Abdalbasit Adam Mariod *Editor*

African Edible Insects As Alternative Source of Food, Oil, Protein and Bioactive Components

Springer

African Edible Insects As Alternative Source of Food, Oil, Protein and Bioactive Components

Abdalbasit Adam Mariod
Editor

African Edible Insects As Alternative Source of Food, Oil, Protein and Bioactive Components

Springer

Editor
Abdalbasit Adam Mariod
Indigenous Knowledge and Heritage Centre
Ghibaish College of Science and Technology
Ghibaish, Sudan

ISBN 978-3-030-32951-8 ISBN 978-3-030-32952-5 (eBook)
https://doi.org/10.1007/978-3-030-32952-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Chapter 1
Importance of Insects as Food in Africa

Arnold van Huis

Abstract In Africa, about 470 insect species are recorded as edible, of which caterpillars are most consumed followed by grasshoppers, beetles, and termites. Most of those are collected from nature. There are several insect species, such as locusts and grasshoppers, that are pests of crops but which can be eaten at the same time. There are some edible insect species which are harvested in large number contributing to food security. Three of those species are discussed: the mopane caterpillar, the African bush cricket, and the shea caterpillar. However, when we would like to promote insects as food then harvesting from nature is not an option anymore, as overexploitation already occurs. Then we need to rear the insects. That can be done in semi-domesticated systems such as for the palm weevil or by farming insects as mini-livestock such as for crickets. We discuss the nutritional value of edible insects, and how they can contribute to food security. We also give examples of how insects can be processed and marketed. We conclude with the prospects of how edible insects can assure food security and improve the livelihood of the African people.

Keywords Sub-Saharan Africa · Edible insects · Insects as food · Nutrition · Food security · Harvesting insects · Farming insects

1.1 Introduction

The level of prevalence of undernourishment in sub-Saharan Africa aggravated over the last few years. It went first down from 24.3% of the population in 2005 to 20.7% in 2014 but then went up again to 23.2% in 2017, affecting 237 million people, while the number of people experiencing severe food insecurity in 2017 was 346

A. van Huis (✉)
Laboratory of Entomology, Wageningen University & Research,
Wageningen, The Netherlands
e-mail: arnold.vanhuis@wur.nl

A. Adam Mariod (ed.), *African Edible Insects As Alternative Source of Food, Oil, Protein and Bioactive Components*, https://doi.org/10.1007/978-3-030-32952-5_1

million (34%) (FAO et al. 2018). In Africa in 2017, 59 million (30%) of the children under five were affected by stunting (chronic malnutrition) and 14 million (7%) by wasting (acute malnutrition). The influence of climate change on production and livelihoods is strongest in Africa as dryland farming and pastoral rangeland systems dominate livelihood systems for 70–80% of the continent's rural population (Neely et al. 2009). Conditions of desertification and drought are aggravated by the impacts of human activities. Changes in climate impact heavily on nutrition through (1) impaired nutrient quality and dietary diversity of foods produced and consumed; (2) effects on water and sanitation, with their implications for patterns of health risks and disease; and (3) changes in maternal and child care and breast feeding (FAO et al. 2018).

Meat production in sub-Saharan Africa has been estimated to be 7334 thousand tons in 2005/2007 (only 2.6% of global meat production) and is expected to grow by 2.9% per annum up to the year 2050 (Alexandratos and Bruinsma 2012). Because of environmental reasons, dietary changes are urgently needed (Springmann et al. 2018), and insects, being already an important food source, should be considered.

The recorded number of insect species that are eaten in Africa is 472 (Fig. 1.1) (Jongema 2017). The most abundant group of species eaten are caterpillars (Lepidoptera) (31%), followed by grasshoppers, crickets, and locusts (Orthoptera) (23%). The Coleoptera, in particular the larvae follow (19%), and then termites (Isoptera) (7%), bees, wasps and ants (Hymenoptera) (7%), true bugs (Heteroptera) (6%), aphids, scale insects, cicadas, and leafhoppers (Homoptera) (4%), and flies (Diptera) (1%). The rest (3%) consists of cockroaches (Dictyoptera), mayflies

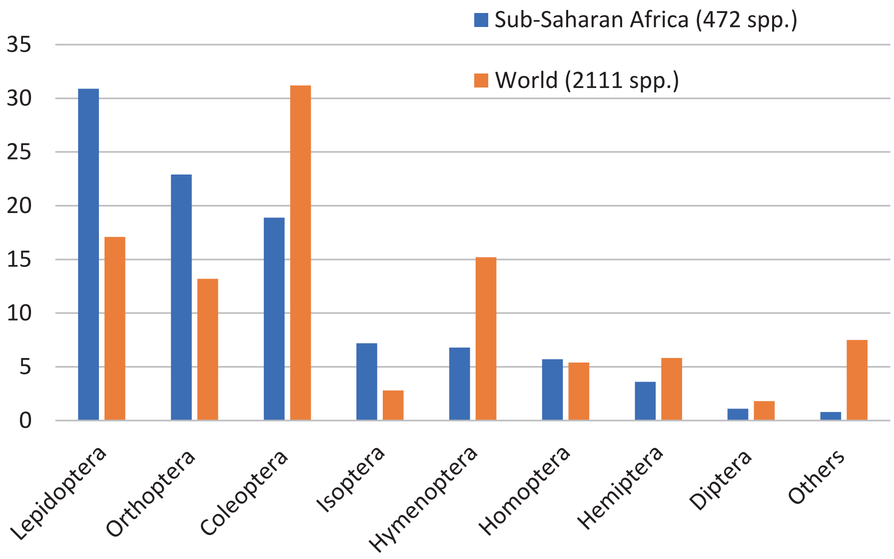

Fig. 1.1 Percentage of recorded edible insect species per insect order in sub-Saharan Africa and the world (Jongema 2017)

(Ephemeroptera), and other arthropod species such as hard ticks (Ixodidae) and spiders (Araneae).

When comparing these figures with those of the world (Fig. 1.1), then it seems that in Africa there are more recorded edible insect species in the Lepidoptera (caterpillars), Orthoptera (grasshoppers, crickets, and locusts), and Isoptera (termites) and less in the Coleoptera (beetles) and Hymenoptera than in the rest of world. There may be several reasons. They are recorded species which means that they have only been included in the database when known from literature. Taking the Lepidoptera, considerable effort has been made by several authors (Malaisse et al. 2017) to categorize those. Another reason is the continental diversity of an insect group; for example, termites have the largest diversity in Africa (38% of all species) (Lewis 2003).

Several review articles have been written about edible insects in Africa: Kelemu et al. (2015); Malaisse (2005) and van Huis (2003). We will deal with recent developments and cover traditional harvesting, semi-domestication, and farming of insects. We mention some economic important (pest) species and briefly deal with insects as feed for animals. Then we discuss nutritional issues, processing and marketing and how insects can contribute to food security. We finish with giving an outlook on insects as food in sub-Saharan Africa.

1.2 Pest Insects as Human Food

Certain insects can be a pest and at the same time are consumed by humans. The most well-known pests are the four locust species in Africa: the desert locust (*Schistocerca gregaria*), the migratory locust (*Locusta migratoria*), the brown locust (*Locusta napardalina*), and the red locust (*Nomadacris septemfasciata*) (Orthoptera: Acrididae). They may cause considerable damage to crops in Africa. When they occur during upsurges and plagues, they are eaten. However, it is a curse and a blessing at the same time. Sometimes it has been suggested that eating them could be used a control method. However, the extent of bands and swarms is so large and often in remote areas that this is not an option. The consumption of those locust may be a health risk as they are often treated with pesticides (Saeed et al. 1993).

The fall army worm *Spodoptera frugiperda* (Lepidoptera: Noctuidae), a serious pest of maize on the American continents feeding on young leaf whorls, ears, and tassels, has been reported for the first time in early 2016 in West and Central Africa (Goergen et al. 2016), and has spread to other parts of Africa (FAO 2017). Would it be an option to eat the caterpillar? Another indigenous pest, the African armyworm, *Spodoptera exempta* is capable of destroying entire crops by feeding on early stages of cereal crops. Mbata (1995) mentioned that this species is eaten by the local population in Zambia. The question is whether *S. frugiperda* can be eaten.

The caterpillar *Cirina forda* (Lepidoptera: Saturniidae) is found in western Africa, including Ghana and Nigeria, but also in Zimbabwe, the Democratic

Republic of the Congo, and South Africa. In Ghana and Nigeria, the larvae may cause heavy defoliation of the African shea tree (*Vitellaria paradoxa*). In southwestern Nigeria, it is widely marketed, and commonly consumed as a cheap delicacy being served as snacks or as an essential ingredient in vegetable soups along with carbohydrate food (Adepoju and Daboh 2013; Paiko et al. 2014). Its nutritional value is high (Akinnawo and Ketiku 2000) and it can be used as human food or animal feed (Omotoso 2006) replacing fishmeal in poultry diets (Amao et al. 2010; Oyegoke et al. 2006). Artificial rearing on the leaves of the African shea tree is possible (Ande and Fasoranti 1998).

Another pest, the variegated grasshopper *Zonocerus variegatus* (Orthoptera: Pyrgomorphidae) attacks food and cash crops such as banana, cassava, cocoa, citrus, cowpea, maize, soybeans, and yam in central and West Africa (Kekeunou et al. 2006). In Nigeria, the control of the variegated grasshopper has been reported as a control method (Iduwu and Modder 1996). In this country the grasshoppers are caught at night during the cold weather (November–February); at low temperatures because inactivity of the cold-blooded animals enables easy catching. After being boiled and roasted, they are displayed in markets and sold like meat (Solomon et al. 2008). Considering the high nutritional content, the grasshopper can both be used as food for humans and feed for animals and fish (Ademolu et al. 2010, 2017; Alegbeleye et al. 2012; Olaofe et al. 1998; Sani et al. 2014; Solomon et al. 2008). This is despite the fact that when molested, both sexes and instars expel an odorous, milky secretion of which the odour is repulsive or unpleasant to human beings (Idowu and Idowu 1999). This is the reason that the insect species is called "criquet puant" in French which means "stinking locust."

1.3 Economic Important of Edible Insect Species

Although there are quite some edible insect species that are economically important we only discuss the mopane caterpillar, the African edible bush cricket and the shea caterpillar. Some other species were already mentioned in Sect. 1.2.

1.3.1 Mopane Caterpillar

The mopane caterpillar *Imbrasia belina* (Lepidoptera: Saturniidae) (Fig. 1.2) feeds on the mopane tree *Colophospermum mopane*. The larvae are not only popular food in many cultures in southern Africa, they also are often an important source of income for rural households. In South Africa in 1983, it was estimated that 1.6 million kg of traditionally prepared dried caterpillars were traded (Dreyer and Wehmeyer 1982). In Stack et al. (2003) it was mentioned that Styles (1994) estimated that yearly 9500 million caterpillars were harvested in an area of 20,000 km^2,

Fig. 1.2 Dried mopane caterpillar *Imbrasia belina* (Lepidoptera: Saturniidae). Photo credits and copyright: Hans Smid—www.bugsinthepicture.com

only in South Africa, for the value of about US$ 85 million at that time. Approximately 40% goes to producers, who are primarily poor rural women.

The protein content of the larvae is high with large amounts of all of the essential amino acids, essential, fatty acids (linoleic acid, α-linolenic acid), and many minerals (such as iron and zinc) critical to normal growth, development, and health maintenance (Glew et al. 1999). In the Limpopo Province in South Africa, the trade and consumption of mopane caterpillars contributed to rural household food security (Baiyegunhi et al. 2016). However, overexploitation and commercialisation threatens the long-term management of the mopane woodlands, and a balance need to be found between sustainable harvesting of mopane caterpillar and improving the livelihoods of the rural poor (Baiyegunhi and Oppong 2016). Strategies proposed are delaying the supply of the stock to the market and practices to maintain a sufficient number of fifth-instar mopane caterpillars, as well as safeguard the host tree against exploitation and ways to preserve the pupae (Gondo et al. 2010). Also restrictive harvesting periods have been proposed but there are doubts about its effectiveness (Akpalu et al. 2007). As the occurrence of mopane caterpillar is erratic and periodically fails to produce caterpillars of harvestable size, there is now an increased interest in developing domestic farming techniques of the caterpillars at the household level. However, this depends on the technical feasibility as parasitism, predation and diseases proved to be challenge besides that it was costly (Ghazoul 2006). It depends also on a number of other issues, such as farming only becoming interesting when levels of wild populations that can be harvested are low (Hope et al. 2009).

Cereals have low iron and zinc bioavailability, and it has been attempted to enrich cereals with mopane caterpillar in Zimbabwe (Gabaza et al. 2018). However, the bio-accessibility of iron and zinc was not improved, it only increased the iron and zinc content of the enriched fermented cereals. Also the nutritional potential of the mopane caterpillar has been studied in diets through its use in fortified blended foods formulations (Kwiri et al. 2014). Allergic reactions to the consumption of mopane caterpillar are possible (Kung et al. 2011; Okezie et al. 2010).

1.3.2 The African Edible Bush Cricket

The African edible bush cricket *Ruspolia differens* (Orthoptera: Tettigoniidae) is considered a delicacy in Uganda and is called by the Lugandan name "nsenene." It also occurs in Kenya, Rwanda, Tanzania, and Madagascar. The insect species appears in nocturnal flying swarms of a high density, during May–April and November–December and are gathered as a highly prized item of human food (McCrae 1982). *Ruspolia nitidula* locally may be boiled or eaten raw, or sun-dried, fried, and flavored with onions, or used to make a soup (Agea et al. 2008). Sun-dried insects may be kept for several months.

The grasshopper oviposits on the leafage of grasses on which they develop (Bailey and McCrae 1978). Due to their inactivity during cold weather they are collected in the morning by hand from the grasses. As the grasshoppers during their nocturnal flights are attracted by light, women and children often engage in collecting from street lights; however, with the traffic that is a dangerous undertaking. There is homestead collection and harvesting in a more commercial way. Light traps are made by folding corrugated iron sheets into a cone shape. The lights attract the insects, which hit the sheets and then fall in large buckets with a hole on the lid (Mmari et al. 2017). It is also attempted to mass-rear the insects (Lehtovaara et al. 2018; Malinga et al. 2018a, b; Rutaro et al. 2018a, b).

1.3.3 Shea Caterpillar

The shea caterpillar *Cirina butyrospermi* (Lepidoptera: Saturniidae) only has the African shea tree as a host. It is highly valued as a human food item in Burkina Faso and Mali (Séré et al. 2018). Caterpillars can be dried, fried or boiled and used in various meals. The insect has exceptional nutritional characteristics, with 63% protein, 15% fat, as well as vitamins and minerals (Anvo et al. 2016b). It has also potential as fish feed (Anvo et al. 2016a, 2017). However, one of the main constraints on the consumption of this insect is its seasonal availability, due to its univoltine cycle. Therefore, it has been studied whether it would be possible to rear the insects by breaking the diapause (Bama et al. 2018; Rémy et al. 2018).

1.4 Insect as Feed

Small farmers in Africa feed chickens and guinea fowls with termites. They do so by breaking open small termite nests such as those of *Microtermes* spp. (van Huis 2017). However, in Togo they also used a method to lure termites to clay containers in which they have placed for example dry stems of sorghum or other cereals. They add some water and then put the pot upside down with the opening on a termite gallery. Then they wait until there are enough termites (3–4 weeks) and then they empty the pot for the chicks (Farina et al. 1991).

The costs of feeding fish and poultry is often 60–80% of the total production costs, and this is due to the relative expensive protein sources such as fish meal and soy meal (Ssepuuya et al. 2017). These conventional protein sources could be replaced by 10–100% with insects (grasshoppers, house fly maggots, *Cirina forda* larvae, termites) without affecting the growth performance of fish and poultry. Moreover, insect-based feed in some cases performed better than conventional feed.

Worldwide there is a lot of interest to develop insect-based food and in particular the black soldier fly *Hermetia illucens* (Diptera: Stratiomyidae) and the housefly *Musca domestica* (Diptera: Muscidae) are candidates and were also considered of interest for West Africa (Kenis et al. 2014). Roffeis et al. (2018) looked at the economic implications of implementation in this part of Africa. Considering the prices of conventional feeds, there seems to be potential to substitute imported fishmeal with insect-based feeds, but there were no economic advantages over plant-based feeds.

1.5 Farming Insects

Simple rearing methods are sometimes carried out by the local population. It is also called semi-domestication in which the captive state of wild insects in which the living conditions are controlled by humans. Van Itterbeeck and Van Huis (2012) gave a number of examples of how to increase the predictability and availability of edible insects such as manipulating shifting cultivation and fire regimes in Africa to improve forest caterpillar exploitation. Below we give an example of the palm weevil. However, when insects are produced as mini-livestock, we can call it farming. We give an example of crickets which can be farmed by households.

1.5.1 Palm Weevil

Palm weevil larvae are one of the edible insects that are popularly eaten in different parts of the world. In Africa, the African palm weevil *Rhynchophorus phoenicis* (Coleoptera: Curculionidae) is considered a delicacy. The larvae (Fig. 1.3) are widely consumed raw, boiled, fried, smoked, and sometimes used in the preparation of stews and soups, as part of a meal or as a complete meal (Nrior et al. 2018). The African palm weevil is common in the humid lowland forest and savannah areas of Africa. It feeds mainly on oil palm, date palm, raffia palm, and coconut palm. The larvae are important pests of these plant species, due to their boring action into plant stems. Oil palms cut down for palm wine production, but also trunks of dead or wounded palms attract adult weevils. The females after mating lay their eggs in the

Fig. 1.3 African palm weevil larvae (*Rhynchophorus phoenicis*; Coleoptera: Curculionidae) sold at a local market in Yaoundé, Cameroon. (Photo by author)

trunks and when the larvae are full grown in about 4 weeks, they are harvested (Muafor et al. 2015). Traditional harvesting methods of African palm weevil larvae are very destructive to the ecosystem, as a single collector can cut down more than 1100 raffia trunks (Ayemele et al. 2016). For this reason it is studied whether the larvae can be reared. Quayea et al. (2018) showed that agro-waste materials from fruits, banana, pineapple, and millet waste can be used as alternative feed resources. Muafor et al. (2017) developed simple rearing techniques using as substrate Raphia palms. They were able to produce the insect year round and increase the production at least four times in comparison to the harvest obtained in the wild.

The palm weevil larvae have a high nutritional value (Cito et al. 2017; Edijala et al. 2009; Ekpo 2010; Ekpo and Onigbinde 2005, 2007; Mba et al. 2017; KOFFI et al. 2017; Lenga et al. 2012; Nzikou 2010; Okunowo et al. 2017; Omotoso and Adedire 2007; Quaye et al. 2018). Processing also influences the nutritional value; for example, grilling, roasting, or boiling increased the biological value (Ekpo 2011) and solubility of proteins (Womeni et al. 2012). Adeboye et al. (2016) developed cookies of good quality and acceptability by supplementing wheat flour with 10% palm weevil larvae flour. Due to the high microbial (bacteria and fungi) load, adequate hygienic practices and proper processing are needed before they can be consumed (Nrior et al. 2018).

1.5.2 Crickets

Among the different species of edible insects, crickets are one of the most interesting as they have shown particular promise in addressing food and nutrition insecurity. Their high nutritional quality makes a variety of cricket species attractive for rearing. Besides their life cycle is considerably shorter than that of traditional livestock species. They also require a reduced-size rearing space and are able to recycle agricultural by-products, while having a high feed conversion ratio (Caparros Megido et al. 2017). Cricket rearing is popular in Thailand where 20,000 smallholder farms produce more than 7500 tonnes a year (Hanboonsong et al. 2013). The Flying Food project, a consortium between partners from Kenya, Uganda and the Netherlands, produced a manual for trainers who will teach small holder farmers how to setup and maintain a cricket rearing production system (Beckers et al. 2019). Also in Kenya, farming of crickets (*Acheta domesticus* and *Gryllus bimiculatus*) have been introduced for households (Ayieko et al. 2016).

In Kenya, a new cricket of the genus *Scapsipedus* (Orthoptera: Gryllidae) has been described (Tanga et al. 2018). This species has been reared for 3 years in the research facility at the International Centre of Insect Physiology and Ecology (icipe), Duduville Campus, Nairobi, Kenya. It has been demonstrated through several research activities that it is a very promising species for mass rearing for food and feed. They named the species *Scapsipedus icipe* n. sp.

1.6 Nutrition

Edible insect species in Cameroon (R. *phoenicis*, *R. differens*, *Z. variegatus*, *Macrotermes* sp., *Imbrasia* sp.) are considerable sources of fat (Womeni et al. 2009). Their oils are rich in polyunsaturated fatty acids, of which essential fatty acids are linoleic and linolenic acids. The "polyunsaturated fatty acid–saturated fatty acid" ratio is in the majority of cases higher than 0.8. The major fatty acids (occurring at more than 10%) of *R. phoenicis* are palmitic acid, oleic acid and linoleic acid while those of *G. belina* and *C. forda* are palmitic, oleic, linoleic, and stearic acids (Amadi and Kiin-Kabari 2016).

Two caterpillar species sold in South Africa and Zimbabwe had high iron and zinc, in particular iron is an important nutrient for combating anaemia (Payne et al. 2015). In the Democratic Republic of Congo the efficacy of a cereal made from caterpillars was assessed on reducing stunting and anaemia in infants at 18 month of age (Bauserman et al. 2015). It did not reduce the prevalence of stunting, but those infants had higher Hb concentration and fewer were anaemic.

Payne et al. (2016) compared energy and 12 relevant nutrients for three commonly consumed meats (beef, pork and chicken), and six commercially available insect species (the cricket *A. domesticus*, the honeybee *Apis mellifera*, the domesticated silkworm *Bombyx mori*, the mopane caterpillar *I. belina*, the African palm weevil larva *R. phoenicis* and the yellow mealworm *Tenebrio molitor*). They used two models. According to the Ofcom model, no insects were significantly "healthier" than meat products. According to the Nutrient Value Score, crickets, palm weevil larvae and mealworm had a significantly healthier score than beef and chicken. It was difficult to draw general conclusions as there was a large variation between edible insect species in nutrient content. It seems that in the context of overnutrition meat product may be preferred over certain insect species, while in the context of undernutrition certain insects species are a better choice.

1.7 Contribution to Food Security

Niassy et al. (2016) showed a gender bias toward women and children in the collection and consumption of edible insects. Women and children play an active role in the whole value chain of edible insects including collection, processing, and packaging. By collecting they secure stocks of proteins for household consumption and generate income as has been shown for the mopane caterpillar in South Africa (Baiyegunhi et al. 2016). In Zimbabwe, the harvesting and processing of the mopane caterpillar is carried out by women and children while men in general dominate the more lucrative long-distance and large-volume trading chains, but in general the collection and marketing is carried out by relatively poor people (Kozanayi and Frost 2002). In South Africa, where the edible stink bug *Encosternum delegorguei* (Hemiptera: Tessaratomidae) is a traditional delicacy of some ethnic groups in South Africa and Zimbabwe, women control 72% of the market (Dzerefos et al. 2014).

1.8 Processing and Marketing Insects

In Kenya, termites and lake flies were collected and processed in the laboratory under different types of cooking methods such as baking, boiling, and steam cooking under pressure. The processed products, such as crackers, muffins, sausages, and meat loaf, were readily accepted (Ayieko et al. 2010). In the same country a number of processed products with crickets were developed and presented to consumers. Children were particularly attracted to biscuits and the fried foods such as fritters, samosa, and pancakes (Ayieko et al. 2016). Processing can have an effect on the digestibility and vitamin content of edible insects as was shown by Kinyuru et al. (2010) with the termite *Macrotermes subhyalinus* and the grasshopper *R. differens*. In Kenya, it was also investigated how consumers evaluated the sensory attributes of a common bakery product (buns) that was blended with cricket flour. Providing information on the product could enhance consumer acceptance of the insect-based food (Pambo et al. 2018). However, Kinyuru et al. (2009) also showed that it depends on the concentration of insect flour in the product.

1.9 Conclusions

Although insect consumption is common in Africa, the danger exists that western food habits are copied and that insects as traditional food are being considered as a poor man's diet (Niassy et al. 2016; van Huis 2013). This seems strange as in the western world insects are now increasingly being appreciated as nutritious food and more sustainable than the common meat products (Van Huis and Oonincx 2017). Kelemu et al. (2015) called it for Africa "*an overlooked food source*" and she mentions with others (Kelemu et al. 2015) that "*within the context of sustainable diet, the use of insects as food and feed has a significant role to play in assuring food security and improving the livelihood of the African people*." However, traditionally insects have been harvested from nature and when this food source is going to be promoted than this is not an option anymore. Insects need to be reared and urgently rearing methods need to be developed for a number of species which are highly popular in Africa. This would change the food source from being seasonal to a continuous available food item. Besides also processing methods need to be developed to make them into readily available insect-based products with a long shelf life.

References

Adeboye AO, Bolaji TA, Fatola OL (2016) Nutritional composition and sensory evaluation of cookies made from wheat and palm weevil larvae flour blends. Ann Food Sci Technol 17:543–547

Ademolu KO, Idowu AB, Olatunde GO (2010) Nutritional value assessment of variegated grasshopper, *Zonocerus variegatus* (L.) (Acridoidea: Pygomorphidae), during post-embryonic development. Afr Entomol 18:360–364. https://doi.org/10.4001/003.018.0201.

Ademolu KO, Simbiat ES, Concilia I, Adeyinka AA, Abiodun OJ, Adebola AO (2017) Gender variations in nutritive value of adult variegated grasshopper, *Zonocerus variegatus* (L) (Orthoptera:Pygomorphidae). J Kansas Entomol Soc 90:117–121. https://doi.org/10.2317/170325.1.

Adepoju OT, Daboh OO (2013) Nutrient composition of *Cirina forda* (Westwood) enriched complementary foods. Ann Nutr Metab 63:139–144

Agea JG, Biryomumaisho D, Buyinza M, Nabanoga GN (2008) Commercialization of *Ruspolia nitidula* (Nsenene grasshoppers) in central Uganda. Afr J Food Agricult Develop 8:319–332

Akinnawo O, Ketiku AO (2000) Chemical composition and fatty acid profile of edible larva of *Cirina forda* (Westwood). Afr J Biomed Res 3:93–96

Akpalu W, Muchapondwa E, Zikhali P (2007) Can the restrictive harvest period policy conserve mopane worms in Southern Africa? A bio-economic modelling approach. Working paper number 65, University of Pretoria.

Alegbeleye WO, Obasa SO, Olude OO, Otubu K, Jimoh W (2012) Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings. Aquac Res 43:412–420. https://doi.org/10.1111/j.1365-2109.2011.02844.x.

Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision global perspective studies team. ESA working paper no 12-03, Agricultural Development Economics Division. Food and Agriculture Organization of the United Nations, Rome. www.fao.org/economic/esa

Amadi E, Kiin-Kabari D (2016) Nutritional composition and microbiology of some edible insects commonly eaten in africa, hurdles and future prospects: a critical review. J Food Microbiol Safety Hygiene 1:107. https://doi.org/10.4172/2476-2059.1000107

Amao OA, Oladunjoye IO, Togun VA, Olubajo K, Oyaniyi O (2010) Effect of Westwood (*Cirina forda*) larva meal on the laying performance and egg characteristics of laying hen in a tropical environment. Int J Poult Sci 9:450–454

Ande AT, Fasoranti JO (1998) Some aspects of the biology, foraging and defensive behaviour of the emperor moth caterpillar, *Cirina forda* (Westwood). Int J Tropic Insect Sci 18:177–181. https://doi.org/10.1017/S1742758400023377.

Anvo MPM, Toguyéni A, Otchoumou AK, Zoungrana-Kaboré CY, Kouamelan EP (2016a) Evaluation of *Cirina butyrospermi* caterpillar's meal as an alternative protein source in *Clarias gariepinus* (Burchell, 1822) larvae feeding. Int J Fish Aquatic Stud 4:88–94

Anvo MPM, Toguyéni A, Otchoumou AK, Zoungrana-Kaboré CY, Kouamelan EP (2016b) Nutritional qualities of edible caterpillars *Cirina butyrospermi* in southwestern of Burkina Faso. Int J Innov Appl Stud 18:639–645

Anvo MPM, Aboua BRD, Compaoré I, Sissao R, Zoungrana-Kaboré CY, Kouamelan EP, Toguyéni A (2017) Fish meal replacement by *Cirina butyrospermi* caterpillar's meal in practical diets for *Clarias gariepinus* fingerlings. Aquac Res 48:5243–5250. https://doi.org/10.1111/are.13337.

Ayemele AG, Muafor FJ, Levang P (2016) Indigenous management of palm weevil grubs (*Rhynchophorus phoenicis*) for rural livelihoods in Cameroon. J Insects Food Feed 31:43–50. https://doi.org/10.3920/JIFF2016.0002

Ayieko MA, Oriamo V, Nyambuga IA (2010) Processed products of termites and lake flies: improving entomophagy for food security within the Lake Victoria region. Afr J Food Agric Nutr Dev 10:2085–2098

Ayieko MA, Ogola HJ, Ayieko IA (2016) Introducing rearing crickets (gryllids) at household levels: adoption, processing and nutritional values. J Insects Food Feed 2:203–211. https://doi.org/10.3920/JIFF2015.0080

Bailey WJ, McCrae AWR (1978) The general biology and phenology of swarming in the East African tettigoniid *Ruspolia differens* (Serville) (Orthoptera). J Nat Hist 12:259–228. https://doi.org/10.1080/00222937800770151.

Baiyegunhi LJS, Oppong BB (2016) Commercialisation of mopane worm (*Imbrasia belina*) in rural households in Limpopo Province. South Afr Forest Policy Econom 62:141–148. https://doi.org/10.1016/j.forpol.2015.08.012.

Baiyegunhi LJS, Oppong BB, Senyolo GM (2016) Mopane worm (*Imbrasia belina*) and rural household food security in Limpopo province. South Afr Food Security 8:153–165. https://doi.org/10.1007/s12571-015-0536-8.

Bama HB, Dabire RA, Ouattara D, Niassy S, Ba MN, Dakouo D (2018) Diapause disruption in *Cirina butyrospermi* Vuillet (Lepidoptera, Attacidae), the shea caterpillar, in Burkina Faso. J Insects Food Feed. https://doi.org/10.3920/JIFF2017.0068

Bauserman M et al (2015) A cluster-randomized trial determining the efficacy of caterpillar cereal as a locally available and sustainable complementary food to prevent stunting and anaemia. Public Health Nutr 18:1785–1792. https://doi.org/10.1017/S1368980014003334.

Beckers E, et al (2019) Training manual: cricket rearing for small holder farmers using the 30/3 crate system. Flying Food project, Wageningen

Caparros Megido R, Haubruge É, Francis F (2017) Chapter 5. Small-scale production of crickets and impact on rural livelihoods. In: Van Huis A, Tomberlin JK (eds) Insects as food and feed: from production to consumption. Wageningen Academic Publishers, Wageningen, pp 101–111

Cito A, Longo S, Mazza G, Dreassi E, Francardi V (2017) Chemical evaluation of the *Rhynchophorus ferrugineus* larvae fed on different substrates as human food source. Food Sci Technol Int 23:529–539. https://doi.org/10.1177/1082013217705718.

Dreyer JJ, Wehmeyer AS (1982) On the nutritive value of mopanie worms. S Afr J Sci 78:33–35

Dzerefos CM, Witkowski ETF, Toms R (2014) Use of the stinkbug, *Encosternum delegorguei* (Hemiptera, Tessaratomidae), for food and income in South Africa. Soc Nat Resour 27:882–897. https://doi.org/10.1080/08941920.2014.915368.

Edijala JK, Egbogbo O, Anigboro AA (2009) Proximate composition and cholesterol concentrations of *Rhynchophorus phoenicis* and *Oryctes monoceros* larvae subjected to different heat treatments. Afr J Biotechnol 8:2346–2348

Ekpo KE (2010) Nutrient composition, functional properties and anti-nutrient content of *Rhynchophorus pheonicis* (F) larva. Ann Biol Res 1:178–190

Ekpo KE (2011) Effect of processing on the protein quality of four popular insects consumed in Southern Nigeria. Arch Appl Sci Res 3:307–326

Ekpo KE, Onigbinde AO (2005) Nutritional potentials of the larva of *Rhynchophorus phoenicis* (F). Pak J Nutr 4:287–290

Ekpo KE, Onigbinde AO (2007) Characterization of lipids in *Rhynchophorus pheonicis* larval oil. Pak J Sci Ind Res 50:75–79

FAO (2017) FAO advisory note on fall armyworm (FAW) in Africa. Advisory note 5. June 2017. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/a-bs914e.pdf

FAO, IFAD, UNICEF, WFP, WHO (2018) The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition. FAO Licence: CC BY-NC-SA 30 IGO, Rome

Farina L, Demey F, Hardouin J (1991) Production de termites pour l'aviculture villageoise au Togo. Tropicultura 9:181–187

Gabaza M, Shumoy H, Muchuweti M, Vandamme P, Raes K (2018) Baobab fruit pulp and mopane worm as potential functional ingredients to improve the iron and zinc content and bioaccessibility of fermented cereals. Innovative Food Sci Emerg Technol 47:390–398. https://doi.org/10.1016/j.ifset.2018.04.005.

Ghazoul J (2006) Mopani woodlands and the mopane worm: enhancing rural livelihoods and resource sustainability. Final technical report. DFID, London

Glew RH, Jackson D, Sena L, VanderJagt DJ, Pastuszyn A, Millson M (1999) *Gonimbrasia belina* (Lepidoptera: Saturniidae), a nutritional food source rich in protein, fatty acids and minerals. Am Entomol 45:250–253

Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M (2016) First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS One 11:e0165632. https://doi.org/10.1371/journal.pone.0165632.

Gondo T, Frost P, Kozanayi W, Stack J, Mushongahand M (2010) Linking knowledge and practice: assessing options for sustainable use of mopane worms (*Imbasia belina*) in southern Zimbabwe. J Sustain Develop Africa 12:281–305

Hanboonsong Y, Jamjanya T, Durst PB (2013) Six-legged livestock: edible insect farming, collection and marketing in Thailand. Food and Agriculture Organization of the United Nations. Regional Office for Asia and the Pacific, Bangkok

Hope RA, Frost PGH, Gardiner A, Ghazoul J (2009) Experimental analysis of adoption of domestic mopane worm farming technology in Zimbabwe. Dev South Afr 26:29–46

Idowu AB, Idowu OA (1999) Pharmacological properties of the repellent secretion of *Zonocerus variegatus* (Orthoptera: Prygomorphidae). Rev Biol Trop 47:1015–1020

Iduwu A, Modder W (1996) Possible control of the stinking grasshopper *Zonocerus variegatus* (L) (Ortohptera: Pyrgomorphidae) in ondo state, through human consumption. The Nigerian Field 61:7–14

Jongema Y (2017) List of edible insect species of the world. Laboratory of Entomology, Wageningen University, Wageningen. https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm

Kekeunou S, Weise S, Messi J, Tamo M (2006) Farmers' perception on the importance of variegated grasshopper (*Zonocerus variegatus* (L.)) in the agricultural production systems of the humid forest zone of Southern Cameroon. J Ethnobiol Ethnomed 2:17. https://doi.org/10.1186/1746-4269-2-17.

Kelemu S (2015) Insects: an overlooked food source. Int J Tropic Insect Sci 35:1–2. https://doi.org/10.1017/S174275841500003X.

Kelemu S et al (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insects Food Feed 1:103–119. https://doi.org/10.3920/JIFF2014.0016

Kenis M, Koné N, Chrysostome CAAM, Devic E, Koko GKD, Clottey VA, Nacambo S, Mensah GA (2014) Insects used for animal feed in West Africa. Entomologia 2:107–114

Kinyuru JN, Kenji GM, Njoroge MS (2009) Process development, nutrition and sensory qualities of wheat buns enriched with edible termites (*Macrotermes subhylanus*) from Lake Victoria region, Kenya. Afr J Food Agricult Nutr Develop 9:1739–1750

Kinyuru JN, Kenji GM, Njoroge SM, Ayieko M (2010) Effect of processing methods on the in vitro protein digestibility and vitamin content of edible winged termite (*Macrotermes subhylanus*) and grasshopper (*Ruspolia differens*). Food Bioprocess Technol 3:778–782. https://doi.org/10.1007/s11947-009-0264-1.

Koffi DM, Cisse M, Koua GA, Niamke SI (2017) Nutritional and functional properties of flour from the palm (*Elaeis guineensis*) weevil *Rhynchophorus phoenicis* larvae consumed as protein source in south Côte d'Ivoire. Ann Univ Dunarea de Jos of Galati Fascicle VI – Food Technol 41:9–19

Kozanayi W, Frost P (2002) Marketing of mopane worm in southern Zimbabwe. Institute of Environmental Studies, Harare, p 31

Kung SJ, Fenemore B, Potter PC (2011) Anaphylaxis to mopane worm (*Imbrasia belina*). Ann Allergy Asthma Immunol 106:538–539. https://doi.org/10.1016/j.anai.2011.02.003.

Kwiri R, Winini C, Muredzi P, Tongonya J, Gwala W, Mujuru F, Gwala ST (2014) Mopane worm (*Gonimbrasia belina*) utilisation, a potential source of protein in fortified blended foods in zimbabwe: a review. Global J Sci Front Res 14:55–67

Lehtovaara VJ, Roininen H, Valtonen A (2018) Optimal temperature for rearing the edible*Ruspolia differens* (Orthoptera: Tettigoniidae). J Econom Entomol 111:234. https://doi.org/10.1093/jee/toy234

Lenga A, Kezetah C, Kinkela T (2012) Conservation et étude de la valeur nutritive des larves de *Rhynchophorus phoenicis* (Curculionidae) et *Oryctes rhinoceros* (Scarabeidae), deux coléoptères d'intérêt alimentaire au Congo-Brazzaville. Int J Biol Chem Sci 6:1718–1728. https://doi.org/10.4314/ijbcs.v6i4.28

Lewis VR (2003) Isoptera (Termites). In: Resh VH, Cardé RT (eds) Encyclopedia of insects. Academic, Amsterdam, pp 604–608

Malaisse F (2005) Human consumption of Lepidoptera, termites, Orthoptera, and ants in Africa. In: Paoletti MG (ed) Ecological implications of minilivestock. Science Publishers, Inc., Enfield, pp 175–230

Malaisse F, Mabossy-Mobouna G, Latham P (2017) Un atlas des chenilles et chrysalides consommées en Afrique par l'homme (An Atlas of caterpillars and chrysalises consumed by man in Africa). Geo-Eco-Trop 41:55–66

Malinga GM, Valtonen A, Lehtovaara VJ, Rutaro K, Opoke R, Nyeko P, Roininen H (2018a) Diet acceptance and preference of the edible grasshopper *Ruspolia differens* (Orthoptera: Tettigoniidae). Appl Entomol Zool 53:229–236. https://doi.org/10.1007/s13355-018-0550-3.

Malinga GM, Valtonen A, Lehtovaara VJ, Rutaro K, Opoke R, Nyeko P, Roininen H (2018b) Mixed artificial diets enhance the developmental and reproductive performance of the edible grasshopper, *Ruspolia differens* (Orthoptera: Tettigoniidae). Appl Entomol Zool 53:237–242. https://doi.org/10.1007/s13355-018-0548-x

Mba FAR, Kansci G, Viau M, Hafnaoui N, Meynier A, Demmano G, Genot C (2017) Lipid and amino acid profiles support the potential of *Rhynchophorus phoenicis* larvae for human nutrition. J Food Compos Anal 60:64–73. https://doi.org/10.1016/j.jfca.2017.03.016.

Mbata KJ (1995) Traditional uses of arthropods in Zambia. In: DeFoliart G, Dunkel FV, Gracer D (eds) Food insect newsletter volumes 1013; 1988 through 2000. Aardvark Global Publishing Company, Salt Lake City, pp 235–237

McCrae AWR (1982) Characteristics of swarming in the African Edible Bush-Cricket *Ruspolia differens* (Serville) (Orthoptera,Tettigonioidea). J East Afr Nat History Soc National Museum 178:1–5

Mmari MW, Kinyuru JN, Laswai HS, Okoth JK (2017) Traditions, beliefs and indigenous technologies in connection with the edible longhorn grasshopper *Ruspolia differens* (Serville 1838) in Tanzania. J Ethnobiol Ethnomed 13:60. https://doi.org/10.1186/s13002-017-0191-6.

Muafor FJ, Gnetegha AA, Gall PL, Levang P (2015) Exploitation, trade and farming of palm weevil grubs in Cameroon. Center for International Forestry Research (CIFOR), working paper 178, Bogor, Indonesia. https://doi.org/10.17528/cifor/005626

Muafor FJ, Gnetegha AA, Dounias E, Le Gall P, Levang P (2017) Chapter 6. African Palm Weevil farming: a novel technique contributing to food security and poverty alleviation in rural sub-Saharan Africa. In: van Huis A, Tomberlin JK (eds) Insects as food and feed: from production to consumption. Wageningen Academic Publishers, Wageningen, pp 113–125

Neely C, Bunning S, Wilkes A (eds) (2009) Review of evidence on drylands pastoral systems and climate change: implications and opportunities for mitigation and adaptation Land Tenure and Management Unit (NRLA), Land and Water Division, land and water discussion paper 8. Food and Agriculture Organization of the United Nations, Rome

Niassy S, Affognon HD, Fiaboe KKM, Akutse KS, Tanga CM, Ekesi S (2016) Some key elements on entomophagy in Africa: culture, gender and belief. J Insects Food Feed 2:139–144. https://doi.org/10.3920/JIFF2015.0084

Nrior RR, Beredugo EY, Wariso CA (2018) Dual purpose edible insect larva (*Rhynchophorus phoenicis*) in south south Nigeria—microbiological assessment of body parts, IOSR. J Environ Sci Toxicol Food Technol 12:59–68. https://doi.org/10.9790/2402-1209035968

Nzikou JM (2010) Characterisation and nutritional potentials of *Rhynchophorus phoenic* larva consumed in Congo-Brazzaville. Marien Ngouabi University, Brazzaville

Okezie OA, Kgomotso KK, Letswiti MM (2010) Mopane worm allergy in a 36-year-old woman: a case report. J Med Case Rep 4:42. https://doi.org/10.1186/1752-1947-4-42.

Okunowo WO, Olagboye AM, Afolabi LO, Oyedeji AO (2017) Nutritional value of *Rhynchophorus phoenicis* (F.) larvae, an edible insect in Nigeria. Afr Entomol 25:156–163. https://doi.org/10.4001/003.025.0156.

Olaofe O, Arogundade LA, Adeyeye EI, Falusi OM (1998) Composition and food properties of the variegated grasshopper, *Zonocerus variegatus*. Trop Sci 38:233–237

Omotoso OT (2006) Nutritional quality, functional properties and anti-nutrient compositions of the larva of *Cirina forda* (Westwood) (Lepidoptera: Saturniidae). J Zhejiang Univ Sci 7:51–55

Omotoso OT, Adedire CO (2007) Nutrient composition, mineral content and the solubility of the proteins of palm weevil, *Rhynchophorus phoenicis* f. (Coleoptera: Curculionidae). J Zhejiang Univ Sci B 8:318–322

Oyegoke OO (n.d.). H-index : 1Aj AkintolaH-index: 1Jo FasorantiH-index: 1

Oyegoke OO, Akintola AJ, Fasoranti JO (2006) Dietary potentials of the edible larvae of *Cirina forda* (westwood) as a poultry feed. Afr J Biotechnol 5:1799–1802. https://doi.org/10.5897/AJB06.189.

Paiko YB, Jacob JO, Salihu SO, Dauda BEN, Suleiman MAT, Akanya HO (2014) Fatty acid and amino acid profile of emperor moth caterpillar (*Cirina forda*) in Paikoro local government area of Niger State, Nigeria. Am J Biochem 4:29–34. https://doi.org/10.5923/j.ajb.20140402.03.

Pambo KO, Okello JJ, Mbeche RM, Kinyuru JN, Alemu MH (2018) The role of product information on consumer sensory evaluation, expectations, experiences and emotions of cricket-flour buns. Food Res Int 106:532–541. https://doi.org/10.1016/j.foodres.2018.01.011.

Payne CLR, Umemura M, Dube S, Azuma A, Takenaka C, Nonaka K (2015) The mineral composition of five insects as sold for human consumption in Southern Africa. Afr J Biotechnol 14:2443–2448. https://doi.org/10.5897/AJB2015.14807.

Payne CLR, Scarborough P, Rayner M, Nonaka K (2016) Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition. Eur J Clin Nutr 70:285–291. https://doi.org/10.1038/ejcn.2015.149.

Quaye B, Atuahene CC, Donkoh A, Adjei BM, Opoku O, Amankrah MA (2018) Nutritional potential and microbial status of african palm weevil (*Rhynchophorus phoenicis*) larvae raised on alternative feed resources. Am Sci Res J Eng Technol Sci 48:45–52

Quayea B, Atuahene CC, Donkoh A, Adjei BM, Opoku O, Amankrah MA (2018) Alternative feed resource for growing african palm weevil (*Rhynchophorus phoenicis*) larvae in commercial production. Am Sci Res J Eng Technol Sci 48:36–44

Rémy DA, Hervé BB, Sylvain ON (2018) Study of some biological parameters of *Cirina butyrospermi* Vuillet (Lepidoptera, Attacidae), an edible insect and shea caterpillar (*Butyrospermum paradoxum* Gaertn. F.) in a context of climate change in Burkina Faso. Adv Entomol 6:81510. https://doi.org/10.4236/ae.2018.61001

Roffeis M et al (2018) Life cycle cost assessment of insect based feed production in West Africa. J Clean Prod 199:792–806. https://doi.org/10.1016/j.jclepro.2018.07.179.

Rutaro K, Malinga GM, Lehtovaara VJ, Opoke R, Nyeko P, Roininen H, Valtonen A (2018a) Fatty acid content and composition in edible *Ruspolia differens* feeding on mixtures of natural food plants. BMC Res Notes 11:687. https://doi.org/10.1186/s13104-018-3792-9.

Rutaro K et al (2018b) Artificial diets determine fatty acid composition in edible *Ruspolia differens* (Orthoptera: Tettigoniidae). J Asia Pac Entomol 21:1342–1349. https://doi.org/10.1016/j.aspen.2018.10.011.

Saeed T, Dagga FA, Saraf M (1993) Analysis of residual pesticides present in edible locusts captured in Kuwait. Arab Gulf J Sci Res 11:1–5

Sani I, Haruna M, Abdulhamid A, Warra A, Bello F, Fakai I (2014) Assessment of nutritional quality and mineral composition of dried edible *Zonocerus variegatus* (grasshopper). J Food Dairy Technol 2:1–6

Séré A et al (2018) Traditional knowledge regarding edible insects in Burkina Faso. J Ethnobiol Ethnomed 14:59. https://doi.org/10.1186/s13002-018-0258-z.

Solomon M, Ladeji O, Umoru H (2008) Nutritional evaluation of the giant grasshopper (Z*onocerus variegatus*) protein and the possible effects of its high dietary fibre on amino acids and mineral bioavailability. Afr J Food Agric Nutr Dev 8:238–248

Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, de Vries W, Vermeulen SJ, Herrero M, Carlson KM, Jonell M, Troell M, DeClerck F, Gordon LJ, Zurayk R, Scarborough P, Rayner M, Loken B, Fanzo J, Godfray HCJ, Tilman D, Rockström J, Willett W (2018) Options for keeping the food system within environmental limits. Nature 662:519–525

Ssepuuya G et al (2017) Use of insects for fish and poultry compound feed in sub-Saharan Africa—a systematic review. J Insects Food Feed 3:289–302. https://doi.org/10.3920/jiff2017.0007

Stack J, Dorward A, Gondo T, Frost P, Taylor F, Kurebgaseka N (2003) Presentation title: mopane worm utilisation and rural livelihoods in southern Africa. Paper presented at the international conference on rural livelihoods, forests and biodiversity, Bonn, Germany.

Styles CV (1994) The big value in mopane worms. Farmer's Weekly 22:20–22

Tanga CM, Magara HJO, Ayieko MA, Copeland RS, Khamis FM, Mohamed SA, Ombura FLO, Niassy S, Subramania S, Fiaboe KKM, Roos N, Ekesi S, Hugel S (2018) A new edible cricket species from Africa of the genus *Scapsipedus*. Zootaxa. https://doi.org/10.11646/zootaxa.0000.0.0

Van Huis A (2003) Insects as food in sub-Saharan Africa. Insect Sci Appl 23:163–185

Van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583. https://doi.org/10.1146/annurev-ento-120811-153704.

Van Huis A (2017) Cultural significance of termites in sub-Saharan Africa. J Ethnobiol Ethnomed 13(8). https://doi.org/10.1186/s13002-017-0137-z.

Van Huis A, Oonincx DGAB (2017) The environmental sustainability of insects as food and feed. A review. Agron Sustain Dev 37:43. https://doi.org/10.1007/s13593-017-0452-8.

Van Itterbeeck J, Van Huis A (2012) Environmental manipulation for edible insect procurement: a historical perspective. J Ethnobiol Ethnomed 8:1–19. https://doi.org/10.1186/1746-4269-8-3.

Womeni HM, Linder M, Tiencheu B, Mbiapo FT, Villeneuve P, Fanni J, Parmentier M (2009) Oils of insects and larvae consumed in Africa: potential sources of polyunsaturated fatty acids. J Oleo Sci 16:230–235

Womeni HM, Tiencheu B, Linder M, Nabayo EMC, Tenyang N, Mbiapo FT, Villeneuve P, Fanni J, Parmentier M (2012) Nutritional value and effect of cooking, drying and storage process on some functional properties of *Rhynchophorus phoenicis*. Int J Life Sci Pharma Res 2:203–219

Chapter 2
African Edible Insect Consumption Market

Cordelia Ifeyinwa Ebenebe, Oluwatosin Samuel Ibitoye, Inwele Maduabuchi Amobi, and Valentine Obinna Okpoko

Abstract Consumption is the utilization of economic goods to satisfy needs. Africa is home to the rich diversity of insects with over 1500 species of insects. Several reports highlighted the nutritional, medicinal values and industrial uses of some edible insects. The global edible insects market is mainly segmented by insect type, product type, application, and geography. Insects can be grown on organic waste. The potential of edible insects in curbing the menace of malnutrition and ensuring food security has necessitated so much interest in the production, marketing, and utilization of edible insects.

Keywords Edible insect · Consumption · Commercialization · Market

2.1 Introduction

Consumption is often defined as the utilization of economic goods to satisfy needs. The dictionary of marketing terms defined consumption as the process of using consumer products in order to satisfy desires, real or imaginable needs so that the products are used up, transformed or deteriorated in such a manner as not to be either reusable or recognizable in their original form (https://www.allbusiness.com/

C. I. Ebenebe (✉)
Microlivestock Unit, Department of Animal Science and Technology, Nnamdi Azikiwe University, Awka, Nigeria
e-mail: ci.ebenebe@unizik.edu.ng

O. S. Ibitoye
Forestry Research Institute of Nigeria, Onigambari Forest Reserve, Ibadan, Oyo State, Nigeria

I. M. Amobi
Federal University of Kashere, Gombe, Nigeria

V. O. Okpoko
Bioconservation Unit, Department of Zoology, Nnamdi Azikiwe University, Awka, Nigeria

A. Adam Mariod (ed.), *African Edible Insects As Alternative Source of Food, Oil, Protein and Bioactive Components*, https://doi.org/10.1007/978-3-030-32952-5_2

barrons_dictionary/dictionary-consumption-4965423-1.html). African edible insect consumption market therefore refers to the business of promoting production, buying, and selling of edible insects and products derived from insects as well as other beneficial services from insects including entotherapy/zootherapy. Promotion of edible insect production requires preservation of forests where the insects thrive or provision of simulated environment or other devices for mass production of insects. In the wild, the volume of edible insects and by-products from it correlates with the wealth of forest resources. The African continent is endowed with rich forest resources, especially tropical rain forests (Bernard and Womeni 2017).

According to FAO (2005), forests and woodlands in Africa occupy an estimated 650 million hectares (21.8%) of the land area of this continent and account for 16.8% of the global forest cover. On average, forests account for 6% of gross domestic product (GDP) in Africa, which is the highest in the world. In Uganda, for example, forests and woodlands are now recognized as an important component of the nation's stock of economic assets and they contribute in excess of US$546.6 million to the economy. Leal et al. (2016) highlighted the relationship between the forest ecosystem and insect biodiversity. Insects according to Alaloiun (2014) play an essential role in forest ecosystems by affecting the primary production and evolution of plants. They form a critical link between plants and higher trophic levels (Crawley 1997, cited in Alaloiun 2014). There are over 1500 species of edible insects across Africa, this is closely related to its tropical climate and magnitude of tropical rainforest that is majorly home for an enormous species of insects. Today, these vast species of insects have become a singular resource in sustaining food security and curbing the menace of malnutrition in the continent.

Sidiki Sow (2016) in his report on "Insect Protein for Food Security in West Africa" stated that by 2050 the world population will be 9.4 billion, with 2.4 billion people in Africa. This teeming population will demand double amount of food and animal feed production to meet nutritional needs of man and animal. Van Huis (2015) and Alexandratos and Bruinsma (2012) reported that meat consumption in sub-Saharan Africa is expected to double from 202% from 2010 to 2050. It will therefore be a herculean task to feed such a huge population especially in Africa where the World Food Program (2016) already reported that one out of every four Africans is undernourished, 1.2 M people are in urgent need of food assistance in Mali, Niger, and Burkina Faso, and USS 11.5 M is needed to offset food deficit challenges in Mali and Niger. In Kenya USAID in 2014 reported that 1.5 million people needed food assistance, while cases of kwashiorkor is presently reported in northern part of Nigeria (Hamidu et al. 2003). If the extrapolation on population growth for 2050 becomes real, feeding of such a massive population will mean increase in agricultural activities and its concomitant environmental degradation. Of all food nutrients, animal protein deficiency is more pronounced, with records as low as 7–10 g/person/day in many African countries against the 35 g/person/day recommended by FAO (1991) for normal growth and development.

Besides, massive production of livestock to increase animal protein supply and consumption will lead to environmental issues especially higher levels of greenhouse gases (GHG), pollution of water resources and making land unavailable for other uses. According to Food and Agricultural Organization (FAO), livestock is the world's largest user of land resources, with grazing land and cropland dedicated to the production of feed representing almost 80% of all agricultural land. Judging by the hunger rate in Africa, if 50% of this land is used in producing food for human consumption, hunger rate would have drastically reduced. Livestock also requires large amount of water, grains used in feed formulation required about 1000–5000 kg of water to grow depending on the region (Chapagain and Hoekstra 2003). Livestock itself contains between 5 and 20 times more water per kg product (Chapagain and Hoekstra 2003). In most African countries, there is little or no factual record on the level of environmental degradation associated with livestock activities.

However, given the triad doom-spelling factors in Africa (fast growing population, natural resource degradation by slash-and-burn agriculture, and high level of malnutrition), edible insect cultivation and utilization as food and feed appear very promising in ensuring food security in the continent. FAO (2008) (cited in Van Huis 2013 recommended insects as alternative source of food, capable of meeting the animal protein demands of a growing population while preserving the environment. As a follow-up to the FAO workshop in Chiang Mai in 2008, the Non-Wood Forest Products Programme of the FAO Forestry Department and the Wageningen University and Research Centre (WUR) (Laboratory of Entomology) initiated a collaborative effort to promote entomophagy; thus FAO (2013) outlined common insects consumed globally, including beetle, grasshoppers, locusts, and crickets. Consumption of larva of many insects has also been documented. In an earlier work FAO (2013) reported consumption of mopane caterpillar (*Imbrasia belina*) in Angola, Botswana, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. Malaise (1997) identified 38 different species of caterpillar consumed across the Democratic Republic of Congo, Zambia, and Zimbabwe. Evidently, rearing insects requires remarkably less land than farming other categories of livestock (Oonincx and de Boer 2012).

Several reports in literature highlighted the nutritional, medicinal values and industrial uses of some edible insects (Ekpo and Onigbinde 2004, 2005; Banjo et al. 2006; Edijala et al. 2009; Alamu 2014; Mbah and Elekima 2007; Ebenebe and Okpoko 2014; Schabel 2010). According to Braide et al. (2010) protein content of edible insects ranged from 21 to 65% and therefore compares favorably with meat and fish proteins. Igwe et al. (2011) also reported that insect larvae are rich in essential amino acids like lysine and threonine which are deficient in grain and cereals. Similarly, Ekpo and Onigbinde (2004) had earlier reported that edible insect larvae are rich in essential fatty acids like linoleic and linolenic acids while Igwe et al. (2011) reported on vitamin content of edible insects. Apart from the nutritional and medicinal benefits, there are other ecological, magical, and spiritual benefits of insects; therefore edible insect consumption market in Africa will address all of these aspects of insect benefits and the level of commercialization in Africa. According to FAO (2012), edible insects contain high-quality protein, vitamins, and amino acids for humans. Insects have a high food conversion rate; for example, crickets need six times less feed than cattle, four times less than sheep, and twice less than pigs and broiler chickens to produce the same amount of protein. Besides, they emit less greenhouse gases and ammonia than conventional livestock (Oonincx et al. 2010). Insects can be grown on organic waste. The potential of edible insects in curbing the menace of malnutrition and ensuring food security has necessitated so much interest in the production, marketing, and utilization of edible insects.

The global edible insects market is mainly segmented by insect type (crickets, mealworms, black soldier flies, buffalos, grasshoppers, ants, silkworms, cicadas, and others), product type (whole insects, insect meal, insect powder, insect protein bars and protein shakes, insect baked product and snacks, insect confectionaries, insect beverages, insect oil, and others), application (human consumption, animal nutrition, and cosmetics and pharmaceutical), and geography.

2.2 Edible Insects as Food in Africa

Edible insect consumption in Africa is as old as the continent. The continent is home to the richest diversity of insects with over 1500 species of insects (Raheem et al. 2019) ranging from caterpillars (Lepidoptera) to termites (Isoptera), locust, grasshoppers, cricket (Orthoptera), ants and bees (Hymenoptera), bugs (Heteroptera and Homoptera), and beetles (Coleoptera) (Saliou and Ekesi 2017). Although almost all African countries practice entomophagy, there is considerable variation in the most consumed insect order in the continent.

Saliou and Ekesi (2017) listed the most dominant insect eating countries to include Democratic Republic of Congo, Congo, The Central African Republic, Cameroun, Uganda, Zambia, Zimbabwe, Nigeria, and South Africa. Kelemu et al. (2015) and Kelemu (Kelemu 2016) gave a country-by-country run down of common species/orders of insects consumed in each of the African countries (Fig. 2.1 and Table 2.1), while Adeoye et al. (2014) showed diversity of edible insects in the African subregion.

In the Central African Republic, 96 species of insects are consumed. Of these 96 species, Roulon-Doko (1998) cited in Raheem et al. (2019) stated that insects of the order Orthoptera (locust and grasshopper) were the most consumed (40% consumption level), followed by Lepidoptera (36%), Isoptera (termites 10%), Coleoptera (beetles 6%), and others such as cicadas and crickets (8%) (Table 2.2).

In Kenya, Kinyuru et al. (2012, 2013) showed that six species of edible insects are consumed in the western part of Kenya. Of the six species four are termites of four different subspecies (*Pseudocanthotermes militaris* H., *Macrotermes bellicosus* S., *Macrotermes subhyalinus* R., and *Pseudocanthotermes spiniger* S.), the rest are black ant and long-horned grasshopper. Ayieko et al. (2012) posited that insect species like “agoro” termites, black ants, crickets, and grasshoppers form part of traditional menu in the western part of Kenya (Table 2.3).

In Ghana, the report of Anankware et al. (2016) showed that nine edible insects are consumed in Ghana, with scarab beetle (2%), field cricket (5%), shea butter tree

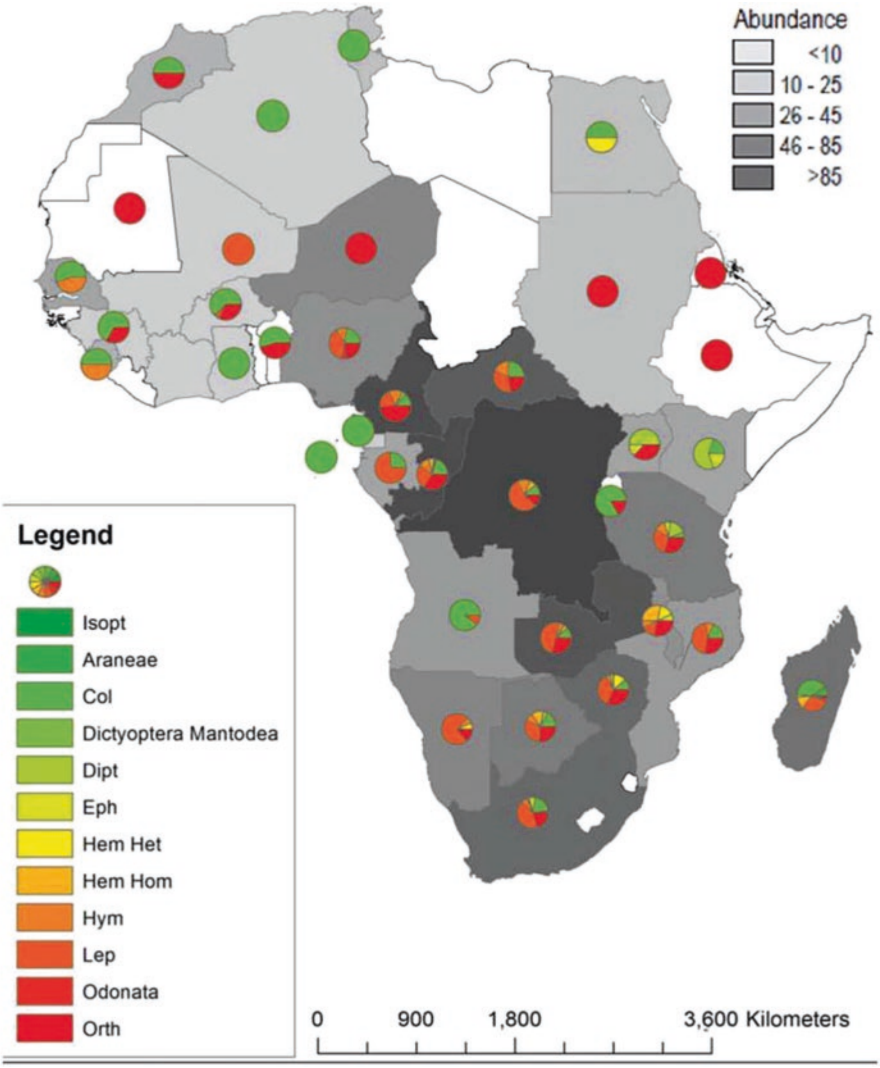

Fig. 2.1 Diversity and abundance of main groups of edible insects in Africa. (Source: Kelemu 2016 in Raheem et al. 2019)

caterpillar (8.7%), house cricket (9.5%), and locust (10%), African palm weevil larvae (47.2%), termites (45.9%), ground cricket (*Scapteriscus vianus*, 33.3%), and grasshoppers (30.5%). His report showed that Northern Ghana dominates in entomophagy as eight out of the nine edible insects consumed are mostly eaten in that region (Table 2.4). In Uganda, Raheem et al. (2019) reported that termites (*Macrotermes* spp.) and grasshopper (*Ruspolia nitidula*) are the most consumed edible insects.

Table 2.1 The most consumed insect species in Africa. Countries and regions of Africa where species are mostly consumed

Order	Scientific and common names	Countries
Coleoptera	*Oryctes owariensis* (Palisot de Beauvois) (Rhinoceros beetle)	DRC, South Africa, Ivory Coast, Sierra Leone Guinea, Ghana, Equatorial Guinea, Guinea Bissau
	Rhynchophorus phoenicis (Fabricius) (African palm weevil)	DRC, Cameroon, Congo, CA Republic, Nigeria, Angola, Ivory Coast, Niger, *São Tomé and Príncipe*, Guinea, Togo
	Oryctes boas (Fabricius) (Boas rhinoceros beetle)	Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau DRC, Congo, South Africa, Botswana, Namibia
Hemiptera	*Encosternum delegorguei* (Spinola) (Stinkbug)	South Africa, Swaziland, Mozambique, Malawi, Zimbabwe, Botswana, Namibia
Hymenoptera	*Apis mellifera mellifera* Linnaeus (European dark bee)	DRC, Zambia, Botswana, Nigeria, Tanzania, Senegal, Sierra Leone, Ghana, South Sudan, Togo, Lesotho, Benin
	Apis mellifera adansoni (Latreille) (Africanized honey bee)	DRC, Zambia, CA Republic, Nigeria, Tanzania, Sierra Leone, Ghana, Benin
	Carebara vidua (Smith)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi, Sudan, Kenya, South Sudan
	Carebara lignata (Westwood)	Zambia, South Africa, Zimbabwe, Botswana, Sudan, Mozambique, Namibia, South Sudan
	Macrotermes spp. (African mound-building termites)	DRC, Zambia, Zimbabwe, Nigeria, Tanzania, Malawi, Senegal, Uganda, Cote d'Ivoire, Guinea, Ghana, Togo, Burundi
	Macrotermes bellicosus (Smeathman) (Termites)	DRC, Cameroon, Congo, CA Republic Nigeria, Cote d'Ivoire, Kenya, *São Tomé and Príncipe*, Guinea, Togo Liberia, Guinea Bissau, Burundi
	Macrotermes subhyalinus (Rambur) (Mendi Termite)	Zambia, Angola, Kenya, Togo, Burundi
	*Macrotermes falcige*r (Gerstäcker)	Zambia, Zimbabwe, Burkina Faso, Burundi, Benin
	Macrotermes natalensis (Haviland)	DRC, Cameroon, Congo, CA Republic, Nigeria, Burundi, South Africa, Zimbabwe, Nigeria, Malawi
Lepidoptera	*Bunaea alcinoe* (Stoll) (African moth)	DRC, Zambia, South Africa, Cameroon, Congo, Central African Republic, Zimbabwe, Nigeria, Tanzania
	Anaphe panda (Boisduval) (Silk moth)	DRC, Zambia, Cameroon, Congo, CA, Republic, Zimbabwe, Nigeria, Tanzania
	Cirinaforda (Westwood) (Emperor moth)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	Dactyloceraslucina (Drury) (Drury's Owl Moth)	DRC, Zambia, South Africa, Cameroon, Congo, Angola, Gabon, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea

(continued)

Table 2.1 (continued)

Order	Scientific and common names	Countries
	Platysphinx stigmatica (Mabille) (Red spot moth)	DRC, Zambia, Congo, CA Republic, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea, Rwanda, Burundi
	Cirina butyrospermi (Vuillot) (Shea tree caterpillar)	DRC, Zambia, South Africa, Zimbabwe, Burkina Faso, Nigeria, Mali, Ghana
	Epanaphe carteri (Walsingham)	DRC, Zambia, Angola, Gabon, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea
	Imbrasiabelina (Westwood) (Mopane caterpillar, mopane worm, emperor moth)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi
	Gynanisaata (Strand) (African moth)	DRC, Zambia, Malawi, South Sudan
	Eumeta cervina (Druce) (Bagworm)	DRC, Cameroon, Congo, CA Republic, Angola, Gabon, Sierra Leone, Sao Tome
	Imbrasia ertli (Rebel) (Confused Emperor)	Zambia, South Africa, Cameroon, Congo
	Anaphe venata (Butler) (African silkworm)	Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Botswana, Angola
	Imbrasia epimethea (Drury) (African moth)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe
	Urota sinope (Westwood) (Tailed Emperor)	DRC, South Africa, Zimbabwe, Botswana, Gabon, Mozambique, Namibia
Orthoptera	*Schistocerca gregaria* (Forskål) (Desert locust)	Zambia, South Africa, Cameroon, Congo, Botswana, Tanzania, Sudan, Uganda, Ethiopia, Kenya, Sierra Leone, Morocco, Guinea, Lesotho, Mauritania, Somalia, Eritrea, Guinea Bissau
	Acanthacris ruficornis (Fabricius) (Garden locust)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Burkina
	Brachytrupes membranaceus (Drury) (Tobacco cricket)	Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Nigeria, Tanzania, Angola, Togo, Benin
	Nomadacris septemfasciata (Serville) (Red locust)	Zambia, South Africa, Congo, Zimbabwe, Uganda, Mozambique
	Ruspolia differens (Serville) (Longhorn grasshopper)	DRC, Zambia, South Africa, Cameroon, Zimbabwe, Kenya, Uganda, Tanzania
	Zonocerus variegatus (Linnaeus) (Variegated grasshopper)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, São Tomé and Príncipe, Guinea, Ghana, Liberia, Guinea Bissau
	Locusta migratoria migratorioides (Reich & Fairmaire) (Migratory locust)	Zambia, Cameroon, Congo, Zimbabwe, Sudan, South Sudan
	Locusta napardalina (Walker) (Brown locust)	Zambia, South Africa, Zimbabwe, Botswana, Malawi, Libya

(continued)