African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security

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African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security

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REVIEW ARTICLE

Abstract

This paper reviews entomophagy as practised in Africa within the context of food and nutritional security by providing an inventory of the various species of insects that are consumed on the continent and suggests a research for development (R4D) agenda for sustainable utilisation of insects for food and feed. Our survey showed that over 470 species of insects are eaten in Africa. The Central African region remains the most important hotspot of having a culture of entomophagy. The insects mostly eaten in the continent are dominated by the orders Lepidoptera, Orthoptera and Coleoptera. Commonalities were observed across the majority of the insects consumed across Africa, providing opportunities for related R4D activities. An R4D agenda and pathways for using edible insects suggest that socio-economics and marketing studies should address issues of communities' perceptions, based on their cultural background, income and beliefs. Cost-effective rearing, harvesting and processing technologies are required to prevent depletion and ecological perturbations while ensuring continuous availability of insect-based products. Indigenous reports assert that some edible insects harbour medicinal properties; thus, the need to undertake nutritional and bioactive chemical characterisation of main edible insects along the value chain and to investigate food safety issues such as diseases, allergies, and toxicological and chemical hazards. The use of insects for waste conversion into animal feed and fertiliser requires judicious choice of substrate in view of concerns regarding contaminant loads and pathogens occurrence. Responding to these research needs and opportunities, *icipe* has recently established an Insects for Food, Feed and Other Uses Programme with well-defined work packages oriented towards attainment of its Vision and Strategy 2013-2020 document, with a strong orientation towards R4D and a focus on activities that lead to adoption and impact on end users, through broad based complementary linkages and partnerships with agriculture and livestock extension services, Food and Agriculture Organization of the United Nations, Consultative Group on International Agricultural Research and advanced research institutes, non-governmental organisations and the private sector.

Keywords: Africa, entomophagy, food security, *icipe*, inventory

1. Introduction

African food security perspective

It was estimated that nearly 842 million people (12% of the global population) were unable to meet their dietary energy requirements in 2010 to 2013 (Van Huis *et al.*, 2013). The vast majority of the hungry people (827 million) live in developing regions, where the prevalence of undernourishment was at 15% in 2011 to 2013. Africa remains the region with the highest prevalence of undernourishment (Van Huis *et al.*, 2013). Despite both unprecedented economic growth since the turn of the millennium and a steady decline in poverty rates in recent years, sub-Saharan Africa (SSA) continues to grapple with food insecurity (Van Huis *et al.*, 2013). Although recent growth in gross domestic product has brought some improvements to rural populations (IFPRI, 2014), the highest proportion of the vulnerable people is living on less than US$ 1 per capita a day (US$ 1.25 per capita a day is the international poverty line) and unable to access quality food (Folaranmi, 2012). The region as a whole is extremely

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susceptible to frequent food crises and famines that are easily triggered by even the lightest of the likely events in Africa (droughts, floods, pests, economic downturns or conflicts). Incidentally, SSA is the only region where hunger is projected to worsen unless some drastic measures are taken to reverse food insecurity.

To effectively respond, not just to rapid population growth but also to other pressing challenges (including climate change and rising volatile food prices), SSA needs to accelerate its agricultural productivity without delay (IFPRI, 2013). A twin-track approach to reducing hunger is to increase food production, which should permit more income-generating opportunities for smallholders. The 2012 edition of *The State of Food and Agriculture* 2013 made a powerful case for investing in agriculture to reduce poverty and hunger (FAO, 2013). It showed that investing in agriculture contributes strongly to increasing food security, which in turn helps promote economic diversification and growth. Increased agricultural productivity spawns higher incomes and creates income-generating opportunities for otherwise destitute population groups, offering a recognised way to escape the poverty trap in many rural areas.

Indeed, there is much evidence to show that African countries are increasingly focusing on investing in agriculture for economic growth, evidenced by a number of regional and sub-regional initiatives that have put agriculture and agricultural R&D firmly back on the political and donor agendas. Solid agricultural development and financing plans to strengthen agricultural production and food security as part of the Comprehensive Africa Agriculture Development Programme (CAADP) of the New Partnership for Africa's Development (NEPAD) attest to such initiatives. Another important move toward a stronger agricultural sector is the Science Agenda for Agriculture in Africa (S3A) (IFPRI, 2014; UN, 2012), which was initiated in early 2013, and finalised and ratified at the African Union Heads of State Summit in mid-2014 in Malabo, Equatorial Guinea.

With government support, research for development on agriculture that generates knowledge, technologies, and other outputs that are considered public goods will continue to have a large impact on smallholder income, food security, and poverty reduction to improve the economy and livelihood of the poor. Indeed, as the number of people in the world continues to rise, as demand for food and feed increases, and as competition for land resources continues to grow, there is the need to rethink other alternative measures of enhancing food and nutritional security among the vulnerable and affluent consumers alike. Food and Agriculture Organization of the United Nations (FAO) recommends the application of a sustainable diet to improving food and nutritional security among consumers. Sustainable diets are those diets with low environmental impacts that contribute to food and nutrition security and to a healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally accepted, accessible, economically fair and affordable, nutritionally adequate, safe and healthy, while optimising natural and human resources. Sustainable diets can address the consumption of foods with lower water and carbon footprints and promote the use of food biodiversity (including traditional and local foods, with their many nutritionally rich species and varieties) (Saris and Morrison, 2010). The use of insects as food and feed, therefore, aligns perfectly within the context of a sustainable diet (Van Huis *et al.*, 2013).

Why consider insects for food and feed?

Insects are the most abundant multicellular organisms on planet Earth and are thought to account for >70% of all species. Insects are also among the most diverse groups of organisms in the history of life (Scaraffia and Miesfeld, 2012). Numerous crops rely on them for pollination, and their importance extends into other agricultural and human health issues (Dzerefos and Witkowski, 2014; Ingram *et al.*, 1996). Insects have been in existence for at least 400 million years, making them among the earliest land animals. They diverged as members of one of the largest subphyla in arthropods more than 390 million years ago experiencing a rapid evolution and radiation that is considered faster than any other group (Gaunt and Miles, 2002) and migrating into nearly all environmental niches, except the benthic zone (Gibert *et al.*, 2004). Although, about one million species have been classified and named, their actual number is believed to range from 2.5 and 10 million. Important features of their tremendous colonisation success and diversity are their: (1) short life spans compared to most vertebrates; (2) capacity to colonise new niches and to feed on nearly all species of plants and animals; and (3) ability to mount a harmful immune response.

Although mainly recognised as pests or nuisances affecting human, plant and animal health, insects play an essential role in minimising food insecurity in addition to providing ecosystem services (such as pollination, waste degradation and biological control). In a recent review, Van Huis (2013) outlined the important role of insects in assuring food and feed security. Globally, it is believed that 1,900 species of insects are consumed by about 2 billion people, mainly in the developing world (Van Huis, 2013). This has become especially important as the need for alternative protein sources increases due to rapid urbanisation in developing countries and the shifts in the composition of global food demand.

Many insects have been noted as comparable to conventional livestock meat in terms of nutritional content. While a variety of species are commonly eaten, the insects most frequently analysed include lepidopteran larvae (mostly members of the family Saturniidae), coleopteran larvae, a number of different species of grasshoppers and locusts, and several species of termites. In general, the crude protein content of insects ranges from 40 to 75% on dry weight basis, largely depending on species and stage in their life cycle (Rumpold and Schlüter, 2013; Verkerk *et al.*, 2007), with beneficial amino acid profile, and a variable fat content (reported up to >50% in some species) (Verkerk *et al.*, 2007). In the Democratic Republic of Congo (DRC), insect consumption among the indigenous Gbaya accounts for 15% of their protein intake (Roulon-Doko, 1998). Carbohydrates are present in the exoskeleton as chitin, reported in a highly variable range of 1 to 29% (dry weight) (Ramos-Elorduy *et al.*, 1997). Insects are also valuable sources of minerals and vitamins (Bukkens, 2005; Finke, 2013) essential for human development (Adegbola *et al.*, 2013; Michaelsen *et al.*, 2009). The average household in Kinshasa, DRC, ate approximately 300 g of caterpillars per week and 96 tonnes of caterpillars were consumed in the city annually as a major source of protein and other nutrients (Kitsa, 1989; Vantomme *et al.*, 2004). In the Central African Republic, 95% of forest people were dependent on eating insects for their protein intake (FAO, 2004) and insects are sometimes the only source of essential proteins (amino acids), fats, vitamins and minerals for forest people (Van Huis, 2013).

A variety of insect species is the natural feed source for fish and poultry and can be exploited for this purpose (DeFoliart, 1989; Farina *et al.*, 1991; Okedi, 1992). The amino acids derived from most insects' protein are superior to those from plant supplements in poultry feed formulations (Bukkens, 2005; Ravindran and Blair, 1993). In addition, various insect species have a higher proportion of protein content compared to conventional fish and soybean meals (Anand *et al.*, 2008). Furthermore, their clean feeding habits and their efficient food conversion factor (Leung *et al.*, 1970; Nakagaki and DeFoliart, 1991) make them a promising commodity to be promoted for feed.

Insects such as the black soldier fly (BSF), *Hermetica illucens* Linnaeus, common housefly *Musca domestica* Linnaeus and yellow mealworm *Tenebrio molitor* Linnaeus can play dual roles of recycling of organic by-products into high quality compost-fertilisers as well as utilisation of the maggots directly as animal feed (Čičková *et al.*, 2012). High quality compost-fertilisers produced with BSF from municipal waste recycling play a significant role in increasing crop water use efficiency, nutrient uptake, soil organic matter content and crop yield as compared to conventional fertiliser (Van Huis, 2013; Van Huis *et al.*, 2013). Furthermore, insect mass rearing is likely to leave a lighter footprint on the environment than conventional livestock production (Oonincx *et al.*, 2010; Van Huis, 2003). As such promoting insects as food and feed can contribute to mitigating the impact of climate change (Saxe *et al.*, 2013).

Semi-cultivation and harvesting of edible insects have the potential to contribute to habitat conservation and improving food security and livelihood of the rural poor. Larvae and pupae collection, usually carried out by women, was reported to provide cash income for basic expenditure for food, farming inputs and education (Agea *et al.*, 2008; Hope *et al.*, 2009).

Women and children play active roles in the edible insect sector, mainly in the collection, processing and sales. For example, in southern Zimbabwe, the collection, processing (removing gut content, roasting and drying), packing, blending and trading of mopane caterpillars (*Imbrasia belina* Westwood) was traditionally carried out by women (Hobane, 1994; Kozanayi and Frost, 2002) and all these endeavours were an important part of many families' livelihood strategies. With the expanding agribusiness companies in the field of insects as food, feed and waste conversion in Africa (Agbidye and Nongo, 2009; Agea *et al.*, 2008; Ayieko and Nyambuga, 2009), insects clearly have a role to play in significantly contributing to eradication of hunger, malnutrition and food insecurity in Africa (Ayieko *et al.*, 2010; Vantomme *et al.*, 2004) in the UN's post-2015 development agenda.

Evidence of entomophagy in Africa

In many parts of Africa, entomophagy was practised as a traditional heritage (Adriaens, 1951; Bani, 1995; Christensen *et al.*, 2006; Harris, 1940; Hoare, 2007; Nonaka, 1996; Quin, 1959; Weaving, 1973). Studies on African edible insects started before the 20th century (Bequaert, 1921; DeFoliart, 2002a; Netolitzky, 1919; Quin, 1959). The exact number of edible insects in Africa is still under revision despite several attempts. A single community alone has been reported to consume different kinds of insect species. For example, the Mbunda people in Angola, Zambia and Namibia were noted to consume about 31 species of insects (Silow, 1976). In DRC, Takeda (1990) reported 21 species consumed by the Ngandu people. The indigenous Gbaya people have been documented to consume 96 different insect species, which amounts to 15% of their protein intake (Roulon-Doko, 1998). Malaisse (1997) reported 30 species consumed among the Bemba people in northern Zambia, southern DRC and north-eastern Zimbabwe. Obopile and Seeletso, (2013) identified 27 edible insects in Botswana. In Kenya, insect species such as lake flies, 'agoro' termites, black ants, crickets, and grasshoppers, form part of traditionally consumed meals in the western part of the country (Ayieko *et al.*, 2011, 2012). In an earlier assessment, Van Huis *et al.* (2003) reported 246 species of edible insects from 27 countries in Africa. Later, Ramos-Elorduy (2005) noted that Africa is one of the most important hotspots of edible insects biodiversity in the world with 524 species reported from 34 African countries. The objectives of this paper are therefore threefold: (1) to conduct a systematic inventory of the edible insects in Africa to define the hotspot locations where they are consumed; (2) analyse the commonalities between countries and regions; and (3) to define a continental agenda and framework for their sustainable use to improve food security and enhance livelihood.

2. Current inventory of African edible insects

With increasing importance of cataloguing African edible insects, *icipe* embarked on a survey by developing a questionnaire that was embedded on an online platform (www.icipe.org/edibleinsectsurvey) using SurveyMonkey (Supplementary Table S1). The link was shared with more than 500 entomologists, practitioners and students across 54 African countries. An MS-Word format of the same questionnaire was also shared with individuals who were unable to access the online survey (Supplementary Table S1). In addition, intensive data mining of reports and publications using Google search engine was carried out along with personal interviews through *icipe*'s renowned African Regional Postgraduate Programme in Insect Science, and the African Association of Insect Scientists networks, to support the veracity of the survey. Information on the diversity of edible insects was arranged by country/region, according to taxonomic grouping (orders, family and species names) and projected on maps using geographic information system (GIS) application. Distribution map of the diversity and abundance of African edible insects was generated using ArcGIS 10.2 (Esri, Redlands, CA, USA). Random points were generated according to the total number of all the species found in each country. The points were later interpolated using the kriging method in spatial analyst tools to create a raster layer. A shape file layer was generated to map the diversity according to the orders and was represented in pie charts. The survey was conducted between December 2013 and June 2014. Out of the 500 interviewees, 333 responded to the online questionnaire with 12% of the respondents based outside Africa and 88% from various organisations in Africa. Among the respondents, 75% were researchers, 15% students and 10% from the private sector. Of the total respondents, 88% also reported that they were familiar with the role of edible insects in contributing to food security in Africa.

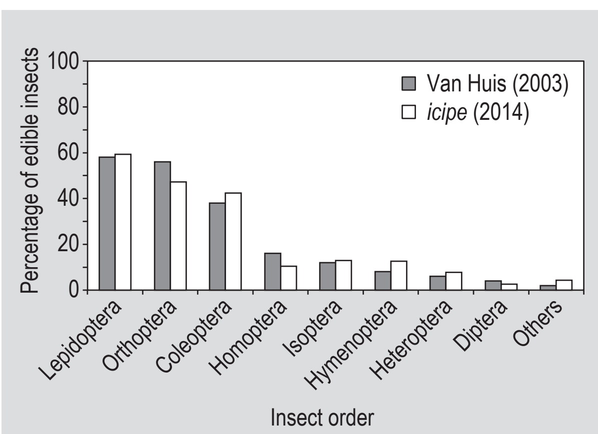

Figure 1. Representation of African edible insects across the main taxonomic groups.

3. Main edible insect groups and consumption hotspots across Africa

The survey data revealed the existence of 470 species of edible insects in Africa. The percentage of edible insects per order is presented in Figure 1. The highest diversity of edible insect species in Africa is found in the following orders: Lepidoptera, Orthoptera and Coleoptera. The Central African region alone was found to host about 256 edible species making it the most important biodiversity hotspot in Africa, followed by southern Africa (164 species) and eastern Africa (100 species). A total of 91 species were found in western Africa. Only 8 species were recorded from northern Africa (Figure 2).

4. Commonalities between countries and regions

Lepidoptera

Caterpillars were the leading edible insects in southern, central and western Africa (Figure 1) where they served

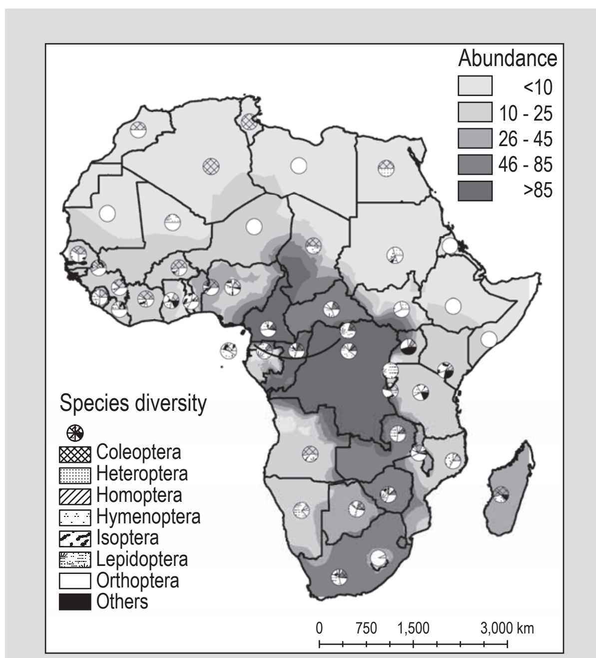

Figure 2. Diversity and abundance of main groups of edible insects in Africa.

as an important source of proteins and vitamins to the households, especially for women and children, and providing a major source of income to the rural populace (Agbidye and Nongo, 2009; Balinga *et al.*, 2004; Banjo *et al.*, 2006). We observed that *Bunaea alcinoë* (Stoll), *Anaphe panda* (Boisduval) and *Cirina forda* (Westwood) were consumed almost everywhere in SSA (Table 1) and concur with earlier reports by DeFoliart (2002b). In southern and Central Africa, the mopane worms *I. belina* and *Imbrasia ertli* Rebel are among the most common species consumed (Malaisse, 2005; Marais, 1996; Mbata *et al.*, 2002; Silow, 1976; Thomas, 2013). In Nigeria, the edible moths, *Anaphe venata* Butler and *C. forda* were the widely marketed edible insects and sold for about twice the price of beef (Ashiru, 1988; Agbidye and Nongo, 2009; Agbidye *et al.*, 2009). Our survey also showed that *Cirina butyrospermi* Vuillot was highly consumed, not only in Burkina Faso and Mali, but also in southern Africa (Bergier, 1941; Fasoranti and Ajiboye, 1993; Silow, 1976). The occurrence of *Cirina* species mostly coincides with the expansion in production of *Vitellaria paradoxa* C.F. Gaerter a shea butter tree with high economic value in Africa (Ande and Fasoranti, 1997; Fasoranti and Ajiboye, 1993; Odebiyi *et al.*, 2009). *Imbrasia oyemensis* Rougeot, which is also consumed in Central Africa (Balinga *et al.*, 2004), is consumed in Côte d'Ivoire (Akpossan *et al.*, 2009). The caterpillars *Eumeta cervina* Druce, *Gynanisa ata* Strand and *Urota sinope* (Westwood) are infrequently consumed in eastern Africa but frequently eaten in Central Africa (Decary, 1937; Razafimanantsoa *et al.*, 2012; Scalercio and Malaisse, 2010). Interestingly, in our survey, no Lepidoptera species was consumed in northern Africa (Table 1; Figure 1).

Table 1. Checklist of the most consumed insect species in Africa. Edibility determined on the number of countries and regions in Africa where the species was reported in the survey.

Order	Species	Countries reported
Lepidoptera	*Bunaea alcinoë* (Stoll)	Democratic Republic of Congo (DRC), Zambia, South Africa, Cameroon, Congo, Central African Republic (CA Republic), Zimbabwe, Nigeria, Tanzania
	Anaphe panda (Boisduval)	DRC, Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Nigeria, Tanzania
	Cirina forda (Westwood)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	Dactyloceras lucina (Drury)	DRC, Zambia, South Africa, Cameroon, Congo, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea
	Platysphinx stigmatica Mabille	DRC, Zambia, Congo, CA Republic, Sierra Leone, Sao Tomé, Equatorial Guinea, Rwanda, Burundi
	Cirina butyrospermi Vuillot	DRC, Zambia, South Africa, Zimbabwe, Burkina Faso, Nigeria, Mali, Ghana
	Epanaphe carteri Walsingham	DRC, Zambia, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea
	Imbrasia belina (Westwood)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi
	Gynanisa ata Strand	DRC, Zambia, Malawi, South Sudan
	Eumeta cervina Druce	DRC, Cameroon, Congo, CA Republic, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea, Rwanda, Burundi, Liberia
	Imbrasia ertli Rebel	Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Botswana, Angola
	Anaphe venata Butler	Zambia, Nigeria, Côte d'Ivoire, Sierra Leone, Guinea, Liberia, Guinea Bissau
	Imbrasia epimethea (Drury)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe
	Urota sinope (Westwood)	DRC, South Africa, Zimbabwe, Botswana, Gabon, Mozambique, Namibia
Orthoptera	*Schistocerca gregaria* (Forskål)	Zambia, South Africa, Cameroon, Congo, Botswana, Tanzania, Sudan, Uganda, Ethiopia, Kenya, Sierra Leone, Morocco, Guinea, Lesotho, Mauritania, Somalia, Eritrea, Guinea Bissau
	Acanthacris ruficornis (Fabricius)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Malawi, Mali, Niger, Togo, Benin
	Brachytrupes membranaceus (Drury)	Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Nigeria, Tanzania, Angola, Togo, Benin
	Nomadacris septemfasciata (Serville)	Zambia, South Africa, Congo, Zimbabwe, Botswana, Nigeria, Tanzania, Malawi, Uganda, Mozambique
	Ruspolia differens (Serville)	DRC, Zambia, South Africa, Cameroon, Zimbabwe, Kenya, Uganda, Tanzania, Malawi
	Zonocerus variegatus (Linnaeus)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, Sao Tomé, Guinea, Ghana, Liberia, Guinea Bissau
	Locusta migratoria migratorioides (Reich & Fairmaire)	Zambia, Cameroon, Congo, Zimbabwe, Sudan, South Sudan
	Locustana pardalina Walker	Zambia, South Africa, Zimbabwe, Botswana, Malawi, Libya
	Gastrimargus africanus (Saussure)	Cameroon, Congo, Niger, Lesotho, Liberia

Table 1. Continued.

Order	Species	Countries reported
Orthoptera (continued)	*Phymateus viridipes brunneri* Bolivar	Zambia, South Africa, Congo, Zimbabwe, Botswana, Mozambique, Namibia
	Gryllus bimaculatus De Geer	Guinea Bissau, Sierra Leone, Guinea, Liberia, Benin, Togo, Nigeria, DRC, Kenya, South Sudan, Zambia
	Anacridium melanorhodon melanorhodon (Walker)	Cameroon, Sudan, Niger
	Paracinema tricolor (Thunberg)	Cameroon, Malawi, Lesotho
	Acheta spp.	Zambia, Zimbabwe, Kenya
Coleoptera	*Oryctes owariensis* Palisot de Beauvois	DRC, South Africa, Congo, Ivory Coast, Sierra Leone, Guinea, Ghana, Equatorial Guinea, Guinea Bissau
	Rhynchophorus phoenicis (Fabricius)	DRC, Cameroon, Congo, CA Republic, Nigeria, Angola, Ivory Coast, Niger, Sao Tomé, Guinea, Togo, Liberia, Benin, Guinea Bissau
	Oryctes boas (Fabricius)	Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau DRC, Congo, South Africa, Botswana, Namibia
Isoptera	*Macrotermes* spp.	DRC, Zambia, Zimbabwe, Nigeria, Tanzania, Malawi, Senegal, Uganda, Côte d'Ivoire, Guinea, Ghana, Togo, Burundi, Benin
	Macrotermes bellicosus (Smeathman)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, Kenya, Sao Tomé, Guinea, Togo, Liberia, Guinea Bissau, Burundi
	Macrotermes subhyalinus (Rambur)	Zambia, Angola, Kenya, Togo, Burundi
	Macrotermes falciger (Gerstäcker)	Zambia, Zimbabwe, Burkina Faso, Burundi, Benin
	Macrotermes natalensis (Haviland)	DRC, Cameroon, Congo, CA Republic, Nigeria, Burundi, South Africa, Zimbabwe, Nigeria, Malawi
Hymenoptera	*Apis mellifera mellifera* Linnaeus	DRC, Zambia, Botswana, Nigeria, Tanzania, Senegal, Sierra Leone, Ghana, South Sudan, Togo, Lesotho, Benin
	Apis mellifera adansoni Latreille	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
Hemiptera	*Encosternum delegorguei* Spinola	South Africa, Swaziland, Mozambique, Malawi Zimbabwe, Botswana, Namibia

Orthoptera

The desert locust *Schistocerca gregaria* (Forskål), *Locusta migratoria migratorioides* (Reiche & Fairmaire), *Nomadacris septemfasciata* (Serville), *Locustana pardalina* Walker and *Anacridium melanorhodon melanorhodon* (Walker) have a continent-wide importance (Table 1). In southern Africa, *N. septemfasciata* and *L. pardalina* seem to be the most dominant species particularly in South Africa, Zambia, Botswana and Lesotho (Table 1). The tree locust *A. melanorhodon melanorhodon,* which is a pest of the gum arabic tree *Acacia senegal* (L.) Willd. is consumed in Sudan and South Sudan (Hassan *et al.*, 2007) (Table 1).

Acanthacris ruficornis (Fabricius) and *Ruspolia differens* (Serville) are common grasshoppers in SSA. The latter species is reported in southern, central and eastern Africa. It is also referred to as 'nsenene' and is the most consumed grasshopper in Uganda, parts of western Kenya and Tanzania (Agea *et al.*, 2008; Kinyuru *et al.*, 2010; Matojo and Yarro, 2013). *Zonocerus variegatus* (Linnaeus) is consumed, not only in Central Africa (Kekeunou *et al.*, 2006) but also in West Africa, particularly in Nigeria (Banjo *et al.*, 2006; Solomon *et al.*, 2008), in the Upper Guinean forests of West Africa in Guinea, Liberia, Côte d'Ivoire and Ghana (Table 1).

Various species of crickets are reported consumed in Africa; however, *Brachytrupes membranaceus* (Drury), *Gryllus bimaculatus* De Geer and *Acheta* spp. are the most common species eaten (Table 1). Another species of cricket *Henicus whellani* Chopard is reported consumed in Southern Africa especially in South-East Zimbabwe (Musundire *et al.*, 2014a).

Coleoptera

Edible coleopterans are mainly represented by rhinoceros beetles (*Oryctes* spp.) and *Rhynchophorus* spp., frequently reported from western, central and southern Africa (Ghesquière, 1947). In western and Central Africa *Rhynchophorus phoenicis* (Fabricius) has high economic value and is considered a delicacy not only in Benin, DRC and Cameroon, but also in West Africa (Cote d'Ivoire) (DeFoliart, 2005; Gbogouri *et al.*, 2013; Riggi *et al.*, 2013; Tchibozo *et al.*, 2005; Womeni *et al.*, 2009). The consumption of *Rhynchophorus* species is, however, not common in eastern and southern Africa. *Oryctes* species (rhinoceros beetles) mainly represented by *Oryctes monoceros* (Olivier), *Oryctes owariensis* Palisot de Beauvois and *Oryctes boas* (Fabricius) are preferred to *Rhynchophorus* spp. with broader edibility over SSA. *Goliathus* spp. and *Augosoma* sp. seem to be typical to Central African countries whereas *Sternocera* spp. are eaten largely in southern African countries.

Isoptera

Edible termites were represented by *Macrotermes bellicosus* (Smeathman), *Macrotermes subhyalinus* (Rambur), *Macrotermes falciger* (Gerstäcker) and *Macrotermes natalensis* (Haviland), and were consumed across many SSA countries (Gessain and Kinzler, 1975; Van Huis, 2003). *M. bellicosus* is reported in Central and West Africa, whereas *M. falciger* and *M. natalensis* are commonly consumed in the continent but mainly in the southern Africa region. *Macrotermes mossambicus* Hagen (*Macrotermes michaelseni*) is mainly found in eastern and southern Africa region.

Hymenoptera

The order Hymenoptera represents the bees, ants and wasps. In our survey, *Apis mellifera mellifera* Linnaeus and *A. mellifera adansoni* Latreille are the main species of bees consumed all over Africa not only for their honey, but also for their larvae (Bahuchet, 1985; DeFoliart, 2002a; Gessain and Kinzler, 1975; Mbata, 1995; Munthali and Mughogho, 1992; Takeda, 1990). *Carebara vidua* Smith, *Carebara lignata* Westwood and *Oecophylla longinoda* (Latreille) were reported as the most common edible ants in Africa (DeFoliart, 2002a; Malaisse, 2005; Silow, 1983). The consumption of *O. longinoda* was reported from the Central African Region (DRC, Cameroon and Chad) (Table 1). The consumption of social wasps *Polistes hebraeus* Fabricius and *Vespula* sp. was reported from Mauritius and Madagascar (Table 1).

Hemiptera

Encosternum delegorguei Spinola remains the most common hemipteran eaten in southern Africa mainly in South Africa, Namibia, Botswana Zimbabwe, Zambia and Malawi (Dzerefos and Witkowski, 2014; Dzerefos *et al.*, 2009, 2013; Musundire *et al.*, 2014b; Teffo, 2006). *Coridius viduatus* (Fabricius) is also consumed in southern Africa among the Ovambo people in Namibia (Fujioka, 2010). Mariod *et al.* (2011) reported that *Agonoscelis versicolor* (Fabricius), and *Agonoscelis pubescens* (Thunberg) are consumed along with *C. viduatus* in Sudan and South Sudan. In the Hemiptera group, *Ioba leopardina* (Distant) was noted to be the main species eaten in southern and Central Africa.

5. Pathways to sustainable use of insects as food and feed

The issue of food security in Africa can certainly be tackled from different angles using edible insects (Moula *et al.*, 2013; Van Huis, 2013; Van Huis *et al.*, 2013; Yen, 2010). Insects can be used as food, feed, and for waste conversion to improve livelihoods but there is need to identify the main challenges and the role of relevant stakeholders for their sustainable use in Africa. The model proposed in Figure 3 describes a pathway to food security in Africa using edible insects and research institutions such as *icipe* and other stakeholders including the private sector, policy makers and non-governmental organisations (NGOs) will be needed to accomplish this goal.

Socio-economics and marketing

Generally, innovations to tackle food security and sustainability largely focus on agricultural production and technological efficiency; however, the social aspects of food security are also important. Diets have changed considerably over the last few decades and consumers' food habits are open to change (Kearney, 2010). The challenge is to encourage that change towards diversified healthy and sustainable diets. Therefore, research on behavioural changes should be given a priority while assessing the role of edible insects as food and feed alternatives. In both rural and urban areas of developing countries, consumers have to expand food choices that fit with their cultures and stages of change in lifestyles so that sustainable diets can be attained. They often face dilemmas of food choices that are available to them in contrast to their background cultures, their income and chosen lifestyle, and beliefs on the nutritional and other health benefits of the foods they choose. It is crucial to conduct studies that elucidate consumers' perception on insects as food and feed in countries and communities where edible insects are not yet part of their diets to document factors that may affect the adoption of edible insects (Adesina and Baidu-Forson, 1995). The commercialisation of edible insects provides significant income to many households in Africa (Agbidye *et al.*, 2009; Agea *et al.*, 2008; Balinga *et al.*, 2004; Van Huis *et al.*, 2013; Yen, 2010). However, poorly understood and poorly organised market chains severely limit agribusiness in Africa. The market constraints encountered by farmers when attempting to diversify their production into edible insects business should be documented.

Mass rearing, harvesting technique and technological upscaling

The ability to colonise and rear insect species is crucially important to all aspects of research and development in insect science (Odhiambo, 1994). It is an important

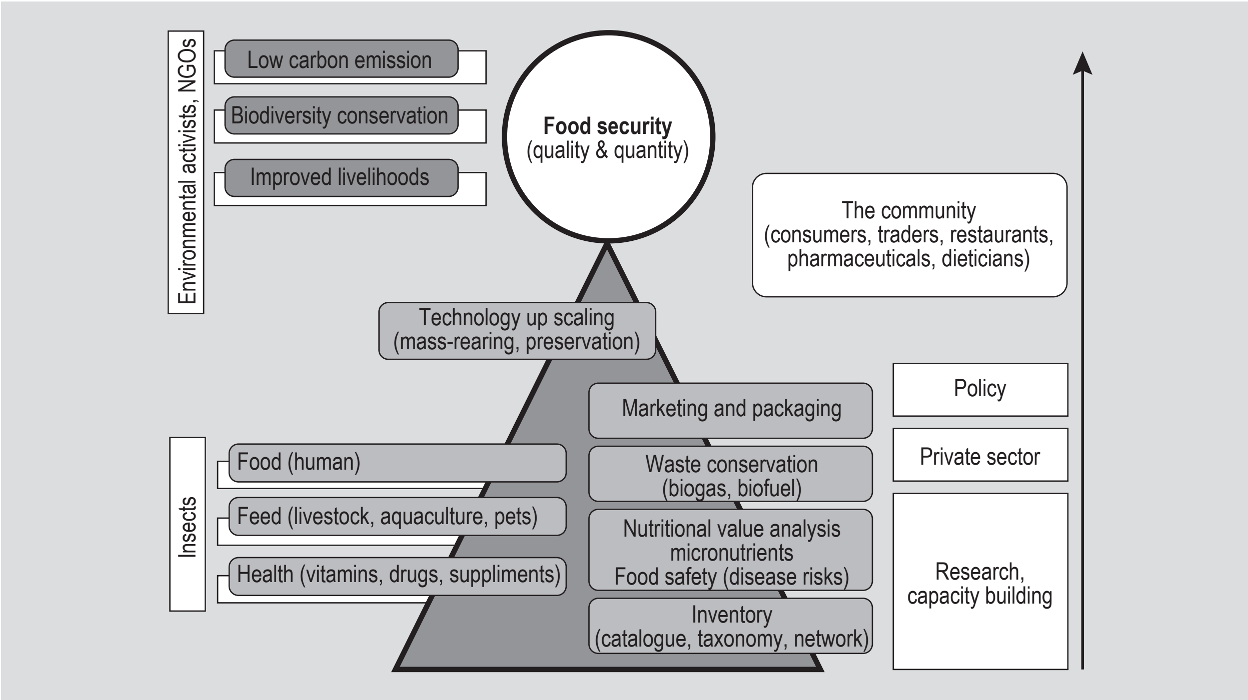

Figure 3. Pathways to using insects for food and feed to improve food security in Africa (NGOs = non-governmental organisations).

prerequisite to availing insects in large quantities for use as food and feed. Insects, being heterotrophs like all animals, require exogenous nutrients for both tissue construction and satisfaction of their energy requirements. Essential nutrients for most insects include amino acids, vitamins, sugars, minerals and growth factors, which must be carefully assessed for target species. To meet these nutritional requirements, a large array of ingredients are exploited and used for artificial diets (Anderson and Leppla, 1992; Ekesi and Mohamed, 2011; Ochieng'-Odero, 1994). Knowing the conditions that enhance adult feeding, mating and oviposition is also critical to successfully establishing mating colonies, which must be carefully assessed for any target species to be reared. Currently, apart from limited cricket farming, the majority of edible insect utilisation in Africa occurs through wild harvesting. For example, grasshoppers are collected in rice paddy using a piece of cloth or by hand at night with the help of light traps. They are also captured in the early morning as low temperatures make them inactive. Traditional local folk songs and dances have been associated with the harvesting of ants in most regions of Africa. Ants' collection is carried out using a long stick pole with a bag attached with strings to the tip. Due to rapid population growth, wild collection practices are not sustainable. Over time, wild harvesting may contribute to the extinction of certain edible insect species as well as to the depletion of their populations. Overexploitation has been documented in South Africa, Botswana, Malawi and DRC (Akpalu *et al.*, 2009; Leleup and Daems, 1969; Thomas, 2013). Ramos-Elorduy (2005) already provided a list of some edible insects that are prone to extinction due to overexploitation. Ethnozoological and ethnobotanical surveys provide baseline scientific knowledge that allows for adaptive conservation management programmes to be developed for sustainable utilisation (Dzerefos and Witkowski, 2014).

It is reported that in some countries, farming communities often resorted to cutting down an entire raffia tree to rear and collect palm weevil larvae (Fasoranti and Ajiboye, 1993). Although capacity building programmes on insect farming business and domestication are now underway in Kenya and Tanzania, with respectively the Kipepeo Butterfly project and the Amani Butterfly project in Arabuko Sosoke and the Usambara Mountains (FAO, 2011), and the beekeeping and caterpillar initiatives in Malawi, Zambia and Zimbabwe (Hope *et al.*, 2009), cost-effective and eco-friendly mass rearing and harvesting technologies, especially in the biodiversity hotspots, are needed to avoid ecological perturbations and at the same time ensuring continuous supply of quality insects for food and feed. Today, modern science combined with valuable traditional knowledge and food culture can immensely contribute to innovation aimed at scaling up of mass rearing technologies across Africa. According to Rumpold and Schlüter (2013) 'Research is required to develop and automatize cost-effective, energy-efficient and hygienic rearing, harvest and postharvest processing technologies as well as sanitation procedures to ensure food and feed safety and produce safe insect products at a reasonable price on an industrial scale, especially in comparison to meat products.' The research development for edible insects mass rearing, harvesting techniques and technological upscaling should, therefore, be oriented towards the following axes: (1) extensive life cycle assessments among a vast array of insect species to enable comparisons of insects with conventional feed and food sources; (2) development of cost-effective feeding diets; (3) increase in innovation in mechanisation, automation, processing and logistics to reduce production costs to a level comparable with other feed and food sources; and (4) maintaining resilient and genetic diversity to avoid colony collapse in insect farming systems. Technological upscaling will also require development of optimised methods and guidelines for diet ingredients, equipment, space, labour and skills.

Nutritional and bioactive chemical composition

Insects are a highly nutritious and healthy food source with high content of nutrients (fats, protein, vitamins, fibre and minerals) required by humans and animals. However, the nutritional composition of edible insects between and within species is highly variable, depending upon metamorphic stage, habitat and diet of the insect (Rumpold and Schlüter, 2013). Although, the nutritional composition of some insect species has previously been investigated in a number of countries, e.g. India, USA, Mexico and Thailand, similar detailed studies on those consumed in Africa and listed in Table 1 are yet to be explored. Likewise, relatively few studies have attempted to report on the bioactive compounds of edible insects despite some species being reported to possess some medicinal properties. For instance, in our current survey, it has been reported that in certain rural communities, the consumption of termites was believed to improve fertility and the consumption of the edible stink bug *E. delegorguei* in South Africa and Zimbabwe had potential medicinal roles that included cures for asthma and heart disease, aiding digestive systems, acting as appetisers and enhancing sexual desires (Musundire *et al.*, 2014b; Teffo, 2006). In a preliminary study of the edible stink bug (*E. delegorguei*) (R. Musundire, personal communication), the presence of alkaloids, flavonoids, anthraquinones, tannins, steroids, triterpenoids and cyanogenic glycosides was detected. However, none of these components was characterised and changes in their levels in different seasons as well as in uncooked and cooked insects, their sources and safety for consumption were not established. Since there is considerable similar indigenous knowledge in this subject area in other rural communities in Africa, to meet the research-for-development agenda and pathways to sustainable use of insects as food, feed and medicinal use, scientific data are required to validate this knowledge. As a first step, the nutritional composition, bioactive compounds and safety for consumption of different insect species under different dietary conditions needs to be extensively investigated.

Disease risk and food safety

Insects are rich in nutrients and moisture, providing a favourable environment for microbial survival and growth (Klunder *et al.*, 2012), and a range of pathogens such as protozoa, fungi, bacteria and viruses have been reported (Vega and Kaya, 2012). For instance, Banjo *et al.* (2006) reported the presence of the pathogenic bacteria *Staphylococcus aureus* Rosenbach, *Pseudomonas aeruginosa* (Schroeter) Migula and *Bacillus cereus* Frankland & Frankland in edible rhinoceros beetle species in West Africa, thereby causing risk to consumers (Ekrakene and Igeleke, 2007). Fungi belonging to the genera *Aspergillus*, *Penicillium* and *Fusarium* have been associated with the mopane caterpillar, *I. belina,* in Botswana and were reported to produce aflatoxins sometimes above the maximum safe level set by FAO (Mpuchane *et al.*, 1996).

Potential pathogens in edible insects need to be assessed along the entire farm-to-table food chain (production, processing, distribution, sale, handling and consumption). For example, leaves of host plants on which the emperor moth, *Bunaea alcinoe* (Stoll), feeds on are the primary source(s) of the microorganisms associated with foodborne illnesses in the guts and skins of the larvae (Braide, 2012). Intensive insect rearing with high densities is expected to be associated with health issues since insects can serve as reservoirs for pathogens as observed in animal production. However, the risk of transmitting zoonotic infections to humans is likely to be lower because insects are taxonomically much more distant from humans than conventional livestock (Van Huis, 2013). In addition to diseases, food safety issues also include allergies, toxicological and chemical hazards. For example, consumption of larvae of *A. venata* has been implicated in seasonal ataxic syndrome in western Nigeria (Adamolekun, 1995). Considerable amount of synthetic chemical insecticides are used during outbreaks for control of desert locust (*S. gregaria*) (Van Huis, 2013) and migratory locust (*Locusta migratoria capito*) and pose a threat to humans when harvested in the wild after aerial pesticidal sprays and consumed. The relationship between allergy and the presence of chitin in arthropods has been established (Muzzarelli, 2010). Increased consumption of chitin can lead to asthma symptoms and allergies and needs to be investigated for other insects. From the insect rearing perspective, many microorganisms attack insects reared in culture to improve food security including entomopathogenic bacteria, fungi, protozoa and viruses (Gouli *et al.*, 2011). The key pathogens that are culprits to colony collapse during rearing of the target insects listed above must be identified and documented, and methods for ensuring quality control to guard against contamination developed to assure disease-free cultures. Heavy metals, pesticides as well as mycotoxins can be accumulated in substrates used for insect rearing and constitute a risk if carried over through the food chain to insects, poultry, fish and humans, and must be properly analysed.

Organic waste conversion

Rural, peri-urban and urban agriculture continue to face recurrent problems of low productivity due to inappropriate soil fertility management strategies. Overuse of huge amounts of chemical fertilisers and pesticides makes the soil acidic and lifeless (IAASTD, 2009). The task of increasing or maintaining the productive capacity of soils under cultivation has become one of the greatest challenges to farmers in SSA (Adamtey, 2010; Adamtey *et al.*, 2009). The use of compost has been identified as a solution for restoring these soils by building up the microbial activity in the soil and making nutrients easily available to plants, ensuring a slow release supply of nitrogen, phosphate, magnesium and sulphur, and providing readily available source of potash, and increasing water holding capacity, hence sustainably increasing fertility and yield (Diacono and Montemurro, 2010; Martínez-Blanco *et al.*, 2013). Although composting is gaining high recognition among farmers in SSA, the process is long (3 to 4 months), affecting the cost of production, availability and quality (nitrogen content) (Adamtey *et al.*, 2009; Danso *et al.*, 2006). In addition to this, safety issues such as pathogens, heavy metals and other potentially toxic residues that can be transmitted from wastes to human and animal food chain through compost has resulted in a low patronage of the technology (Danso *et al.*, 2006; Hargreaves *et al.*, 2008). On the other hand, in a world where the human population is growing exponentially and with the ever-growing rural to urban migration, the management of organic and municipal solid wastes constitutes an important problem in developing countries and specifically in all African countries, and hence poses a major threat to public and environmental health (Drechsel and Kunze, 2001; Martínez-Blanco *et al.*, 2013). The possibility of using various types of wastes in the mass rearing of insects and particularly considering the potential of certain insect species in quick processing of waste and reduction in compost toxicity and pathogen load, represents a unique opportunity to solving this problem and at the same time enhancing soil fertility and waste management problems while creating job opportunities to the youth and improving human and environmental health.

BSF (*H. illucens*) has been reported to solve various environmental problems associated with manure and other organic and municipal wastes, such as reducing manure mass and processing time, moisture content, offensive odours (through aeration and fast drying of substrate), heavy metals and harmful microbes while providing high-value feedstuff for cattle, pigs, poultry and fish (Newton *et al.*, 2005). The speed at which BSF processes various types of wastes, and its capability to clean them from common chemical contaminants and pathogens need to be investigated since the type of waste, contaminant and level of contamination depends on source of waste, characterisation of waste, and systems used for processing. Research activities are needed to promote the mass rearing of such insects for the quadruple role of: (1) providing food and feed; (2) shortening compost processing time and increasing compose utilisation; (3) providing environmental services; and (4) promoting entrepreneurship, particularly for youth and women involved in insect and compost commercialisation.

Processing, storage and packaging

As with many foodstuffs, the use of insects as food and feed along the supply chains will be exposed to a variety of postharvest issues such as inappropriate processing and inadequate packaging and storage. While postharvest processing still has as the main objective the providing of a safe nutritious diet to maintain a healthy life, other aspects, particularly the generation of wealth for the producer and seller, have become increasingly important through the reduction of losses. Insects as food and feed will require special processing and packaging to protect them for the required storage life. While consumers are increasingly looking for foods that reduce preparation and cooking time, food and feed processors and retailers are looking at possibilities for extending product shelf life. Packaging has a vital role to play in containing and protecting insects as food and feed as the harvests move through the supply chain to the consumers or the end users of the feed (Verghese *et al.*, 2013). Nowadays, food habits and consumption trends in developing countries are undergoing transitions. Rapid urbanisation and changes in social and cultural practices have modified food habits of communities (Kearney, 2010). Urbanisation and growing middle class incomes have pushed for new consumer needs and extended value chains that now comprise sorting, grading, processing, packaging, distribution, value addition and retailing as integral undertakings (Parfitt *et al.*, 2010) that must be addressed in the utilisation of insects for food and feed. Furthermore, important characteristics of emerging food markets are the demand for food quality and safety that should be traceable across the food supply chain, and products' packaging and labelling, which helps handlers to keep track of the produce as it moves through the postharvest system (Bollen *et al.*, 2006; Opara, 2003) all of which form part of important research activities that must be undertaken within the context of using insects for food and feed.

Legislation and regulatory measures

One major potential barrier to the utilisation of insects as food and feed is the lack of precise and insect-inclusive legislation, standards, labelling and other regulatory instruments governing the production, use and trade of insects along the food and feed value chains. So far, there has been relatively little international dialogue regarding the incorporation of insects as food and feed into international standards like the Codex. Indeed there are no standards in the Codex that specifically refer to the use of insects as food and feed. Instead, insects are referred to only as impurities that should be excluded. The only attempt at developing a standard for the utilisation of an insect as food was by the Lao People's Democratic Republic for the regional trade of house crickets but the proposal was not ratified because the level of trade at that time was not viewed as sufficient to warrant an action (Van Huis *et al.*, 2013). Despite this, the Codex Alimentarius Commission (Codex, 2010) did note that developing and adopting a standard for insects as food and feed should help increase the quality of insect-based products available, and consequently the level of food safety (Codex, 2010); hence the need for continuous dialogue. Therefore, to support and encourage the development of the sector, there is the need to review the current status of insects as food and feed through desk studies, expert interviews and consultation with relevant governmental authorities and stakeholders with a view to documenting information and paving the way for the development of national and regional standards for use of insects as food and feed.

Broad-based partnerships and strategic linkages

Food and nutritional security has been and is likely to remain one of this century's greatest challenges. Addressing the need to a sustainable food supply requires international effort with a clear sense of long-term challenges and possibilities given the complex relationships between agriculture, land, environmental degradation, climate change and poverty. This has prompted the international community to ratify the implementation of a number of international conventions and other internationally agreed upon development goals such as the Millennium Development Goals, The UN Framework Convention on Climate Change, United Nations Convention to Combat Desertification and Convention on Biological Diversity in response to the various challenges. Three key areas have been identified: (1) increased agricultural production; (2) environmental protection; and (3) poverty alleviation. In response, and at the invitation of NEPAD Steering Committee, FAO, in collaboration with NEPAD Secretariat, has also prepared CAADP presenting broad themes of primary opportunity for investment to reverse the crisis facing Africa's agriculture. CAAPD pillar IV specifically aims to improve agricultural research and systems in order to disseminate appropriate new technologies. The adoption of the Framework for African Agricultural Productivity, prepared under the leadership of the Forum for Agricultural Research in Africa, allows a broad group of development partners to help in scaling up support to science and technology programmes at the regional and national levels. Additionally, building on the foundations established by the 2012 UN Conference on Sustainable Development in Rio de Janeiro, attention is now shifting toward the development of sustainable development goals as an anchor for the post-2015 development agenda (UN, 2012). R4D that employs the use of insects for food and feed in Africa will require high quality partner institutions within the region and globally to achieve its objectives. There is, therefore, the need to carefully assess and build new partnerships with donor agencies aiming at long-term co-operation and application of technologies in this field, and at the same time expand co-operation with institutions and networks with similar or complementary activities to increase efficiency. Beneficial linkages and partnerships should cut across, but should not be limited to agricultural and livestock research institutions, universities, agriculture and livestock extension services, FAO, Consultative Group on International Agricultural Research (CGIAR) and advanced research institutes (ARIs), NGOs, social, economic/financial and market research groups, the private sector (such as insect cottage and processing industries, feed and pharmaceutical industries, etc.) to increase its efficiency and implementation of R4D objectives and activities. In future, a database of institutions detailing existing physical and human capacity of various organisations dealing with the subject of insects for food and feed at national, regional and international levels will be useful for joint R4D capacity.

As a centre of excellence in insect science and its application, *icipe* is obliged to respond to the opportunity of promoting insects as food and feed to add value to the global call by FAO to utilise insects to improve food and feed security and contribute to the livelihood of the African people and protection of biodiversity and ecosystems (Figure 3).

The Centre has responded to this call by establishing the Insects for Food, Feed and Other Uses Programme with the following goal, purpose and objectives:

Goal: To contribute to improving food and feed security and economic wellbeing of smallholder producers while enhancing the quality of the environment through insect-based technologies and innovations in a sustainable manner.

Purpose: To develop, disseminate and promote insect-based technologies for food, feed and other uses to enhance productivity, value addition and overall competitiveness of the agricultural system for improved livelihood.

Objectives: The objectives of the Insect for Food, Feed and Other Uses Programme include:
- development and dissemination of insect-based technologies for food, feed and other uses;
- promoting the processing and marketing of insect-based products for food, feed and other uses to increase income-generation along the value chain;

- contributing to development of enabling policy environment for insect-based food and feed products;
- supporting and strengthening national and regional capacity for insects for food and feed R4D through close partnership with relevant authorities and the private sector; and
- promoting and supporting information exchange and networking among partners involved in insects for food and feed R4D.

The objectives of the Programme are strategically oriented towards attainment of the *icipe*'s Vision and Strategy 2013-2020 document with a strong orientation towards R4D and a focus on activities that lead to adoption and impact on end users. Research activities will be supported by competitive grant systems, bilateral grants, regional networks, multilateral funds and partially by core grants as necessary. Within the proposed strategy, the programme's R4D agenda is developed on the basis of identified and prioritised work packages. Work packages are identified as broad problem domains of significant socio-economic impact within the Programme whose resolution or mitigation could meaningfully impact on the livelihood of beneficiaries and contribute to the achievement of the objectives.

6. Conclusions

Sustainably meeting global food demands is one of humanity's greatest challenges and has attracted considerable attention in the past few years (West *et al.*, 2014). There is general consensus on agriculture's positive contribution to food security through its role in increasing the availability of affordable food and the incomes of the poor. 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. Indeed, Africa has an impressive diversity of edible insects. In our survey, we have been able to identify that 470 species of insects are consumed across the continent. The highest diversity of edible insect species was found in the orders Lepidoptera, Orthoptera and Coleoptera. Commonalities were observed across majority of the insects consumed across western, eastern and southern Africa, providing opportunities for related R4D activities targeted at species that are widely eaten across regions. The development of an edible insect agenda in Africa requires socio-economics and marketing studies and technology upscaling in mass rearing, harvesting, processing, storage and packaging. Nutritional and bioactive chemical characterisation and disease risk of African edible insects need to be investigated to validate indigenous knowledge on medicinal properties and improve food safety levels. Organic waste conversion using edible insects should take into consideration substrate quality in terms of contaminants and heavy metals accumulation. Legislation and regulatory measures need to be clearly defined. *icipe* has positively responded to these challenges by establishing the Insects for Food, Feed and Other Uses Programme to be achieved through broad based partnerships with NARS across Africa, FAO, CGIAR and ARIs, NGOs, and the private sector to increase efficiency and implementation of its objectives.

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Supplementary material

Supplementary material can be found online at http://dx.doi.org/10.3920/JIFF2014.0016.

Table S1. Questionnaire done on SurveyMonkey to inventory the diversity of edible insects in Africa, number of countries and major hotspots of entomophagy and socioeconomical conclusion.

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