and Africa but will attract attention of the whole universe.

Challenges confronting wider acceptance of edible insects

The favourable acceptance of any food is controlled by sentimental, personal, cultural, and situational factors, but motivations are largely based on sensory/pleasure considerations and health. Humans often avoid strange foods especially when they are of animal source (Hanboonsong et al. 2013). Despite numerous benefits of consuming insects, their full acceptance remains one of the impediments to their utilization as a protein food source particularly in the developed countries where consumption of insects is not welcomed by majority of the population (Imathiu 2020). This lack of concern, leads to the neglect of fostering research activities on insects regardless of innumerable opportunities that abound in its consumption. Though the adoption of edible insect farming is only a recent phenomenon, it has started gaining public attention worldwide (van Huis et al. 2013). In contrast, in SSA, consumption of insects is part of the people's culture, and the neophobia is not so pronounced. However, any noephobia observed could be arising from urban younger generations who were not previously exposed to these insects as the youngersters were growing up.

Table 6 Total percentage increase in commercial feed production in Africa

Feed production	2013	2014	2015	2016	2017
Total compound feed	30.97	34.57	36.13	39.5	39.14
Poultry feed	17	21.1	21	20.1	22. 35
Cattle feed	10.7	11	8.64	10.9	12.1
Pig feed	0.4	1.1	2.3	2.1	2.2
Number of feed mills	806	1150	1210	2081	2068

Source: (Alltech 2018)

Beyond the African continent, animal welfare is to be considered. Insects are regarded as 'mini-livestock' and should therefore be harvested and "slaughtered" in a humane way (van Huis et al. 2013). Freezing was considered the best option but due to cost implications, many resort to heating (Barroso et al. 2014; Ezewudo et al. 2015; FAO 2015). Survey (All About Feed 2014) has also indicated that 50% of people are ready to quit animal products produced from insect meal perhaps on ethical grounds.

Among the factors that affect consumer's acceptance of new and traditional foods are perceived risk, benefit, and control with regard to regulation and effective labelling as well as perceptions of potential environmental impact to some extent for some consumers. Several challenges are encountered in the promotion of edible insects farming and consumption. These challenges may be largely influenced by individual's perception, cultural and religious practices both in developing and developed countries (Dobermann et al. 2017).

Top on the rank of these obstacles is food safety issue where consumers willing to eat edible insects and/or edible insects-derived meals are cautious about the microbiological and chemical health risk they could pose (Imathiu 2020). Consumers are concerned about the possibility that insects may contain anti-nutrient properties, food safety related to storage and allergic reactions, consumer suitability and ambiguous or non-existent regulation (Dobermann et al. 2017). Humans are known to exhibit both interest in obtaining a wide variety of nutrients for new foods and reluctance to the possibility that they may be harmful or toxic after consuming them. Therefore there is need to balance the food safety concerns and the nutritional benefits of edible insects.

Another hurdle confronting the consumption of edible insect is the fact that a minimal value is currently added to the edible insects through processing. Up until recently, the majority of the edible insects consumed were either traded as

Table 7 Comparative price of some edible insects with animal products in sub-Saharan Africa

Insect	Price comparison with animal product	Country	References
Cirina forda	Price about twice the price of beef	Nigeria	Adegbola et al. (2013)
Ruspolia nitidula	Price approximately US$ 2.80, while goat meat costs approximately US$ 2.13	Uganda	Agea et al. (2008)
Cirina forda	Sold by retailers at CFA 1250 (US$2.08) per kg compared with beef which sold for CFA 1400 (US$2.33)	Togo	Badanaro et al. (2014)

fresh or had a minimal processing and packaging. The deficiency of this value addition implies that the edible insects can neither be made available for commercial purpose during off-season, nor for export without significant quality deterioration.

The lack of standardization in edible insects' trade is also problematic. Edible insects' trade in general is deficient in standards for weight, quality and packaging. Odongo et al. (2018) reported that edible insect retailing has no standard measurement. They can either be measured using non-standard cups, ladles, or table spoons; the choice of this partially depends on the marketer's inclination and/or the consumer's needs and demands. The deficiency in standard measurement consequently made price-setting for edible insects to largely be based on estimates rather than standard quantity and quality. This current approach to price-setting leads to subjectivity, and mainly depends on the bargaining power of the seller and/or the buyer.

Cautionary matters on insects as food and feed

Overview

Although the utilization of insects as food and feed has great potential in reducing food and nutrition insecurity, it is important to take necessary cautions prior to human consumption of these edible insects to prevent toxic and allergic reactions. Insects are rich in micronutrients and also contain significant proportion of metals and antinutritional factors. Their bodies can carry pathogenic microorganisms and/or induce allergic reactions in human (Patel et al. 2019). Bioaccumulation of heavy metals and antinutrients has been found in the guts, wings and chitin of most edible insects (Idowu et al. 2014). Muzzarelli (2010) established that consumption of chitin is linked with allergy and asthma related symptoms. Eilenberg et al. (2015) reported that insects are susceptible to infection and diseases. Insects can be infected by oral uptake of pathogenic sexual spores which later germinate in their gut resulting in eventual death of the insect. The mineral elements in insects are mostly obtained from their water and food intake; some of which are accumulated at higher doses in their bodies to produce measurable toxic effect which can be transferred to animal or human consumers (Hare 1992).

A survey of over 1300 respondents across 71 countries showed that the majority (88.2%) believed that there is need for more information on the safe use of insects as a food and feed source for both humans and animals,resepectively, while about 50% considered putting off eating fish, chicken or pork fed on a diet containing insect protein (All About Feed 2014). This is a clear indication of knowledge gaps and the need for more studies to provide information and guidelines on safe use of insect as food and animal feed. Following are some key areas to pay attention to, prior to any recommendation of edible insects as food or animal feed.

Anti-nutritional compounds and toxic constituents

Consumption of wild insects can pose a health risk to consumers since the feeds of these insects are not controlled and can be carriers of heavy metals and other toxic constituents. Naturally, insects contain some toxic constituents used as defence against perceived enemies which when consumed in higher concentrations as food in human or as feed in livestock can threaten consumer's health. Some insects feed on plants which contain phytochemicals (of which majority are anti-nutrients) and these can increase the concentration of antinutrients in the insects (Kunatsa et al. 2020). Some edible insects at different stages (larva, nymph and adult) feed on plants. Most edible insects are attached to one or more host plants (Alamu et al. 2013). These insects retain significant levels of these antinutrients in their bodies (Ganguly et al. 2013). Some of the antinutrients in plants are cyanogenic glycosides, tannins, oxalates, phytates, trypsin inhibitors (Ekop et al. 2010; Omotoso 2015; Omotoso and Adesola 2018).

Antinutrients can interfere with certain enzymes responsible for metabolism. Some of these anti-nutritional factors are mineral chelators that affect bioavailability of minerals in human body which can lead to micronutrients deficiency (Hare 1992). Idowu et al. (2019) identified three antinutrients in winged termites, and two species of rhinocerous beetles (*Oryctes monocerus* Olivier and

Oryctes boas Fabricius) obtained in south-western Nigeria. The components identified were phytate, tannin and oxalate with values ranging from 0.011 to 0.217, 0.024 to 0.051 and 0.181 to 0.46 mg/100 g, respectively. Values obtained by the authors were presumed safe since they are less than the recommended values of 22.10 mg/100 g, 150–200 mg/100 g and 105 mg/100 g for phytate, tannin and oxalate, respectively (WHO 2003). Four insects (termites, *Macrotermes nigeriensis*; cricket, *Gryllus assimilis*; grashopper, *Melanoplus foedus*; and moth caterpillar, *Cirina forda*) collected from the northern part of Nigeria contained phytates, tannins, oxalate, saponins and cyanogenic glycoside (Oibiokpa et al. 2017). Similarly insects (*Macrotermes facilger* and *Henicus whellani*) collected from Zimbabwe were found to contain phytochemicals and ant-nutritional compounds (Kunatsa et al. 2020).

Grasshopper and moth caterpillar have high contents of oxalate, saponin and cyanogenic glycosides than other insects. Plants are the main sources of oxalates and cyanogenic glycosides and they are the primary food sources of grasshopper and moth (Alamu et al. 2013; Ganguly et al. 2013). The values obtained for phytates, tannin and oxalate were similar to values reported by Idowu et al. (2019). However, the saponin contents of the four species collected from the northern Nigeria were extremely high (730–1210 mg/100 g). Four other insects, cricket (*G. lucens*), yam beetle (*H. meles*), palm weevil larva (*R. phoenicis*) and grasshopper (*Z. variegatus*), collected from south-eastern Nigeria had high phytate, oxalate and hydrogen cyanide values (Ekop et al. 2010). Grasshopper had the highest values of antinutritional factors of all the four insects evaluated. Values of oxalate, phytate and cyanogenic glycoside in insects collected from eastern Nigeria are higher than the ones obtained from south-western and northern Nigeria (Table 8).

Oxalate and saponin are the predominant antinutrients in all Nigerian edible insects analyzed. Oxalate has the ability to render calcium unavailable for important biochemical roles in the body (Ladeji et al. 2004). The deficiency of calcium can lead to malfunction of some hormone and enzymes in human body. Calcium is required by both children and adults for strong bone formation and maintenance. When oxalate binds with calcium, oxalate crystals are formed which are deposited in the kidney as stone (Bong and Savage 2018). Omotoso and Adesola (2018) reported that phytate was the predominant antinutrient obtained from the four insects (*R. phoenicis, C. forda, Z. variegatus, P. americana*) collected from Ekiti, south-western Nigeria. Saponin and phytate were the dominant antinutrients in *M. nigeriensis* (Table 8) and *O. rhinocerous* (Omotoso 2015). Phytate can be tolerated to a maximum concentration range of 250–500 mg/100 g as reported by Ekop et al. (2008). Phytate can reduce the uptake of magnesium, iron and calcium for necessary biochemical functions (Idowu et al. 2019).

The life cycle stage of edible insect can influence the contents of anti-nutritional factor. Four castes of *Macrotermes subhyalinus* had antinutrients contents with values ranging from 5.4 to 11.7 mg/100 mg, 15.6 to 130 mg/100 g and 4.8×10^{-8} to 5.5×10^{-8} mgTA/ 100 g for oxalate, phytate and tannin, respectively (Ajayi 2012). It was observed that worker termite caste had the highest value in all the antinutrients identified. This is expected since workers interact with their environments and are saddled with the responsibility of fetching food for others. In addition, termites are conditioned to available food choices in their environments such as domestic wastes. Hence, the level of antinutritional factor will correspond to the available food choice (Idowu et al. 2014).

The anti-nutritional factor of insects varied with different geographical locations. In Zimbabwe, two edible insects (*Macrotermes facilger* and *Henicus whellani*) had higher values of oxalate (931 and 140 mg/100 g), tannin (170 mg/100 g and 20 mg/100 g), alkaloids (52,300 mg/100 g, 35,000 mg/100 g) and saponin 53,300 mg/100 g and 57,000 mg/100 g (Kunatsa et al. 2020) than most Nigerian insects. Phytate and cyanogenic glucosides were not detected in all evaluated insect species. The antinutritional composition of host plants differ from one area to another and this could be the reason for variation in antinutritional factors of insects from the different regions (Table 8). *Encosternum delegorguei* obtained from south-eastern Zimbabwe contained 301 mg/100 g tannin, 1260 mg/100 g oxalate and 7400 mg/ 100 g alkaloids. The overview of the antinutrients contents of all insects assessed showed that the majority contained higher contents of oxalate and saponin. Oxalate permitted in human body should not be more than 250 mg/100 g of food samples (Oguchi et al. 1996). Saponin can impair protein digestive enzymes and uptake of vitamins and minerals in the gut (Johnson et al. 1986). Consumption of antinutrients for a longer time can be highly detrimental (Kunatsa et al. 2020).

Insects are usually eaten with staple foods in SSA. Consumption of these insects with high antinutrients containing staple foods can raise the threshold of antinutrients in human. For instance, some tropical crops such as cassava, legumes, and cocoyam are high in hydrogen cyanide and oxalate. When these crops are eaten with insects that have considerable amount of the antinutrients, then the danger might outweigh the expected benefits from the insect. Tshala-Katumbay et al. (2016) reported that hydrogen cyanide can cause cerebral damage and lethargy in man and animals. In acute cases, cyanide poisoning can cause death.

Heavy metals contamination

Insects can be a source of heavy metal contamination in human. These contaminants come from routine agricultural practices such as disposal of animal waste and application of

Table 8 Antinutritional composition of edible insects in sub-Saharan Africa

Species	Order	Region	Tannin (mg/100 g)	Phytate (mg/100 g)	Oxalate (mg/100 g)	Saponin (mg/100 g)	Alkaloids (mg/100 g)	Flavonoid (g/100 g)	Cyanogenic glycoside (mg/100 g)	References
Macrotermes nigeriensis	Blattodea	Southwestern Nigeria	0.59	15.21	0.01	1470	320	0.19 ± 0.01		Omotoso (2015)
Oryctes rhinoceros	Coleoptera	Southwestern Nigeria	0.64	16.10	0.011	1340	190	0.24 ± 0.01	NR	Omotoso (2015)
Oryctes boas	Coleoptera	Southwestern Nigeria	0.039	0.011	0.54	NR	NR	NR	NR	Idowu et al. (2019)
Oryctes monocerus	Coleoptera	Southwestern Nigeria	0.051	0.051	0.181	NR	NR	NR	NR	Idowu et al. (2019)
Macrotermes bellicosus	Blattodea	Southwestern Nigeria	0.024	0.217	0.270	NR	NR	NR	NR	Idowu et al. (2019)
Macrotermes subhyalinus	Blattodea	Southwestern Nigeria	4.7–5.5E-8	15.6–130	5.4–11.7	NR	NR	NR	NR	Ajayi (2012)
Macrotermes facilger	Blattodea	Zimbabwe	170	NR	931	53,300	52,300	NR	NR	Kunatsa et al., 2020
Henicus whellani	Ortthoptera	Zimbabwe	20	NR	140	570,000	35,000	NR	NR	Kunatsa et al., 2020
Macrotermes nigeriensis	Blattodea	Northern Nigeria	0.47	0.09	2.03	990	NR	NR	2.47	Oibiokpa et al. (2017)
Cirina forda	Lepidoptera	Northern Nigeria	0.48	0.09	20.25	1210	NR	NR	11.75	Oibiokpa et al., 2017
Gryllus assimilis	Orthoptera	Northern Nigeria	0.49	0.10	20.93	1000	NR	NR	3.76	Oibiokpa et al., 2017
Melanoplus foedus	Orthoptera	Northern Nigeria	0.52	0.19	25.65	730	NR	NR	11.27	Oibiokpa et al., 2017
Gymnogryllus lucens	Orthoptera	Eastern Nigeria	3.29	2.83	132	NR	NR	NR	21.87	Ekop et al. (2010)
Heteroligus meles	Coleoptera	Eastern Nigeria	3.79	2.80	284	NR	NR	NR	27.34	Ekop et al. (2010)
Rhyhnchophorus phoenicis	Coleoptera	Eastern Nigeria	4.05	2.89	176	NR	NR	NR	24.22	Ekop et al. (2010)
Zonocerus variegatus	Orthoptera	Eastern Nigeria	4.35	2.81	264	NR	NR	NR	32.03	Ekop et al. (2010)
Rhyhnchophorus phoenicis	Coleoptera	SW Nigeria	0.61	19.39	9.74	20.38	15.76	5.39	NR	Omotoso and Adesola (2018)
Cirina forda	Lepidoptera	SW Nigeria	0.54	25.45	6.75	8.65	8.33	3.44	NR	Omotoso and Adesola (2018)
Zonocerus variegatus	Orthoptera	SW Nigeria	0.72	26.49	8.28	6.74	3.55	2.52	NR	Omotoso and Adesola (2018)
Periplanata americana	Blattodea	SW Nigeria	1.13	28.48	7.61	5.46	5.26	4.32	NR	Omotoso and Adesola (2018)
Encosternum delegorguei	Hemiptera	South Eastern Zimbabwe	3100	Nd	1260 g	NR	7400	15,200	23 (μg/ 100 g)	Musundire et al. (2014)

agrochemicals such as pesticides and fertilizers (van Huis et al. 2013; EFSA 2015). The concentration of heavy metal in insects differs from one species to another. Insects can pick up heavy metals and other toxins from their substrate which are then transferred to human (Kelemu et al. 2015). Heavy metal contamination poses a great danger to our environment and major food plant sources (Gholizadeh et al. 2009).

The metals of major health risk when absorbed in higher proportions are aluminium, arsenic, cadmium, chromium, mercury, lead, selenium (McKinney and Rogers 1992). Lead, mercury and cadmium are the most toxic and their rate of absorption is higher in most human and animals. These metals have been implicated in kidney and nervous system damage (Saha and Zaman 2013). Edible aquatic insects are the most susceptible to heavy metal contamination in developing countries since most rivers; dams and streams are polluted with effluents from industrial activities and crude oil refineries (Yabe et al. 2010). The bioaccumulation of these metals in edible insect constitutes a health risk for consumers. *Rhynchophorus phoenicis* (larva) and *Macrotermes bellicosus* (winged), two Nigerian insects, contained relatively high values of cadmium (11.70 mg/kg, 13.10 mg/kg) and lead (41.60 mg/kg, 42.18 mg/kg) when analysed for heavy metals (Banjo et al. 2013). The risk is greatly increased when insects heavily contaminated with heavy metals are consumed frequently.

Waste materials released from mining factories which fall on insects' body surfaces and wrong application of pesticides close to the habitat of these species can serve as contaminants sources. It therefore becomes imperative to always know the insects' habitat history and possible industrial activities in the areas before they are processed for foods and feeds. Bioaccumulation of heavy metals by edible grasshopper from grasses at different trophic levels has been reported (Devkota and Schmidt 2000). Of all heavy metals obtained, the bioaccumulation of lead and cadmium in insects were higher than other metals (Banjo et al. 2013). The high bioaccumulation was credited to their high level of toxicity.

In a related work, exposure of four larvae of insects to waste substrate from United Kingdom, China, Mali and Ghana showed higher cadmium concentration (Charlton et al. 2015). In reared insects, high concentration of heavy metals in insects fed bran was observed; therefore, appropriate diet should be fed to insects (Bednářová et al. 2010). In edible grasshopper harvested in western Uganda, however, higher concentrations of lead were observed than other heavy metals (chromium, zinc and cadmium). The high level of lead was attributed to inappropriate usage of pesticides. Further analysis revealed carcinogenic potential was 10 times over the recommended levels in the analyzed samples (Kasozi et al. 2019). Devkota and Schmidt (2000) also reported that female insect species accumulate cadmium in their bodies more than their male counterparts.

Microbial contamination of edible insects

Insects have also been linked with aflatoxin contamination when they feed on mouldy or contaminated substrate. Musundire et al. (2016a) revealed that aflatoxin contamination was detected in edible stinkbug stored in recycled grain containers. This implies that the storage facilities and the environmental conditions can influence the microbial contamination of edible insects. Both domesticated and wild insects can be contaminated with aflatoxins during feeding and storage. When setting up food safety standards for edible insect as food, aflatoxin limit in insects must be given priority. In another study, Kachapulula et al. (2018) assessed the level of aflatoxin contamination in two Zambia insects (caterpillars and termites) using lateral flow immunochromatography. The average aflatoxin concentrations exceeded Zambia's required limits of 10 μg/kg in the moth (*Gynanisa maja*-11 μg/kg; *Gonimbrasia zambesina*-12 μg/kg), and the termite (*Macrotermes falciger*-24 μg/kg). Poor storage facilities significantly increased aflatoxins to unsafe levels in caterpillars (4800 μg/kg). Proper storage and good hygiene procedures are therefore essential to reduce human exposure to aflatoxins.

Insects reared for food and feed are susceptible to microbial attack and as a result, clean production facilities are required for both production and processing of insects. It is also important to note that growing insects on organic residues with high levels of mycotoxins will require more investigations because of bioaccumulation tendencies of these toxic compounds. Fraqueza and Patarata (2017) identified some intrinsic microbiota in insects which include Enterobacteriaceae (*Proteus, Escherichia), Staphylococcus, Pseudomonas, Streptococcus, Bacillus, Lactobacillus, Micrococcus,* and *Acinetobacter.* These are sources of microbiological hazards in insects which can be reduced by good hygienic practices.

Further research needs and future prospects

A The SSA is evidently endowed with diversity of edible insect species. *The influence of climate change may lead to edible species emerging in areas where they had not been previously reported. In such situations, entomologists, food scientists and biochemists should promptly establish collaborations to investigate the safety indices for the incorporation of such species into human food or animal feed and to* evaluate the comparative performance of emerging or yet-to-be assayed species in different laboratory conditions; apart from the species for which the potentials as food and feed ingredients have been explored. *This will consequently necessitate the publication of the checklists of edible insects at reasonable intervals* *in different regions of the world. On the corollary, the effect of climate change on the exisiting insect species, their habitas and nutrient vomposition, also need to be investigated for further understanding and development of appropriate adaptaion response strategies.*

B With the on-going campaign for the usage of insects as food and feed, the need for sustainable harvesting of wild population of edible insects and mass production via insect farming is indispensable. Schabel (2010) has suggested the concept of "entomoforesty" for the conservation of the endangered forest edible insects which are under the threat of chemical insecticides from the arboriculturists whose primary interests in the forests are the economic trees. Large scale production of insect meal for food and feed will positively affect the environmental and economic impacts of livestock industry if production delivers protein quantities comparable to fish meal or soya bean meal.

C The usage of organic wastes to feed mass reared insects requires further empirical studies by insect biologists and biochemists, before it can be adopted. Some authors (van Huis et al. 2015; van Huis and Oonincx 2017; Vareals and Langton 2017) have suggested the production of artificial diets from organic forest wastes for insect farming of the forest edible insect species. It becomes very imperative to undertake a clear assessment on factors that limit the use of insect as food and feed. Risks associated with large scale production of insects need to be assessed, including cost implication.

D Since some pathogenic microorganisms are employed in the biological pest control scheme, insect pathology should be given attention in order to identify the susceptibility of different edible insect species to human and zoonotic pathogens. Concerns on allergens and mycotoxins could be addressed through proper processing. This will allay the fears of people whose culture does not support entomophagy and the use of insects as animal feed. Similarly, issues of insect predation, parasitism and cannibalism need to be investigated to ensure multiplication of desirable insect species is not retarded.

E The effect of different postharvest processing techniques such as drying, cooking, frying, roasting, fermentation etc. on quality (chemical, physical, nutritional and sensory) attributes of insects during storage should be adequately investigated in order to establish the best processing method that will ensure the best nutritional and functional properties with good keeping quality. This will enable the consumers to choose their preferred processing methods for each species.

F Research on bioavailability of minerals and vitamins inherent in edible insects is still scarce. It is important to study the interaction between the anti-nutritional factor and vital nutrients in the body. In vitro toxicological and biochemical bioassays should be carried out to investigate the behaviuor of some of the heavy metal contaminants on vital internal organs and hematological parameters. The relationship between the amount of insect consumed and bioavailability of minerals in the body need critical assessment to establish the safety of edible insects.

G *Additionally, there is the need for empirical studies on the biologically active compounds obtained from African edible insects in order to ascertain if there is continental influence on the quantitative and qualitative composition of the inherent bioactive natural products in sub-Saharan African species. The need for interdisciplinary collaborative studies with chemists/biochemists for the characterization of the biologically active ingredients in the edible insects is necessity to exploit the valuable natural resources of the sub-Saharan African edible insects. In such cases, it is important to evaluate the impact of the developmental stages of the edible insects on the biochemical properties of the extracted compounds. Attention will also be required in* the extraction and purification of specific components like enzymes from edible insects. The mechanism of bioactivity and the specific compounds responsible for such bioactivity should be elucidated in future studies on the biologically active compounds obtained from the edible sub-Saharan African insects.

H In SSA, investment in the insect rearing industry will be a fascinating sustainable solution to address prolonged challenges of high feed cost, heavy dependence on importation of fish meal and perhaps ease competition that exist between man and farm animal for available fish stock. Besides, it has the tendency of generating huge employment opportunities in an eco-friendly manner.

I In order to achieve the market and livelihoods potential of edible insects, it is imperative to deliberate on the key challenges confronting its commercialization. This can be actualized by putting into consideration the following activities:

1 The present knowledge about consumer preferences and barriers for insects use as human food and animal feed is scanty; and this information is necessary to set up a commercialization trajectory. Therefore, there is the need to further examine the nutritional values of emerging edible species of insects to efficiently promote insects as healthy food or feed. This will also enlighten the potential consumers on the nutritional benefits of consuming edible insects and encourage the consumers to adjust their negative perception about edible insect; thus increasing the consumer willingness to eat insects.

2 Before embarking on the mass-production of insect-based food and feeds, there is need to promote and observe food safety and hygiene practices along the whole edible insect value chain, wild harvesting inclusive. This is to ascertain

that the highly nutritious food which requires little resources to produce is available to the consumers in a condition that does not create any health risks. This has the potential to boost value chain addition and the international trade of good quality insect-based products.

3 It will be necessary to illuminate and intensify what socio-economic benefits of insect gathering versus farming can offer in terms of livelihood opportunities, income generation as well as enhancement of food security status of the impoverished in the society. In addition, the environmental effects of harvesting and farming of insects should also be explored to facilitate comparison with conventional farming and livestock rearing practices which may be more environmentally damaging. Quantitative data obtained from empirical studies are necessary, apart from general perceptions to be able to convince stakeholders including policy-makers and regulators in the food industry.

4 In order to advance insect consumption and farming, strategic approaches need to be devised and geared in the direction of value addition into goods which are more appealing, which people from different cultures can easily associate with. Addition of value to edible insects will not only improve the shelf-life of the edible insects beyond the harvesting season(s) but would increase income returns. Designing suitable and affordable packaging that is attractive to the consumers and promotion of edible insect consumption on print and online media will enhance the demand of edible insects and their products. For instance, edible insects can be produced into granular or paste forms to improve its acceptability which can be integrated into other foods in the form of fortification.

5 It will be necessary to establish standards for quality assessment, grading, packaging, and labelling to improving the marketing and consumer perceptions. This will give comprehensive legal framework at national and international levels to pave way for more investment. As much as the aforementioned facts are crucial, efforts should be geared towards reduced costs of production and eventual wholesale or retail prices of edible insects.

6 Capacity development of value chain actors is key to drive the agenda for insects as food and feed forward. The subjects needs to be incorporated in the education curricula right up to tertiary levels.

7 Developing the insect sector for food and feed requires resource mobilisation and private sector engage ment to ensure sustainability. Governments in SSA will need to provide a conducive policy environment and offer the right incenitves to lure investors into this sub-sector.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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